HATCH™ energy

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Low Head Hydro Market Assessment

Volume 1 - Main Report

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List of Acronyms/Abbreviations

AC	Alternating current
BCTC	British Columbia Transmission Corporation
BCUC	British Columbia Utilities Corporation
CC	Combined cycle
CETC	CANMET Energy Technology Center
CFD	Computational fluid dynamics
COD	Commercial operation date
CPI	Consumer price index
DC	Direct current
e	Efficiency
EA	Environmental assessment
EPA	Electricity Purchase Agreement
g	Acceleration due to gravity, 9.81 cubic metres per second squared
GHG	Greenhouse gases
h	Head, in metres
IEA	International Energy Agency
IGCC	Integrated coal-gasification combined cycle
kW	Kilowatt
kWh	Kilowatt-hour
m	Metre
MW	Megawatt
MWh	Megawatt-hour
NEB	National Energy Board
NRCan	Natural Resources Canada
O&M	Operations and maintenance
OEB	Ontario Energy Board
OPA	Ontario Power Authority
P	Power, in watts
PV	Photovoltaic
Q	Flow rate, in cubic metres per second
R&D	Research and development
RES III REFI	Request for Expression of Interest for Renewable Energy Supply
RESOP	Renewable Energy Standard Offer Program
SO_x / NO_x	Sulphur oxides/nitrogen oxides
VLH Turbine	Very low head turbine
WPPI	Wind power production incentive

Hydropower Glossary

Balance of Plant Equipment	All powerhouse equipment not directly related to the turbine, generator and their operation.
Brushes	With the slip ring, make an electrical connection to the rotational assembly in a generator.
Capacity Factor	The ratio of the actual energy generation of a power plant to the energy that would have been generated had it operated at its nameplate capacity.
Direct Driven	A direct-driven generator is mechanically linked directly to the turbine with no intermediary gearbox.
Distributor	Control mechanism to direct water into an inward flow turbine, includes wicket gates.
Draft Tube	The conduit through which water exits the turbine.
Exciter	Generator equipment that provides power to electromagnets. Not required if permanent magnets are used.
Francis Turbine	An inward flow hydropower turbine. Water flows from the spiral case outside of the runner, through the runner and out the center (often the bottom). Typically used in the 10- to 350-m head range.
Generator	A generator converts the rotational motion of the turbine into electricity.
Head	The head on a hydroelectricity plant is the difference between the upstream and downstream water levels. This is the driving force behind energy generation.
Headwater Level	The water level upstream of a hydropower plant.
Kaplan Turbine	A propeller type turbine with adjustable runner blades.
On-Peak Hours	Peak electrical demand hours.
Peaking	Utilizing reservoir storage to operate a power plant to maximize generation during periods of high electrical demand.
Powerhouse	The building containing the electromechanical equipment at a hydro plant.
Rated (speed/flow)	The (speed/flow) at which a turbine is designed to be operated.
ROR	Run-of-river. ROR hydro plants only minimally alter the natural flow patterns in a river.
Runaway (speed/flow)	The (speed/flow) at which a turbine will run with all gates open and no load from the generator.
Runner	The rotating component of a hydro turbine.
SCADA	Supervisory Control and Data Acquisition. Controls the operation of, and acquires data from, hydropower plants.

Slip Ring	With brushes, makes an electrical connection to the rotational assembly in a generator.
Spiral Casing	The conduit through which water enters an inward flow turbine. The diameter decreases as the conduit encircles the turbine, giving the outer edge a spiral shape.
Tailwater Level	The water level downstream of a hydropower plant.
Turbine	A turbine converts energy from fluid flow into rotational motion to be converted into electricity by the generator.

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1 Introduction

1. Introduction

Natural Resources Canada (NRCan) champions innovation and expertise in earth sciences, forestry, energy and minerals and metals to ensure the responsible and sustainable development of our nation's natural resources.

Mandate and Vision

NRCan works to ensure the responsible development of Canada's natural resources, including energy, forests, minerals and metals. It also uses its expertise in earth sciences to build and maintain an up-to-date knowledge base of our landmass and resources.

NRCan develops policies and programs that enhance the contribution of the natural resources sector to the economy and improve the quality of life for all Canadians.

NRCan conducts innovative science in facilities across Canada to generate ideas and transfer technologies. It also represents Canada at the international level to meet the country's global commitments related to natural resources.

NRCan Vision: Improving the quality of life of Canadians by creating a sustainable resource advantage.

The **CANMET Energy Technology Centre (CETC)**, the energy research and development arm of NRCan, is Canada's leading federal government science and technology organization with a mandate to develop and demonstrate energy efficient, alternative and renewable energy technologies and processes.

Working in collaboration with associations, academia, government and industry, CETC aims to improve the economics and efficiency of renewable energy technologies, including wind energy, small and low head hydro, marine energy, solar thermal, photovoltaic systems and energy storage. It is actively involved in research and development (R&D) to support the growth of the renewable energy industry.

By harnessing the natural energy of the sun, wind, and moving water, it is possible to improve the sustainability of our energy production and consumption in ways that will deliver profound benefits to the environment and human health. These forms of energy are renewable for future generations, and serve as great alternatives to traditional forms of energy that release carbon dioxide emissions and other pollutants into the earth's atmosphere.

CETC pursues a number of initiatives in the development of renewable energy technologies. Experts in wind energy at CETC work alongside with industry in developing and testing wind turbines to optimize their practical utilization to meet energy demands. Its scientists are discovering innovative ways to exploit solar energy, and have developed a variety of technologies that use solar energy to fulfill air and water-heating needs. Improving the efficiency and cost-effectiveness of hydro-electricity technologies is also a priority of CETC, including marine hydraulic technologies to harness tidal and wave energy. Specialists work extensively on small hydro technologies, through such work as modeling software that can be used for simulations and optimization of the generation of hydro-electricity.

While renewable energy sources currently do not account for a large portion of the world energy supply, CETC's work in Canada and abroad demonstrates a proactive approach to achieving a sustainable society. As these technologies become more prevalent, the research undertaken by CETC scientists will position Canada to have a leading edge in the worldwide renewable energy industry, while making significant efforts to improve the state of the environment.

NRCan contracted the services of Hatch Ltd. (Hatch) to conduct a "Low Head Hydro Market Assessment" with specific interest in emerging technologies. This report fulfills the obligations of the contract and was produced in its entirety by Hatch.

1.1 Background

Hydropower is the most predictable of the renewable energy sources, with highly efficient systems and extremely low maintenance costs. It is clean and renewable, with zero greenhouse gas emissions during operation.

There is significant potential in Canada for low head hydro. Almost 5000 MW of low head hydro potential has been identified across over 2000 sites in Canada, including only sites of up to 50 MW. In Ontario and Manitoba alone, 21 low head sites with individual capacities of over 50 MW have been identified for a combined potential of over 3000 MW. Low head hydro potential mainly exists in sluice gates, irrigation canals, drinking water pressure release valves and municipal wastewater outfalls, as well as in numerous rivers. There are approximately 10 000 existing low head dams and hydraulic structures for flood control and water supply/irrigation across Canada[I].

The majority of developed hydro sites in Canada are not low head. In Canada and internationally, many low head sites near load centers have not been developed, because they are not currently economical due to the high cost of equipment, associated civil works and environmental mitigation requirements; low head sites require large equipment to accommodate greater water volume and slower turbine speeds. As a result, the low head hydro market is still open and Canada has an opportunity to lead in this area.

The purpose of this study is to perform a market assessment on low head hydro developments in Canada. This includes identification and assessment of

- available and emerging technologies for developing low head hydro
- the current economics of low head hydro in Canada
- the Canadian potential for low head hydro development
- the barriers to low head hydro development, and
- strategies to promote low head hydro development.

This information is necessary to assist provincial and federal policy makers and R&D managers to plan the level and direction of support programmes, development strategies and R&D activities in the low head hydro field. The results of this market assessment will be used to devise strategies to promote market acceptance of low head hydro and to advance and expand the science and

I Tung, Tony T. P., J. Huang, C. Handler, and G. Ranjitkar. 2007. Better Turbines for Small Hydro. *Hydro Review*. March 2007. Note: Not all of these 10 000 sites were identified in this study and included in the low head hydro potential quoted herein.

technology available for low head hydropower generation. Stakeholders in the low head hydro sub-sector also require market information to better formulate business plans. The technological assessment will be made available to the hydropower sector and the public via website access and promoted at forums such as hydropower conferences, workshops and meetings.

This report is a market assessment for low head hydropower in Canada concentrating on resource potential of sites with less than 15 m of head and the technologies available to develop this resource**.** The resource assessment portion of the report covers all low head sites including those with storage up to (and including) 50 MW but only run-of-river sites (ROR) beyond 50 MW.

2 Small and Low Head Hydro

2. Small and Low Head Hydro

2.1 Small Hydro Defined

There is no agreed upon definition on small hydro. Typically, small hydro is thought to include hydropower plants with a generating capacity of between 1 and 10 MW. The Canadian Electricity Association (CEA) proposed the following definitions based on individual unit sizes (not total station capacity):

- Pico less than 10 kW
- Micro 10 to 100 kW
- Mini 100 kW to 1 MW
- Integer 1 MW to 10 MW
- Medium 10 to 100 MW
- Large greater than 100 MW.

The term "integer hydro" was adopted rather than "small hydro" to avoid confusion resulting from the fact that "small hydro" has been previously defined in various ways by different authorities.

Definitions based on generating capacity, however, can be misleading because they do not necessarily reflect the physical size of the plant or the machinery. One reason for this is that hydro stations are generally discussed as a whole, not as a group of individual units. A large plant may be comprised of several smaller physical units. Also, the size of a turbine/generator set is not directly dependent on the capacity. The physical size of a unit depends more on the design water flow rate for the unit than on the generating capacity.

Two hydropower sites of the same capacity can have vastly different equipment size requirements based on the chosen units and the available head. In British Columbia, where high head development sites are more readily available than in the rest of Canada, large generating capacity plants can have electromechanical equipment which is relatively small in physical size.

The technology portion of this study concentrates on individual units sizes that fall into the CEA "integer hydro" rating since a 10-MW turbine is the typical limiting size available for 15 m of head. Sites with potential resources greater than 10 MW would utilize multiple generating units.

2.2 Low Head Hydro Defined

"Head" refers to the elevation difference between the water levels upstream and downstream of a hydroelectric power plant. As with small hydro, there is not a standard accepted definition of low head hydro. In many jurisdictions, projects with a head of 1.5 to 5 m are considered to be low head. However, in jurisdictions such as British Columbia, that have an abundance of very high head sites available, 15 m is considered to be low head.

Generally, projects with a head under 1.5 or 2 m are not viable with traditional technology. New technologies are being developed to take advantage of these small water elevation changes, but they generally rely on the kinetic energy in the streamflow as opposed to the potential energy due to hydraulic head. These technologies are often referred to as kinetic hydro and are not considered in this study.

For the purposes of this study, the upper limit of "low head hydro" was assumed to be 15 m. However, because of the variability of generating units that meet this criterion, another category was broken out for sites with heads between 1.5 and 5 m to account for the different technologies available for this head range.

2.3 Run-of-River Defined

ROR hydro developments do not alter the natural flow patterns downstream of the hydroelectric facility. River flows that are diverted through the facility to generate electricity are released back to the river without detention. Flows not diverted are spilled, also without detention. Therefore, the flow rate in the river downstream of the facility is approximately equal to that upstream. As a result, generation at ROR developments is highly dependent on the natural water cycle. By contrast, plants that are permitted to regulate flows in the river can store and utilize water as needed to meet variations in electrical demand. However, there are environmental concerns associated with water storage or "peaking" operations, since they alter natural water level and flow cycles in the river.

Like storage projects, ROR developments often incorporate a dam and a reservoir, but generally at a much smaller scale. A reservoir is only required at a ROR project to provide sufficient water depth for the facility to operate. No significant fluctuation in the upstream water level is permitted. Therefore, a large dam structure and storage reservoir are often not warranted. Because all inflow into the reservoir is either used to generate electricity or is spilled, flow rates and water levels downstream of the plant are essentially unregulated and fluctuate according to the natural water cycle. This is thought to significantly reduce the environmental impact associated with the development.

2.4 Advantages and Disadvantages of Low Head Hydro

As with larger hydropower developments, low head hydropower site layouts can vary dramatically from one to another. The development relies on the natural topography of the region in order to take advantage of differences in water elevation to provide head on the plant. This means that there can be tremendous variation in the civil works between sites. Caution must, therefore, be used when making generalizations about low head hydro sites; what applies to one site may not apply to another. However, some broad generalizations can be made.

There are several advantages to low head hydro over other generation types. While not all will apply to a given site, some of the advantages include the following:

- generally smaller impounded reservoir area than for large hydro sites. This reduces both the environmental impact of the projects and associated mitigation costs.
- many low head hydro projects are ROR hydro projects. This is thought to reduce both the environmental impact of the projects and the associated mitigation costs.
- there are a large number of existing low head dams and hydraulic structures for flood control and water supply or irrigation. Many of these are suitable for development of low head hydro.

This can significantly reduce the capital investment required to develop a hydro station and reduce environmental mitigation and monitoring costs due to reduced environmental impacts.

- diversification of the energy supply is a goal of many governments. Encouraging the development of low head hydro sites can help to meet this goal.
- development of low head hydro sites can also
  - provide short-term economic benefits for local communities during construction
  - improve water access and navigation in headponds
  - enhance sport fishing opportunities in headponds
  - enhance access for resource users to previously inaccessible areas
  - benefit for First Nations if partnerships are formed, including income and jobs for community members.

There are also some disadvantages associated with low head hydro developments over other generation types. Again, not all will apply to a given site. Some potential disadvantages include the following:

- Generally, small and low head hydro have limited or no control over when energy is available for generation. Small reservoirs mean that very little water can be stored to be used for generation to follow demand. ROR sites are even more limited; they must generate when water is available with no seasonal storage allowed. Depending on the Power Purchase Agreement, this inability to follow the load can reduce revenues because water cannot be stored for generation during peak demand periods. This in turn would make the project as a whole less economically viable.
- The major disadvantage of low head hydro projects is the project economics. Many of the costs associated with developing a site do not scale down linearly from large to small projects; meaning that on a per megawatt basis, small projects can be far more expensive than large developments.

3 Low Head Hydropower in Canada

3. Low Head Hydropower in Canada

3.1 Current Market Status

Hydroelectric power plants produce nearly all of the electricity generated in British Columbia, Manitoba, Quebec and Newfoundland and Labrador, as well as a significant portion of the generation in Ontario and New Brunswick. The development of this resource promoted economic growth both in terms of the initial construction as well as the secondary and tertiary industries drawn to abundant and low-cost energy.

Worldwide, hydropower produces approximately 17% of the total electricity generated. In Canada, hydroelectric plants provide an installed capacity of over 72 500 MW.

Statistics Canada[ll] maintains a database listing statistics of all electricity generation in Canada. In 2006, Canada had a total of approximately 3500 MW of developed small hydro at 359 sites. Statistics Canada does not have information about head beyond 1986. At that time, approximately 560 MW across 99 sites had less than 15 m of head. The installed Canadian small and low head hydro sites are listed by province in Table 3.1.

Table 3.1: Installed Capacity of Canadian Small and Low Head Hydro (1 to 50 MW)

Province	Installed Small Hydro (MW)	No. of Small Hydro Developments	Installed Low Head Hydro (MW)	No. of Low Head Hydro Developments
British Columbia	752	40	–	–
Alberta	309	21	38	3
Saskatchewan	23	3	–	–
Manitoba	11	2	–	–
Ontario	1052	124	252	56
Quebec	692	84	151	21
New Brunswick	85	10	13	4
Nova Scotia	174	35	64	11
Prince Edward Island	–	–	–	–
Newfoundland and Labrador	216	31	32	3
Yukon	77	5	–	–
Northwest Territories	31	4	10	1
Nunavut	–	–	–	–
TOTAL CANADA	**3422**	**359**	**560**	**99**

Note: Small hydro data is from 2006 while the low head hydro data is dated 1986.

Virtually all of the viable large hydro sites in Canada have been (or are being) developed. These sites offer the best economics and even though they may not be located close to population or industrial centres, their size can justify the cost of a long transmission connection. Most of the small sites that are conveniently located have also been developed. The majority of the remaining sites are small, remote, ROR sites. They are typically more expensive to develop, per unit of capacity, since they are

ll Statistics Canada, "Electric Power Generating Stations", Catalogue 57-206-XIB, Table 4, reference year 2006.

frequently too small or remote to connect cost effectively to the existing grid and, because they are often operated as ROR plants, they can produce only fluctuating or seasonal power.

BC Hydro hopes to attract 5000 GWh per year of clean energy; much of this is expected to be hydro, although it is unknown how much will be small hydro. The minimum energy requirement of a project is 25 GWh/yr, which would be approximately a 6-MW plant with a 50% capacity factor. BC Hydro has also issued a Standard Offer Program for clean renewable projects that are specifically less than 10 MW. Again, it is unknown how much will be hydro. Ontario, through the Ontario Power Authority (OPA), also has a Renewable Energy Standard Offer Program (RESOP) restricted to projects less than 10 MW. As of March 31, 2008, 301 projects totalling 1268 MW had executed an RESOP contract[III]. Nineteen contracts totalling 66 MW have been water power projects. Of the 279 contracts, 81 projects (34 MW) have reached commercial operation. Eight hydroelectric projects representing 6.7 MW or 20% of the total installed capacity has reached commercial operation.

Despite all of the negatives, small and low head hydro can have a role to play in local, regional and provincial development. Because they are small and are often ROR, the impact of low head hydro developments on the environment can be much smaller and associated environmental mitigation costs can be much lower than traditional hydroelectric developments.

Small hydro plants can play a role in replacing diesel electricity generation in remote locations, where the relatively high initial cost of the small hydro facility can be offset by the high operational costs of diesel generation. A base oil price in excess of $100 per barrel, plus the cost of transportation by winter road and/or air to remote communities in the north, drives the cost of diesel generation quite high. In an entirely remote area, the diesel unit will have to be retained and emergency fuel supplies kept available, but the overall cost of generation could be lowered significantly through the addition of small and low head hydro.

Small hydro sites can also effectively supply communities that already have a grid connection. A local hydro plant can provide security of supply in case of a transmission outage, but can also provide electrical stability to a radial transmission line. In an interconnected situation, small hydro can obtain an additional benefit from the system, since the storage at a large hydro facility can act as a “battery” to store the intermittent energy from a ROR plant.

Many small hydro sites are completely remote. In Ontario, the Standard Offer Program specifies that projects must be able to connect to a local distribution system. The OPA, however, has recognized that there might be circumstances where an otherwise viable small hydro site cannot so connect. Hatch identified 53 potential hydroelectric sites that are within 10 km of a transmission line[IV]. The OPA has recommended that these sites still be eligible for the RESOP.

3.1.1 International Market Status

Over the past few decades, renewable energy generation has grown significantly. From 1970 to 2001, the share of renewable energy generation in the total energy mix rose from 4.6% to 5.5% in

III See progress reports at: http://www.powerauthority.on.ca/sop/Page.asp?PageID=1224&SiteNodeID=308&BL_ExpandID=161.

IV Hatch Ltd., for Ontario Waterpower Association and Ministry of Natural Resources, “Evaluation and Assessment of Ontario’s Waterpower Potential”, October 2005.

the 26 International Energy Agency (IEA) member countries[V]. Hydropower makes up a large portion of the renewable energy mix; in 2001, hydropower represented 36% of the renewable energy and 86% of electricity generated from renewable sources in IEA countries.

However, in IEA countries, the rate of growth in the hydropower sector has been decreasing in recent decades. In the period of 1970 to 1980, hydropower generation experienced an average annual growth of 2.6%. This decreased to 0.7% in the period from 1981 to 1990 and 0.4% in the period from 1991 to 2001. The portion of electricity generated from renewable sources fell from 24% in 1970 to 15% in 2001 Electricity generation from wind and solar power has been growing extremely quickly (an average annual growth rate of over 23% from 1980 to 2001), but because they represent such a small portion of the overall energy mix, this growth has not been able to balance the limited growth in the hydropower sector[VI].

In recent years, there has been a renewed push for electricity generation from renewable sources. This has led to an increase in investment in all forms of renewable energy, including small hydro. Over 65 countries worldwide have renewable energy policy targets in place[VII]. This includes Canada, the United States and all of the European Union countries. In 2007, over $100 billion was invested globally in the renewable energy sector, including installing capacity, manufacturing plants and R&D.

In 2007, China invested $12 billion in small hydro and other renewable energy sources. By 2005, China had an installed hydropower capacity of 115 GW, 35 GW of which were small hydro (under 50 MW). It is expected that 300 GW of hydropower will be on-line by 2020[VIII].

3.2 Canadian Potential

The potential in Canada for small and low head hydropower was assessed by reviewing studies and databases with hydropower potential listings. Unfortunately, there has been little recent fieldwork done to quantify hydropower potential, low head or otherwise. Most of the data available is based on field work produced several decades ago, when low head hydro was not a high priority. Thus, existing data on low head hydro potential may not be comprehensive.

The initial step in identifying hydropower potential in Canada is to identify alternative sources of information. The primary database used to compile the list of potential small hydropower sites in Canada was provided by NRCan. Several other databases and studies were also used and these are listed in Appendix A. This includes the 2005 Hatch report "Evaluation and Assessment of Ontario's Waterpower Potential" for the Ontario Waterpower Association and the Ontario Ministry of Natural Resources. The resulting database is included in Appendix B.

There were various motivations behind the compilation of the data sources consulted as part of this study. As a result, each data set contained different types of information. For example, all data sets contained information about the potential size of the sites (in megawatts), and most included the

V IEA member countries are: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

VI Organization for Economic Co-operation and Development and International Energy Agency, "Renewable Energy, Market and Policy Trends in IEA Countries", 2004.

VII "Global Status Report: Keeping It Clean", *Renewable Energy World*, Volume 11, Issue 2, April 2008.

VIII "Powering Progress: China's Clean Energy Revolution", *Renewable Energy World*, Volume 10, Issue 1, January 2007.

gross head available to the potential development, but only the 2005 Hatch report included information about which sites are thought to be "practical" to develop with today's economics.

Each data source was reviewed and all sites with a head listed as 15 m or less and a potential capacity listed as 50 MW or less were included. The low head hydro potential, by province, is summarized in Table 3.2. In Canada, there are estimated to be over 2300 potential sites for low head hydro development, with a total potential capacity of almost 5 GW.

Table 3.2: Canadian Low Head Hydro Potential (<15-m Head)

Province/Territory	No. of Sites	Total Available Capacity (MW)	Estimated Practical Capacity (MW)
British Columbia	10	11	3
Alberta	22	75	21
Saskatchewan	28	178	50
Manitoba	34	338	95
Ontario	526	2046	573
Quebec	1554	1991	558
New Brunswick	54	175	49
Nova Scotia	5	11	3
Prince Edward Island	6	2	1
Newfoundland and Labrador	49	27	8
Yukon	insufficient data	insufficient data	insufficient data
Northwest Territories	11	12	3
Nunavut	insufficient data	insufficient data	insufficient data
TOTAL	**2329**	**4866**	**1363**

It is important to consider two points in reference to the hydropower potential listed herein. First, as noted above, Table 3.2 is based on a review of existing studies and databases that are in many cases several decades old and were not mandated to specifically target low head hydro potential. Many potential development sites may have been excluded from these past studies and databases or simply overlooked because of the low available head. Traditionally these sites have not been economical, but with the advent of new technologies and practices along with increased energy costs, historically unattractive sites may now be economical.

The second point to consider with respect to the hydropower potential listed herein is that no attempt was made to do a rigorous analysis of the practicality of particular sites. This report does not address the issue of whether any of the sites identified in Appendix B are viable or not. It is up to the waterpower developer to determine if a site meets financial objectives through detailed specific study of the potential revenue, engineering, construction, environmental, social, regulatory and financing aspects of the project.

However, an estimate of "practical" sites to develop is listed in Table 3.2. The Hatch report "Evaluation and Assessment of Ontario's Waterpower Potential" estimated the practicality of sites based on several criteria, including

- site economics
- transmission requirements
- and the political/public policy surrounding the site in question.

Of the 3949 MW (745 sites) identified with under 50 MW capacity in Ontario, 2046 MW (526 sites) were identified as having under 15 m of gross head available. Of this, 573 MW (82 sites) were identified as either "Probable or Committed" or "Practical" projects; this amounts to approximately 28% of the available sites. The "Estimated Practical Capacity" listed in Table 3.2 was calculated by assuming the 28% ratio of "practical" sites to total sites is constant across Canada. This is obviously a broad assumption with considerable uncertainty. The resulting numbers should be used for illustrative purposes only and the large uncertainty should be kept in mind.

The information available for the Yukon and Nunavut did not include data about available head, so no assessment of low head hydro capacity could be made. However, there is significant small hydro capacity available. In the Yukon, 147 sites have been identified with a potential installed capacity of over 85 MW. In Nunavut, 8 small hydro sites with almost 30 MW of potential installed capacity were identified. These estimates are very conservative; there are likely very many other small hydro sites in the northern interior that have not been identified due to their remoteness. In fact, there are many large hydro sites in the north that have not been developed for a variety of reasons, including the lack of local load.

For Manitoba and Ontario, information was available for low head, ROR sites with over 50-MW capacity. In Manitoba, 10 sites with a combined installed capacity of almost 1800 MW were identified and in Ontario, 11 sites with combined installed capacity of almost 1500 MW were identified.

Table 3.2 lists only potential low head hydro plants with between 1-MW and 50-MW capacity. There is, however, significant low head hydro potential in Canada for sites with less than 1-MW capacity. In Ontario, 560 MW of potential low head hydro have been identified[IX].

[IX] International Energy Agency, International Small-Hydro Atlas, http://www.small-hydro.com/, Accessed March 2008.

4 State of Technology

4. State of Technology

Hydropower is a conceptually simple and mature technology. A report produced by the National Energy Board (NEB)[X], provides good insight into the state of the electricity market in Canada and puts context on the Canadian national policy towards development of new electric generation to meet growing demand. The following discussion expands on the NEB technology assessment, concentrating on the low head hydro technologies.

Low head hydro turbines find their normal application in the head range of 3 to 15 m. Power generation at low head is associated with low power output for each unit of water flowing through the turbine. The power output of a hydropower turbine/generator unit is proportional to both the head and flow rate as given by

$$P = r \times g \times Q \times h \times e$$

where,

P	=	power (watt)
r	=	density of water, typically 1000 kg/m^3
g	=	acceleration due to gravity, 9.81 m/s^2
Q	=	flow rate (m^3/s)
h	=	head (m)
e	=	efficiency (varies with flow rate and head, typical values at peak=0.9, and at maximum output = 0.85).

This power equation shows that as the head decreases the flow rate must increase accordingly to produce the same power. The size and cost of water conveyance structures and electromechanical equipment required for a hydroelectric project depends largely on the flow rate. The larger electromechanical equipment also requires larger powerhouse facilities. This results in construction costs increasing exponentially as the head decreases, imparting a much larger cost per installed kilowatt to a low head hydro development. There are, however, some new technologies being developed to circumvent this problem. For example, if a turbine/generator set is placed directly in a stream, with little structural works required, the high cost of the large electromechanical works can be balanced by a reduced need for structural works.

Turbine blades and hydraulic passages are optimized for certain velocities, therefore, for higher flows the turbine dimensions must increase. The power output of a turbine increases with the square of the runner diameter (D^2) whereas the weight of the turbine increases approximately with the cube of the runner diameter (D^3). The cost of a turbine is generally proportional to its weight. Therefore, the power-to-weight (and power-to-cost) ratio is proportional to 1/D. As the flow rate increases, the power-to-cost ratio decreases.

Not only is the relative cost of the turbine higher at low heads, but the generator cost is also higher. Because low head turbines are associated with high flows and low rotational speeds, the runaway speeds are about 3 times the rated speed, and runaway flows are 2 to 2.5 times the rated flow.

[X] "Emerging Technologies in Electricity Generation an Energy Market Assessment" (March 2006), http://www.neb-one.gc.ca/clf-nsi/rthnb/nwsrls/2006/fctsht06-eng.html.

Direct-driven low speed generators with large rotor diameters are subject to high centrifugal forces at such high runaway speeds, resulting in use of more material to resist the internal stress. This means that low head electromechanical equipment gives less power for a unit weight of material and, hence, that generators for low head schemes are generally more expensive.

Another factor that can significantly affect power generation of low head schemes is the relatively high variation in head when the tailwater level rises during periods of high river flows. For a plant with 3 m of head, a rise of 1.5 m in tailwater level significantly reduces the head on the plant. This has a two-fold effect:

- The head available for generation is reduced by 50%.
- The minimum discharge is reduced due to a lack of driving head.

Typically, these factors can combine to result in a 65% loss in power production.

Each low head hydro scheme needs a detailed analysis to find an optimal and most economic solution keeping in view the hydrology, site topography, civil structures, the connected load or grid system, environmental factors, and constraints on transportation.

4.1 Existing Turbine Designs for Low Head

For a head range of 3 to 15 m, the type of turbine currently used for new installations is predominantly of axial flow type followed by Francis type turbines.

A brief description of the advantages and disadvantages of each of the traditional turbine types is included in the following sections.

4.1.1 Axial Flow Turbines

Axial flow turbines are those turbines in which the flow though the runner is aligned with the axis of rotation. The straight flow horizontal bulb turbine evolved from the conventional Kaplan/propeller turbine. The various existing axial flow turbine configurations for low head application are variants of the straight flow horizontal bulb turbine.

The distinguishing features of a conventional Kaplan/propeller turbine are

- its distributor is cylindrical with the pivoting axis of the wicket gates parallel to the runner axis of rotation
- the flow turns by 90° from exit of wicket gates to inlet of runner
- has a spiral casing and a 90° elbow draft tube
- runner blades can be adjustable or fixed
- wicket gates can be adjustable or fixed
- a vertical shaft configuration is most predominant.

The distinguishing features of a bulb turbine and its variants are

- its distributor is conical with the pivoting axis of the wicket gates inclined to the runner axis of rotation

- the flow remains axial from exit of wicket gates to inlet of the runner
- does not have a spiral casing, the draft tube can be straight conical or have an elbow
- runner blades be adjustable or fixed
- wicket gates can be adjustable or fixed
- turbine shaft can be horizontal, inclined or vertical.

A straight flow turbine passage necessitates the location of the generator in the sealed bulb or open pit upstream of turbine. The size of the generator has to be restrained to the confines of the hydraulic dimension of the bulb or pit. Locating the generator outside the flow path, removes this restraint. Accordingly, several variants to the hydraulic passage are adopted with the turbine shaft horizontal, vertical or inclined.

The primary goal for all low head small hydro schemes is to reduce the overall cost of equipment and the associated civil works. The inherent weakness of a low head small hydro schemes is the low head. The intake, water conveyance systems, powerhouse and the tailrace have to be designed with acceptable flow velocities to minimize the head loss. Even the most simplified civil structures constitute a substantial portion of the overall project costs. Therefore, the thrust of designs for low head projects is to reduce cost of the generating equipment with innovative, efficient and high-quality designs, specifications with only the minimum essential balance of plant equipment, short delivery and installation time and reliable operation.

Present-day small hydro turbines have the following features:

- Turbines are designed for higher specific speeds with improved cavitation characteristics to reduce turbine runner size, increase runner speed and reduce turbine setting.
- Standardized runner sizes of axial flow units for the application range of head and output reduce design, engineering, manufacturing and installation costs.
- Adaptable designs suit site-specific requirements for new and existing sites.
- Environmentally friendly designs use water-lubricated turbine bearings, self-lubricated bearings for runner blades and wicket gates, and oil-free Kaplan runners.
- Direct-driven, cost-effective generators avoid the use of speed-increasing gearboxes where possible for higher combined generating efficiencies. Gearboxes contribute to
  - power losses to the order of 1.5%
  - vibration and noise
  - higher capital and maintenance costs, and
  - environmental risks from lubricating oil.
- Pre-assembled, modular and skid-mounted compact designs for turbines and generators in shop reduce assembly and erection time at site.

- Unattended powerhouses with remote control and monitoring of generating equipment use micro processor-based control and supervisory control and data acquisition (SCADA) systems to reduce operation costs.
- Powerhouses have roof hatches and use mobile cranes for installation and maintenance of powerhouse equipment to eliminate the capital cost of dedicated cranes.
- Vertical axial flow turbines are used for heads above 10 m to reduce the powerhouse footprint and reduce powerhouse civil costs.
- Siphons at turbine inlets prevent turbine runaway and eliminate costly turbine inlet valves.
- Computational fluid dynamics (CFD) are used for turbine design, especially for refurbishment and upgrading projects, to reduce engineering costs. This can be supplemented by experiment for the most-optimized CFD design.

For a given head and runner diameter, the flow passage of an axial flow turbine primarily defines its discharge capacity. An axial flow turbine with a straight passage will pass higher flows than an axial turbine with bends at the inlet, outlet, or both. For example, if the discharge capacity of a straight flow turbine (such as bulb or pit turbine) is about 3.2 m^3/s, the corresponding discharge capacity for turbines with a 45° elbow about is about 2.7 m^3/s. For a turbine with a 90° elbow draft tube, it is only about 2.3 m^3/s. This hydraulic loss reduces both the efficiency and the maximum flows of the turbine. The hydraulic passage of a bulb or pit type turbine is straight, leading to the highest efficiency of the axial flow turbines. All variants of this turbine with a bend upstream or a bend downstream of the runner or its combinations, will have a lower efficiency compared to the bulb/pit turbine.

The runner blades and wicket gates of all axial flow turbines can be designed with different configurations depending on the degree of flow control required and the importance of part load efficiencies. The typical configurations are

- full Kaplan – adjustable runner blades and movable wicket gates
- semi Kaplan – adjustable runner blades, fixed wicket gates
- propeller – fixed runner blades and movable wicket gates, and
- propeller – fixed runner blades and fixed wicket gates.

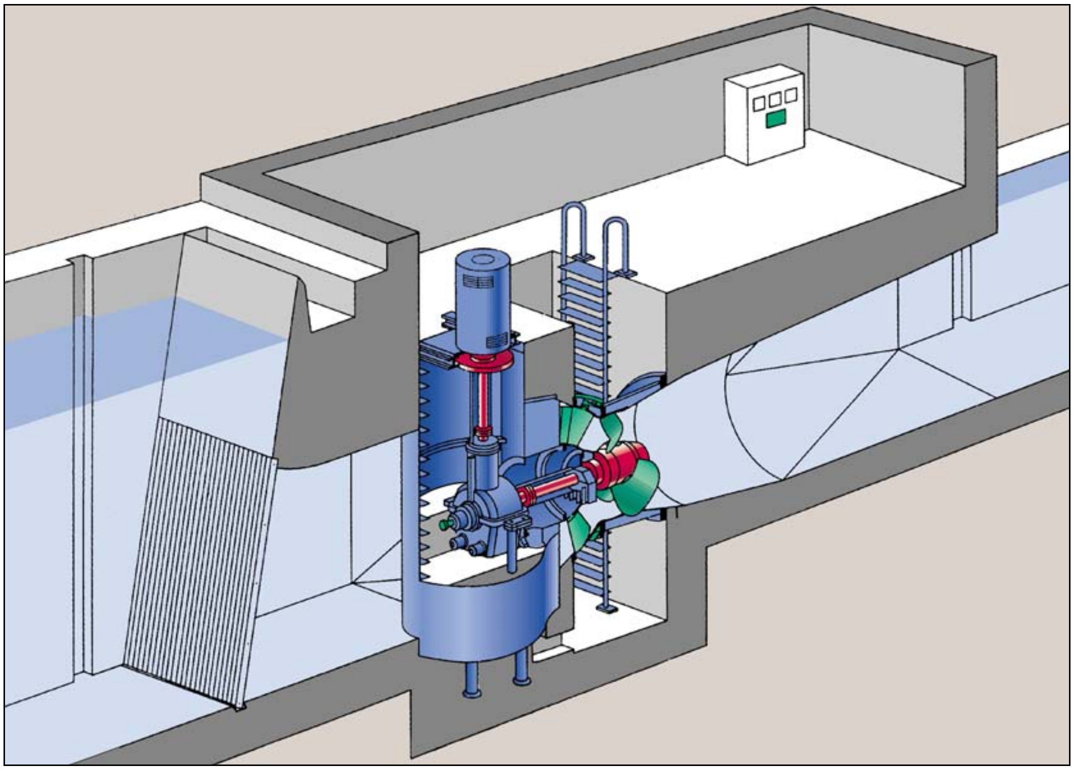
A brief description of the different types of available axial turbine configurations used for low head applications follows. The figures included have been provided by turbine manufacturers for illustration purposes only. Many manufacturers produce each type of turbine. For specific information regarding the available turbines and the head and discharge ranges for which they are suitable, please contact the manufacturers directly.

4.1.1.1 *Pit/Bulb Turbine With a Bevel Gear Drive*

The pit or bulb turbine can have its shaft horizontal or inclined to an angle of 15° to 45°. Head application range is 2 to 8 m and outputs up to 2.5 MW. The right-angle bevel gear drive steps up the low speed of turbine to match the high speed generator. The flow passage is straight including the draft tube. The thrust due to turbine is taken by the gearbox through a rigid coupling and the generator is flexibly connected to the gearbox output shaft. For output up to 400 kW, the design can be with a belt drive and pulleys connected to generator mounted on the top of the turbine casing.

An axial flow, bevel gear turbine is illustrated in Figure 4.1.

Figure 4.1: Axial Flow - Bevel Gear Pit Turbine



Source: Voith Siemens Hydro Power Generation.

4.1.1.2 Straflo Turbines

Straflo turbines are axial turbines with the generator outside of the water channel, connected to the periphery or rim of the runner. This outer rim of the turbine is fitted with seal lips, which are lubricated by a small amount of water designed to permanently leak from the system. The initial designs had fixed runner blades while subsequent designs had adjustable runner blades. These Straflo rim generator units find a wide application in tidal power plants.

The patented VA Tech Hydro Straflo Matrix turbines have been adapted to small hydro applications. They have the following improvements and features over the traditional large size and capacity Straflo Rim generators:

- permanent magnet technology
- Straflo™ technology
- reduced dimensions.

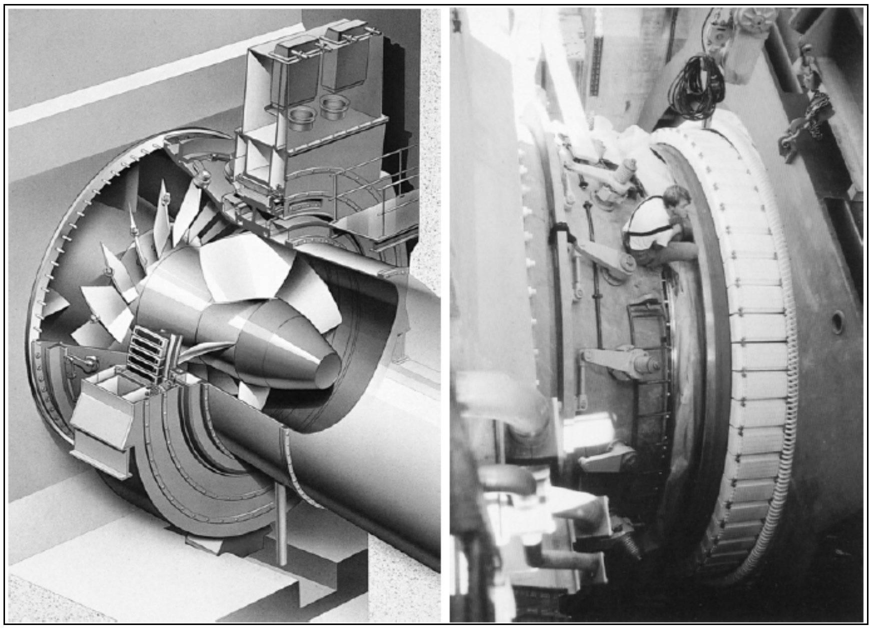
Permanent magnets allow synchronous operation without slip rings and excitation systems.

As no electricity is transferred to the rotor, water can flow through the air gap between the rotor and stator allowing for a very efficient generator cooling. Additionally, this eliminates the main drawback of the traditional Straflo turbines, where the sealing of the generator at a large diameter led to some problems.

The Straflo™ technology has the feature that the turbine runner also serves as support for the generator rotor and both components turn in the flow as a single unit. The resulting compact dimensions render the turbine even more efficient and offer significant advantages if confined space is a factor.

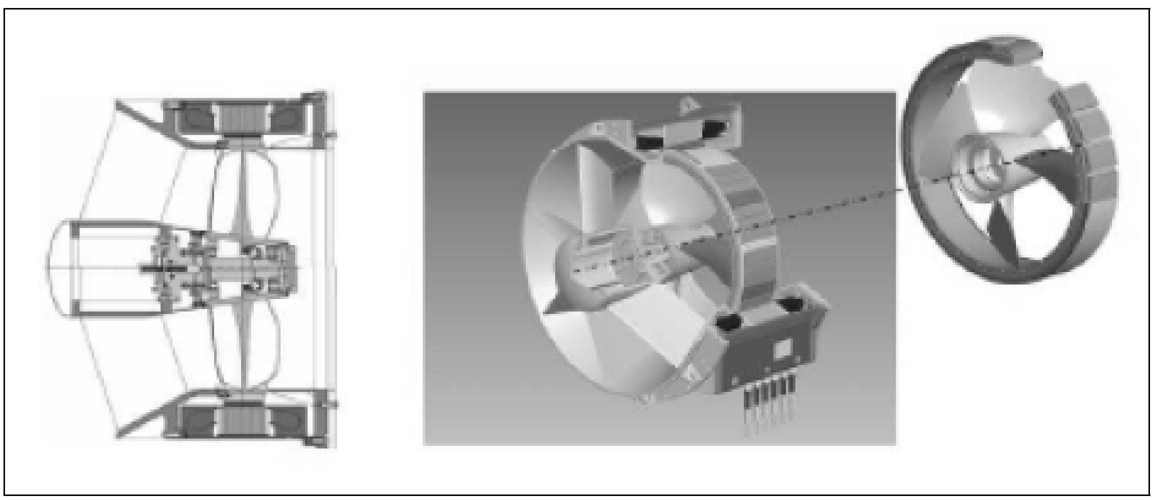
A Straflo turbine and a Straflo Matrix turbine are illustrated in Figures 4.2 and 4.3, respectively.

Figure 4.2: Straflo Turbine



Source: Andritz VA Tech Hydro.

Figure 4.3: StrafloMatrix™ Turbines for Low Head Hydro Applications



Source: Andritz VA Tech Hydro.

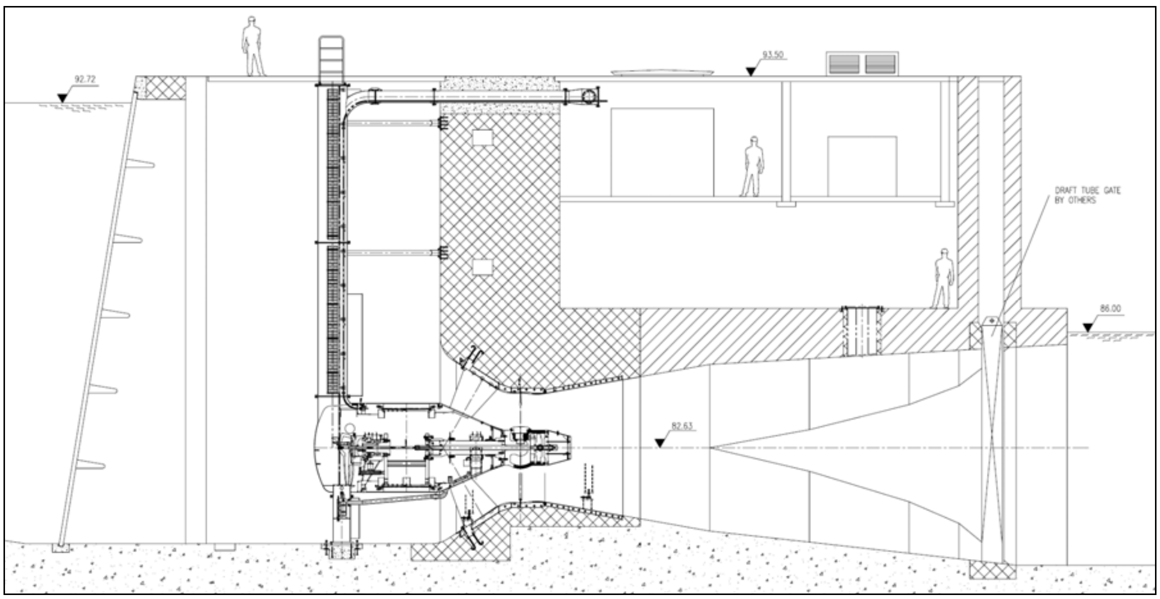
4.1.1.3 ECOBulb Turbine

This ECOBulb is a proprietary design of VA Tech. The turbine is directly connected to the generator, thus avoiding the need for a gearbox. The generator is synchronous, with permanent magnets and a special rotor, the design of which allows reduction of the volume of the poles and, therefore, the bulb diameter. The generator is designed as an integrated part of the turbine, taking advantage of the water flow around the bulb to dissipate the thermal energy due to the electrical losses in the generator.

This generator is a permanent magnet generator (PMG). This technology is discussed in Section 4.2.1.

An ECOBulb turbine is illustrated in Figure 4.4.

Figure 4.4: ECOBulb Turbine



Source: Andritz VA Tech Hydro.

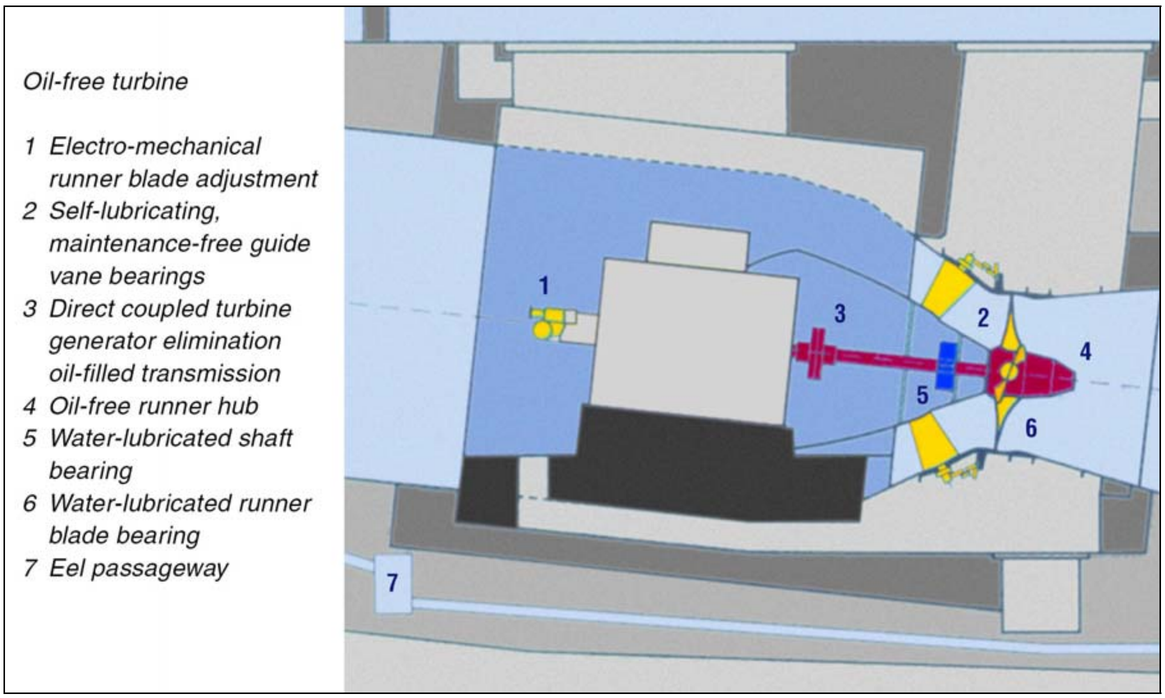
4.1.1.4 Horizontal Axis Pit Turbine

The pit turbine, which is a variation of the bulb turbine, also finds its application in the head range of 3 to 8 m. The generator (with a speed-increasing gearbox) is contained within the upstream pit.

The pit configuration has the advantage of easy access to all the equipment components, in particular the coupling of turbine and speed increaser, the speed increaser itself and the generator. This facilitates inspection, maintenance and repair.

An axial flow pit turbine is illustrated in Figure 4.5.

Figure 4.5: Axial Flow Pit Turbine



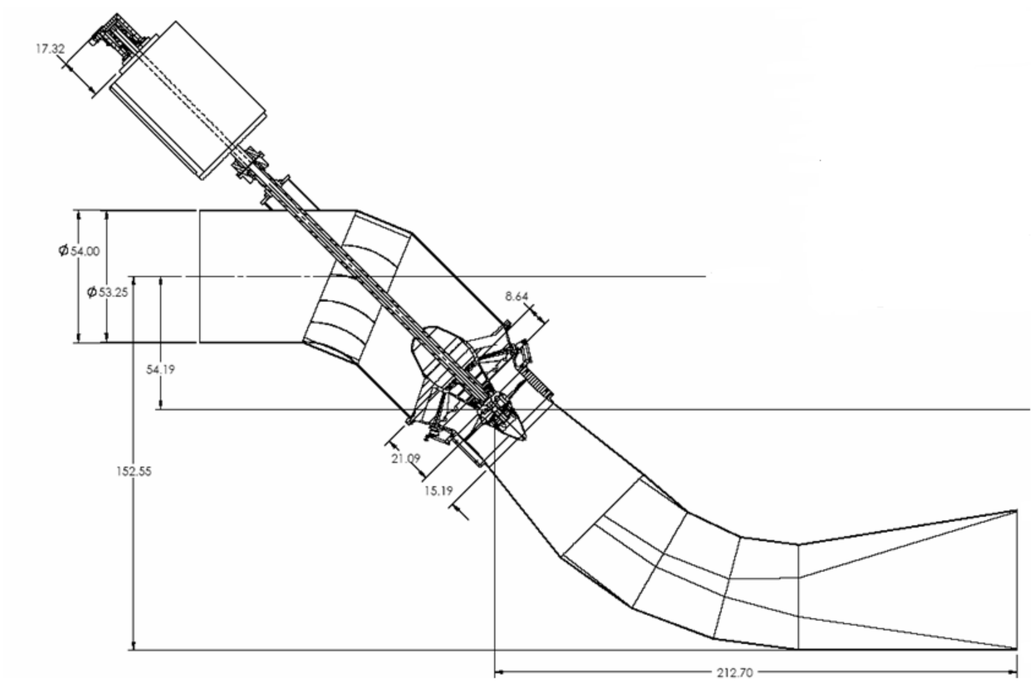
Source: Voith Siemens Hydro Power Generation.

4.1.1.5 Inclined Axis Axial Flow Turbine

This turbine features bends at the inlet and an elbow draft tube with the inclined shaft generally at 45°. The turbine can be connected to a generator either directly or through a speed-increasing gearbox. Depending on the given head and output, the resulting turbine size may require the turbine to be set lower than the required submergence in order to provide adequate water cover at the inlet to prevent air entry. With an inclined axis, access and maintenance of large units is difficult and hence their application is limited to relatively smaller outputs.

An inclined axis axial flow turbine is illustrated in Figure 4.6.

Figure 4.6: Axial Flow Inclined Turbine



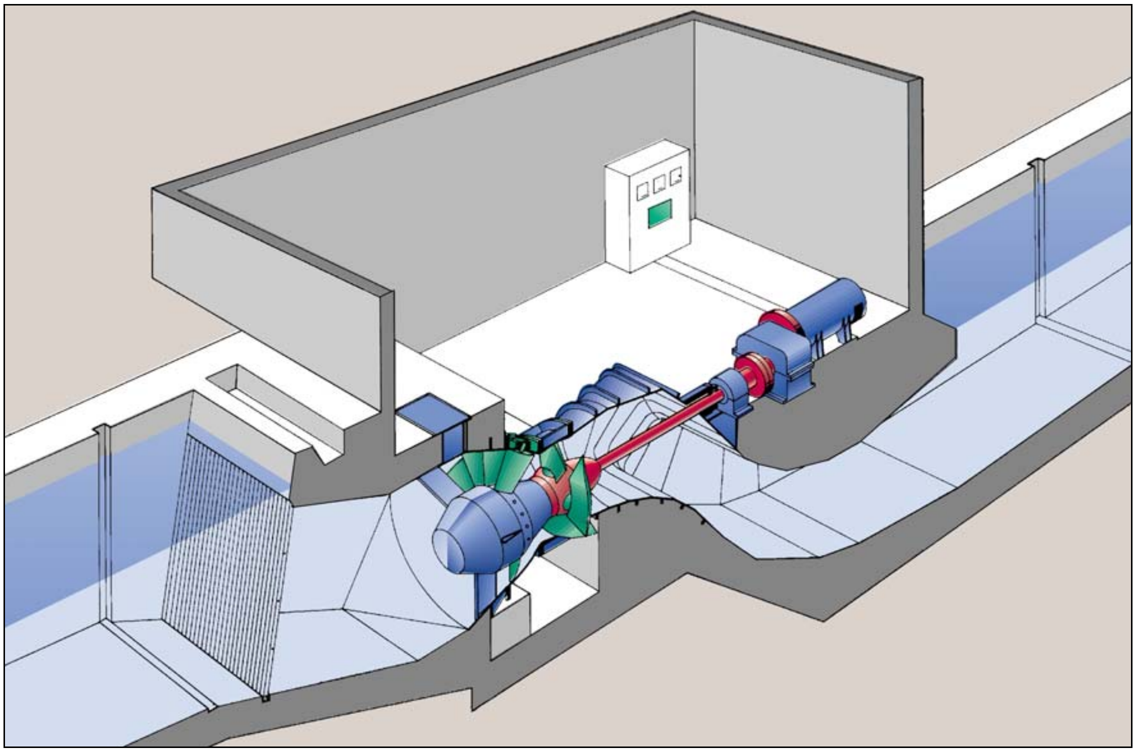
Source: Canadian Hydro Components.

4.1.1.6 Horizontal Axis "S" Type Turbine (Downstream Elbow)

This is a common type of low head axial turbine and is offered by many manufacturers. The head application range is 5 m to 25 m with outputs up to 8 MW. This turbine is characterized by a long turbine shaft which exits the downstream draft tube elbow to connect to a generator either directly or through a gearbox. For a Kaplan runner, the hollow shaft carries the control tubes. This imposes requirement of sufficient space for withdrawal of the tubes, thus increasing the powerhouse length. Earlier designs had shaft failures due to fatigue cracking at the turbine flange (particularly with fabricated shafts). These have been overcome with forged or fabricated shafts and improved designs.

A horizontal axis "S" type turbine with a downstream elbow is illustrated in Figure 4.7.

Figure 4.7: Axial Flow "S" Turbine (Downstream Elbow)



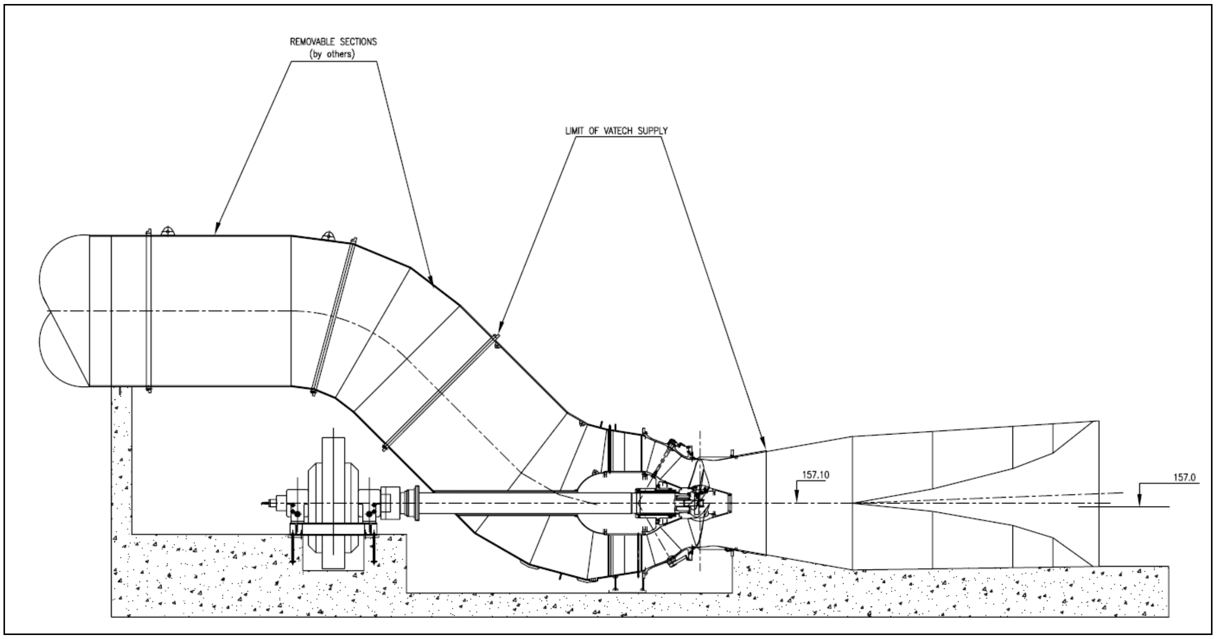
Source: Voith Siemens Hydro Power Generation.

4.1.1.7 Horizontal Axis "S" Type Turbine (Upstream Elbow)

In this configuration, with an upstream elbow, the generator is located below the penstock. The draft tube downstream of the runner is conical and straight. This type of turbine is not offered by all turbine manufacturers. The length of the horizontal shaft for this configuration can be shorter than for a configuration with a downstream elbow (Section 4.1.1.6), making it amenable to a more robust design. The biggest disadvantage is that the generator is located below the penstock. Access by crane to handle the generator is obstructed by the penstock, requiring special design arrangements (a section of the penstock above the generator must be removable). This difficulty can be mitigated to some extent by locating the penstock at an angle.

A horizontal axis "S" type turbine with an upstream elbow is illustrated in Figure 4.8.

Figure 4.8: Axial Flow "S" Turbine (Upstream Elbow)



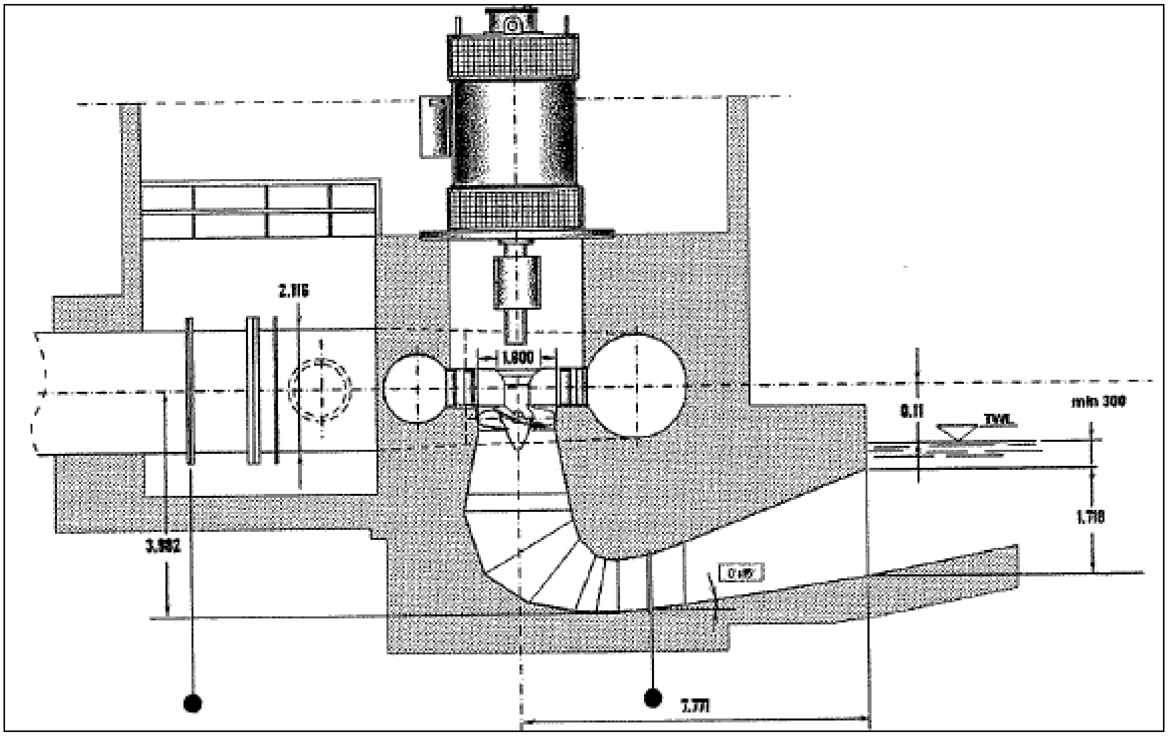
Source: Andritz VA Tech Hydro.

4.1.1.8 Vertical Axis Small Kaplan Turbine With Elbow Draft Tube

This turbine has a design akin to the conventional large vertical Kaplan turbine with a semi-spiral concrete casing and a direct-driven generator or a speed-increasing gearbox. The turbine runner and head cover are not easily accessible. However, the turbine and gearbox can be installed and aligned as one aggregate unit with an embedded elbow draft tube.

A vertical axis small Kaplan turbine is illustrated in Figure 4.9.

Figure 4.9: Vertical Axis Small Kaplan Turbine



Source: Voith Siemens.

4.1.1.9 Vertical Axis Saxo Turbine

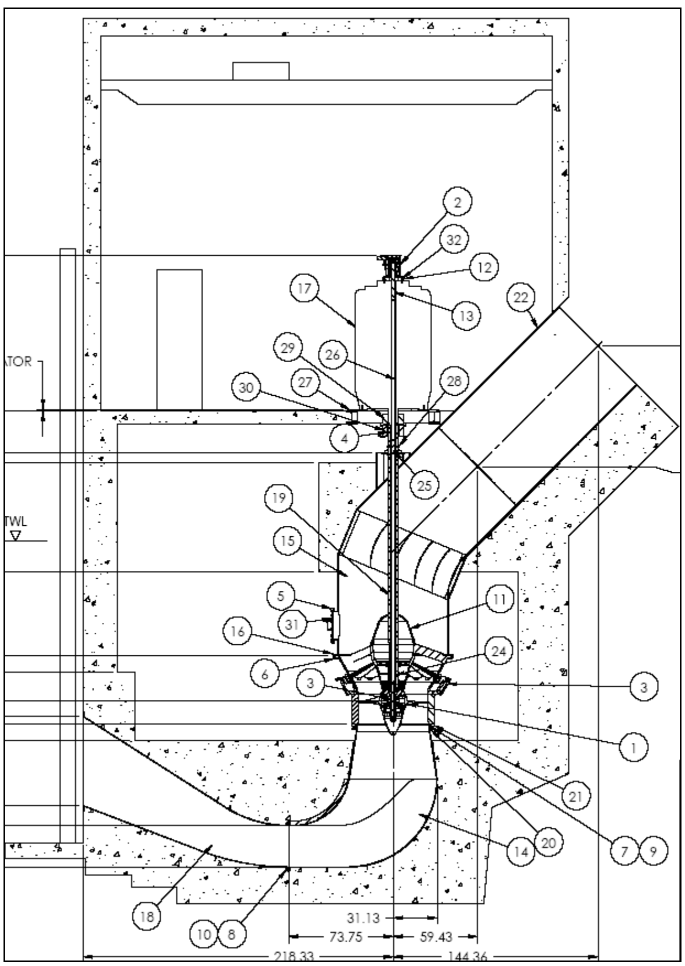
This turbine has an inlet bend of between 45° and 90° or less to suit the penstock installation, and a 90° elbow draft tube. The shape of the water passage resembles a saxophone, hence its name. The head application range is 10 m to 30 m with unit outputs up to 15 MW. This configuration is offered by many manufacturers.

Saxo turbines offer the following advantages compared to other types of axial flow units:

- smallest footprint
- lowest civil costs for new sites, and
- vertical configuration gives the generating unit a stable mechanical behaviour.

An axial flow vertical (saxo) turbine is illustrated in Figure 4.10.

Figure 4.10: Axial Flow Vertical (Saxo) Turbine



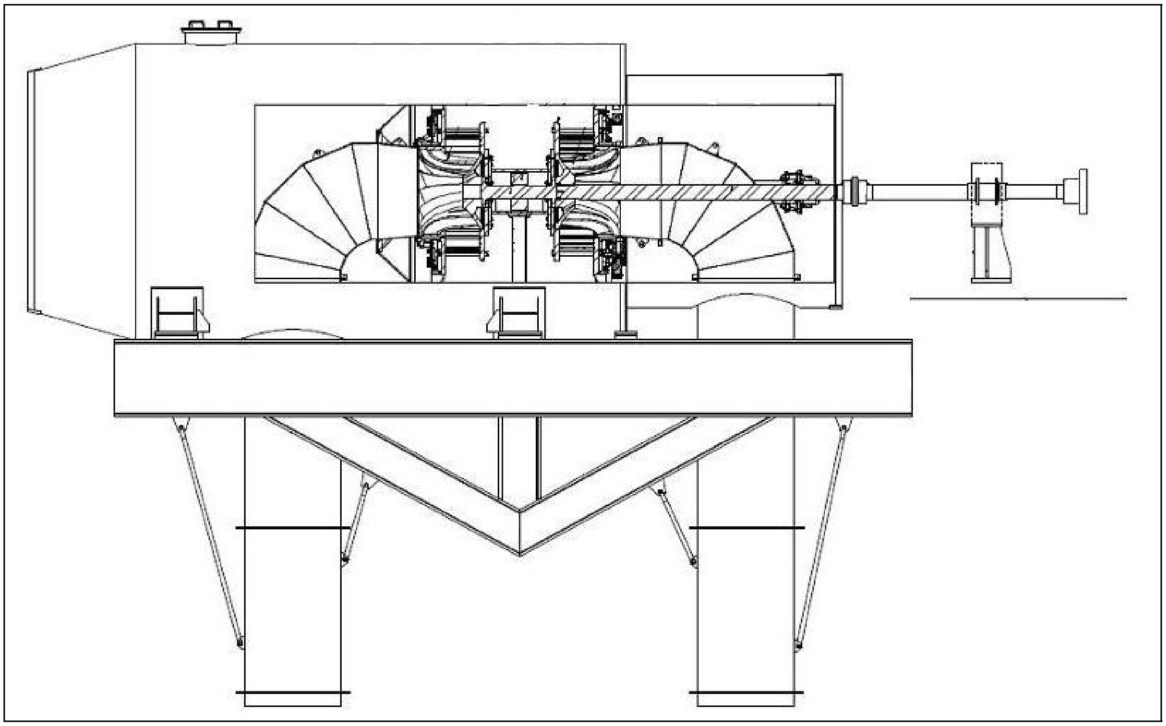
Source: Canadian Hydro Components.

4.1.2 *Horizontal Francis Turbine*

High specific speed Francis turbines can be used for heads of 10 to 15 m and output up to 12 MW. They are set in an open flume or concrete spiral with an elbow draft tube. The turbine is usually set above the tailwater level and facilitates easy access to the runner without dewatering. Many manufacturers offer this type of turbine. For runner sizes above 1.8 m, the turbine is vertical.

Two views of a horizontal axis double runner Francis turbine are illustrated in Figure 4.11.

Figure 4.11: Horizontal Axis Small Francis Turbine



Source: Norcan Hydraulic Turbines.

4.2 Emerging Technologies For Low Head Hydro

In the last 25 years, a number of improvements have been made to small hydro technology, including improvements to hydrologic assessment and project identification and standardized designs of turbines and generators. Some emerging technologies that may find an application in low head hydropower developments are discussed below.

4.2.1 *Permanent Magnet Generators*

Low head hydro installations are almost always characterized by a large variation in either the head, or the flow. Such variations require generation equipment designed to accommodate the variations. Should regulation of frequency (speed) and control of voltage be required, double regulation and external excitation systems are often needed. This results in turbine and generator complexity and a considerable expense to the developer.

One very promising emerging technology proposed for such installations includes unregulated turbines that vary speed with head or flow variations and use permanent magnet type excitation generators (PMG). PMGs produce an output voltage that varies with speed, that is, with head and flow variations.

Some of the advantages and disadvantages of PMGs include

(a) Advantages

- no excitation losses giving very good part load efficiency
- smaller pole pitches than with separate excitation, resulting in lighter design
- no brushes or slip rings
- no gearbox is required for many low head applications. This results in
  - fewer mechanical losses, then higher efficiency
  - more reliability meaning less maintenance and downtime
  - reduced equipment costs
  - smaller powerhouse footprint leading to reduced civil costs.

(b) Disadvantages

- damping of oscillations between grid and rotor is required
- no regulation of the power factor
- voltage is proportional to speed hence no regulation of the voltage
- run-away speed with loss of load gives rise to very high open-circuit voltages
- no isolated operation possible.

PMG is a mature technology used in other industries, but it has not found significant application in the hydropower industry because the rare earth metals used in manufacture of permanent magnets have been very expensive. However, as the patents on the rare earth metals have expired, the cost of magnets has dropped and it has become economically viable to use this technology in hydro generation.

PMG technology faces challenges in getting grid interconnection approvals. Such a system cannot be connected directly to the electrical grid as it is not possible to establish the control of frequency and voltage necessary for successful parallel operation. Currently, power electronics are used to provide the level of protection required, but this is not yet accepted by grid administrators in North America.

4.2.2 Very Low Head Turbine

Another emerging technology is the very low head (VLH) turbine, developed by MJ2 Technologies with support from NRCan[XI]. This innovative turbine design aims to reduce the civil costs of low head

[XI] Information can be found at http://www.vlh-turbine.com/.

hydro developments in order to make projects economically feasible. This is also a "fish-friendly" turbine.

The VLH turbine is a large turbine with a direct-drive variable-speed permanent-magnet generator that is placed directly in a flow channel with between 1.4- and 2.8-m head. This dramatically reduces the civil works required, because there is no need for a complex intake, water conveyance and draft tube, as is generally required for conventional design. This can result in significant overall project cost reductions.

A 410-kW, prototype unit has been in operation in Millau, France since March 2007. This is a 4.5-m diameter unit with a nominal head of 2.5 m, as illustrated in Figure 4.12. As of the time of writing, MJ2 had booked its first three orders deliverable in 2008 and hope to complete others by the end of the year.

Testing was carried out on the prototype turbine to determine the capacity of fish to pass through the turbine without injury. Eels were introduced, allowed to pass through the turbine and then recollected. The mortality rate was very low, with a low percentage of exterior wounds (2%) or internal haemorrhage (1%).

Figure 4.12: MJ2 Technologies' Very Low Head Turbine

Source: http://www.vlh-turbine.com/

4.2.3 Displacement Motor

At the time of writing, Tweedsmuir Green Power Group was in the process of developing an innovative method of capturing energy at low heads using what they term a displacement motor. The details of this technology were not yet released due to pending patent applications; this was expected to be resolved by the fall of 2008. Tweedsmuir Green Power Group had one 7- to 10-kW prototype plant in operation in Tamworth, Ontario, with a 70- to 200-kW plant planned for Crysler, Ontario.

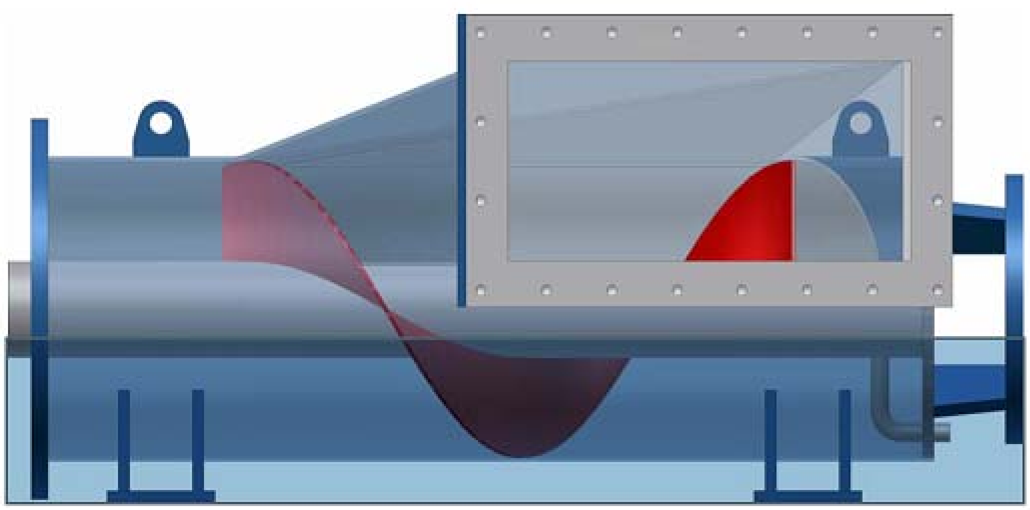
The displacement motor technology uses a closed unit with an eccentric rotor to capture potential energy in streamflow. In some applications, a portion of the kinetic energy is also captured. The system operates at low speeds, maximizing the efficient capture of energy at low heads and low flow rates. An anticipated peak efficiency of approximately 90% is reached at about 2.5 m of head. Efficiencies decrease with increased head above about 4 m.

Tweedsmuir Green Power Group's displacement motor was originally designed to take advantage of energy at existing low head dams in Ontario. Developments of this type are expected to be significantly less expensive than traditional low head hydropower developments. Minimal civil works are required because the units are placed at existing structures, and the unit itself is expected to be very inexpensive when compared to traditional low head hydropower units. Project costs are anticipated to be in the range of $2,000 to $2,400/kW with the cost of the displacement motor making up approximately 25% of the project cost. These costs reflect the capacity of the device to support environmental priorities. Extraordinary costs associated with grid interconnection are also excluded. As with many small hydro technologies, at the time of writing, this remained a significant hurdle for commercialization of the displacement motor.

4.2.4 *"Vaneless" Fish-Friendly Turbines*

With the support of NRCan, Rapid-Eau Technologies (Rapid-Eau) has developed a fish-friendly turbine aimed at minimizing the impact (injury and mortality) to fish passing through the turbine. The fish-friendly turbine design is based on Rapid-Eau's patented "L-type" turbine, a propeller turbine that does not have the guide vanes of a conventional propeller turbine. Instead, the "L-type" turbine uses a casing with a spiral-shaped ramp to guide the flow and create the angular momentum to drive the turbine runner (Figure 4.13). The "L-type" thus is called also a "Vaneless" turbine. The vaneless turbine has been used on a number of small hydro sites in Canada and abroad.

Figure 4.13: Casing of the Vaneless Fish-Friendly Turbine



Development research focused on the design of a structurally simple, non-regulated turbine that would have a very low impact on passing fish, and the ability to use a variable speed drive to give a wide range of operation for low head hydro applications.

Rapid-Eau and Swiderski Engineering Inc. jointly used CFD analysis to check and improve initial designs that were based on theory and experience. Laboratory testing results have shown promising performance of the turbine with an overall efficiency around 87.5%. The ability of running at variable speeds allows the turbine to have very good turbine performance over a large head range. Coupled with the vaneless casing, the turbine is also anticipated to significantly increase the head zone in which fish can pass though the turbine without damage (mortality-free zone). On-site testing would confirm the design for the fish-friendliness of the turbine.

4.2.5 *Electricity Storage*

At present, there is no economical way to store electricity, once produced. Just like oil, coal and natural gas, the "fuel" for hydropower (water) must be stored before its consumption. Electricity must be consumed as it is generated and supply must instantaneously match demand.

The water behind a hydro dam does represent one form of electricity storage in a mixed power supply system. As required, water can be released from a dam and run through a turbine, dispatching power to match the demand. This storage can be used to off-set the variability of wind power and off-set peak demands in a capacity-constrained supply system. This type of operation, however, is not ROR (as discussed in Section 2.3), and can have environmental impacts if the fluctuations in flows severely affect the aquatic habitat or biota in downstream rivers. The degree of impact is dependent on the hydraulic properties of the river and the season in which the change in flows occur.

Demand for electricity, or load, takes a characteristic "shape," depending on the market it serves. The day-to-day and season-to-season fluctuations in demand must be accommodated with sufficient generating capacity to meet the peak power demand and enough fuel to supply the energy demand.

As renewable forms of electricity generation become more prevalent, their variable nature may pose a challenge to integration into the existing electrical grid. Wind, photovoltaic cells and ROR hydro are all less predictable than more traditional means of electricity generation. The ability to store power that is generated when the wind blows, the sun shines, or when the natural river flows, and use it at another time could add tremendous value to these technologies. There are other benefits that storage of electricity would provide and are described in a 2006 National Energy Board (NEB) report[XII]. The NEB identified several emerging technologies for storage of electricity which would benefit all renewable generation with unreliable supply. Since these are not specific to low head hydro, these technologies will not be specifically discussed in this report.

4.2.6 *Other Technologies*

Other emerging technologies include

- turbine designs to reduce mortality of fish passing through the turbine include
  - designs that have helical turbine blades with relatively long wicket gates
  - minimum gap runner turbines which feature reduced gaps between the adjustable blades and hub and runner envelope; reduced gap between the wicket gates and the covers; better pressure distribution across the blades; lower shear stresses in the turbine; and, more rounded blade inlet edges to deflect fish

XII National Energy Board, "Emerging Technologies in Electricity Generation: An Energy Market Assessment", March 2006.

- variable speed turbine and generators with associated controls and inverters to capture energy from wider range of heads and flows to maximize generation
- auto-venting turbines to increase dissolved oxygen in discharges downstream of the dam
- reregulating and aerating weirs used to stabilize tailwater discharges and improve water quality
- upgrades of existing old generating units using replacement turbines and/or runners for higher efficiencies and outputs
- new assessment methods to balance in-stream flow needs of fish and water for energy generation and optimize the operation of reservoir systems
- advanced instrumentation and control systems that modify turbine operation to maximize environmental benefits and energy generation.

4.3 Current Manufacturer Capacity

There is a large manufacturing capacity for small hydropower units in Canada. The following is a list of some of the manufacturers currently active in supplying units to the Canadian small hydro market, together with some of the turbines they offer for applications with under 15 m of head (in alphabetical order):

- Andritz VA Tech Hydro
  - COMPACT Belt Drive Bulb
  - COMPACT Bevel Gear Bulb
  - COMPACT Axial Turbine [Inclined, Vertical (Saxo), Horizontal (Upstream elbow S type)]
  - COMPACT Kaplan
  - COMPACT ECOBulb™ Turbine Generator
  - COMPACT Francis
- Canadian Hydro Components, Almonte, Ontario
  - Axial Flow, Pit (belt, bevel gear, parallel shaft gear)
  - Axial Flow, Inclined
  - Axial Flow, Vertical (Saxo)
  - Francis
- Dependable Turbines Ltd., Surrey, BC
  - Turgo Impulse
  - Pelton
- Litostroj
  - Axial Flow, Pit

    - Axial Flow, Vertical [Saxo]
    - Francis
- Norcan Hydraulic Turbines, Carleton Place, Ontario
    - Axial Flow, Horizontal (downstream elbow)
    - Francis
- Voith Siemens Hydro Power Generation
    - Axial Kaplan, Vertical
    - Axial Kaplan, S-type
    - Axial Kaplan, Tubular
    - Axial Kaplan, Pit
    - Francis.

Andritz VA Tech and Voith Siemens are among the very large turbine manufacturers in the world today, with manufacturing plants in the United States and several other countries. Litostroj is relatively smaller, with a manufacturing plant in Slovenia. Canadian Hydro Components, Norcan Hydraulic Turbines and Dependable Turbines Ltd. are all Canadian companies with considerably smaller manufacturing capacity.

GE Hydro and Alstom Hydro are also very large turbine manufacturers that are well respected in the small hydro sector. However, neither appears to have been recently active in small hydro projects in Canada.

Hatch estimates that between the above companies, a demand of at least 50 turbines and up to 60 or 90 turbines could be met annually.

Due to the relatively small number of new small hydro schemes that have been installed in Canada in the past few years, the demand for small hydro units in Canada has been low compared to the available manufacturing capacity. Dedicated small hydro turbine manufacturers have seen very modest or no growth in their business in the North American continent. If the low head hydro market were to become more economically viable, the demand of units would be easily met with the current manufacturing capacity.

4.4 References

Turbine selection for small low-head hydro developments by JL Gordon, Hydropower Consultant.

The “CAT” from VA Tech Hydro by Dieter KROMPHOLZ VA TECH ESCHER WYSS GmbH.

New Solutions in Energy-Status report on Variable Speed Operation in Small Hydro Power, produced by KWI Architects Engineers Consultants, Germany (supported by European Commission).

Voith Siemens Hydro Power Generation-Small Hydro brochure.

Electrical Equipment for Small Hydropower Plants-Generators with Permanent Magnet Excitation, by Jochen Bard of Kassel University for TNSHP: Small Hydropower Workshop (a PPT presentation).

5 Energy Generation Economics

5. Energy Generation Economics

The economic feasibility of a small hydro development is provided by a favourable combination of site topography, hydrology, location and market conditions. Economic feasibility is the most important aspect influencing the development of a waterpower site. If a site is not economically justifiable, the political, environmental and social issues, which in many ways affect the cost, become moot points. Economic feasibility is based on three factors: the costs of construction and operation, the revenue for energy produced, and the required return on investment. The first two factors are highly variable within Canada, depending greatly on the location of the site. The third, the required return, depends on the developer. A government-owned utility will have different expectations than an independent power producer. With these influences on the economics of a waterpower development, every site is unique, and because of different expectations, one developer may find a site to be an encouraging investment while another will not.

Because of this variability, this report cannot address the issue of whether any of the sites identified in Appendix B are viable or not; it is up to the waterpower developer to determine if a site meets financial objectives through detailed specific study of the potential revenue, engineering, construction, environmental, social, regulatory and financing aspects of the project. It is important to note that, for the waterpower sector specifically, cost and revenue estimations for projects must be premised on assessments of the risks and factors that can affect the ultimate project viability. Factors such as the length of approvals processes, and the availability of water for generation (hydrologic variability), are often out of the direct control of the developer.

For the reasons stated above, in order to facilitate this market assessment of low head hydro, it was necessary to make only broad estimations for the potential range of costs. These estimations were based on recent project data, which has been highly affected by the current construction industry conditions within Canada, the current high international demand on resources, and the international political environment.

5.1 Low Head Hydro Costs

5.1.1 Civil Works

A waterpower development requires civil and environmental works and electromechanical equipment as well as transmission and interconnection to the power grid. For greenfield sites, the costs of the civil, environmental, and transmission works can be anywhere from 50% to 70% of the of the total development costs. A variety of books and manuals have been published in recent years that explain the construction and environmental requirements of waterpower facilities for the non-specialist, so details of these facilities will not be discussed in this report. The typical civil and environmental works for a greenfield waterpower site will include

- diversion dam or weir, with
    - embankment or concrete structure to divert water for power
    - spillway to release floodwaters
    - gates or valves to release in-stream flow needs

  - fish passage (upstream and downstream)
- water passage for power, with
  - intake with trashrack and gate
  - excavated canal, underground tunnel and/or penstock
  - valves/gates at turbine entrance/exit, for maintenance
  - tailrace at exit
- powerhouse for turbine, mechanical, and electrical equipment
- environmental mitigation.

Dam construction can be extremely costly. Generally with new dam construction, there is also a significant amount of work and cost involved with the mitigation of environmental impacts. These two costs render most greenfield sites unviable. Thus, it is far more economic to develop waterpower at an existing site that is close to existing transmission lines.

There are a large number of existing sites in Canada that have low head hydro potential. These include sluice gates, irrigation canals, drinking water pressure release valves and municipal wastewater outfalls, as well as sites in numerous rivers with existing dams. There are approximately 10 000 existing low head dams and hydraulic structures for flood control and water supply/irrigation in Canada; some of these may be viable as low head hydro sites.

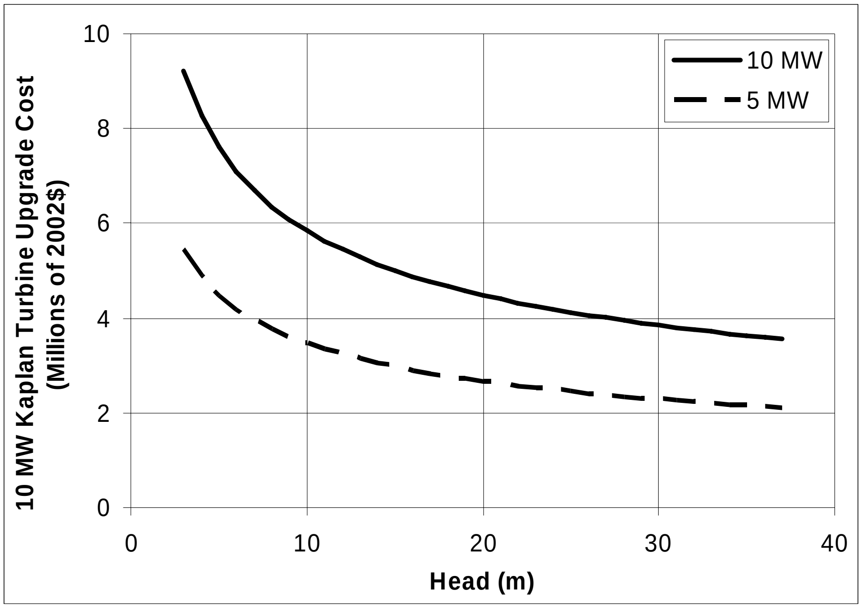
For a waterpower development with this existing infrastructure, the major civil costs are typically reduced to just the water passage for power and the powerhouse, with minimal works for environmental mitigation. While still significant, these costs are generally very small when compared to the cost of new dam construction. By eliminating the need to construct a new dam and the environmental works that accompany it, many sites become more economically viable.

5.1.2 Electromechanical

The electromechanical equipment includes the turbine, generator, and control systems. It is well known that the costs for low head sites are relatively high because the required electromechanical equipment is large and the associated water passages are large. The cost of a 10-MW Kaplan turbine for a design head of 6 m is approximately 84%higher than the cost for a design head of 30 m, as illustrated in Figure 5.1. Thus, in order to achieve the same return on investment under the same revenue conditions, a low head site must have either

- a significantly higher plant factor (more water for generation) than a site with intermediate head, or
- the other costs (civil, etc) must be significantly reduced by installing at an existing dam.

Figure 5.1: Estimated 5-MW and 10-MW Kaplan Turbine Cost[XIII]



5.1.3 *Transmission and Interconnection*

The cost of delivering the generated energy to the consumer can also be a major cost barrier to the development of a site. There are many sites in northern Canada that would be feasible if the site was located close to a demand center or grid connection. There are two reasons why long transmission distances become a concern:

- The cost of building the transmission line, for distances less than 15 km can be approximately 10% of the development cost for a 10-MW, greenfield, low head hydro site.
- There is also a cost associated with lost energy, as described below.

The present means of power transmission is by wires strung on poles or towers. The wires have resistance to the flow of electricity which is directly proportional to the length of the line and inversely proportional to the cross-sectional area of the wires. This resistance causes a loss of power, and therefore a loss of revenue. Thus, the decision on how much to spend on the capital cost for a transmission line is based on a cost-benefit analysis of the construction cost versus the loss of revenue. Less money spent on the transmission line (i.e., smaller wires) results in more loss of revenue, in fact the use of wires which are too small can result in a net present value of lost revenue exceeding the capital cost of the transmission line.

The total costs (capital plus loss of revenue) gets very high for transmitting electricity over long distances. For a 200-km distance, the transmission line can add up to 60% to the capital cost of a 10-MW, greenfield, low head hydro development and result in a 10% loss in revenue. The capital costs and revenue losses of transmission apply equally to any type of power generation and are,

[XIII] Data Source: “Estimation of Economic Parameters of US Hydropower Resources”, INEEL, June 2003.

therefore, a barrier to development of any power source that is not close to a demand or grid connection.

5.1.4 *Low Head Hydro Costs*

Based on the available information and the time available for research, a simplified approach was used for screening purposes to estimate capital costs to develop waterpower.[XIV] Hatch's experience and available historic information was used to assign cost ranges per kilowatt of installed capacity.

As discussed in Section 5.1.1, the civil works make up a significant portion of the overall project costs and can vary dramatically depending on the site. Developing a greenfield site is generally very expensive when compared to adding hydropower capacity to an existing dam. Many existing dams have existing infrastructure that can be utilized by the hydropower development, which can significantly reduce the cost of the civil work required to develop the site. For this reason, costs were developed separately for greenfield sites and existing dams.

It is well known that turbine costs per kilowatt of installed capacity decrease as the size of a project increases, as discussed in Section 5.1.2. This holds true for other aspects of hydropower as well. The cost of civil works, including construction of the powerhouse, water passage and potentially dam construction, decrease on a per kilowatt basis as project sizes increase. Therefore, low head hydro costs were developed for projects that fall in specified ranges of installed capacity.

The estimated cost ranges for greenfield sites and the average cost for developments at existing dams are listed in Table 5.1. These costs include transmission for short distances and are based on close proximity to labour markets and material supplies, and easy site access. For comparison purposes, estimated capital costs for conventional small hydro developments are also included in Table 5.1.

Table 5.1: Estimated Capital Cost for Low Head and Small Hydro Development

Estimated Capital Cost Per Kilowatt of Installed Capacity (2008 $)[XIV]					
		0 to 5 MW	**5 to 10 MW**	**10 to 20 MW**	**>20 MW**
Low Head Hydro	Greenfield Sites	$5,000 to $9,000	$4,000 to $8,000	$3,750 to $7,000	$3,500 to $6000
	Existing Dams	$4,500	$3,750	$3,500	$3,125
Small Hydro	Greenfield Sites	$4,000 to $9,000	$3,500 to $4,500	$3,000 to $4,000	under $3,500
	Existing Dams	$3,500 to $8,000	$3,000 to $4,000	$2,500 to $3,500	under $3,000

The approximate breakdown of the low head hydro project costs are listed in Table 5.2. These are highly dependent on project site and are included for illustration purposes only. As can be noted, all costs are larger for greenfield sites except for the electromechanical costs. These remain relatively

XIV It is extremely important to realize that these estimated costs are only for the purpose of screening a large number of sites in a quick and consistent manner. Actual cost estimates for individual projects must always be developed on a site-specific basis. Costs for remote sites could be significantly higher due to unavailability of skilled labour and expensive transportation of goods and materials.

constant regardless of the site. (The proportion of electromechanical cost is higher for existing sites because the overall project costs are lower, not because the absolute electromechanical costs are higher.)

Table 5.2: Estimated Capital Cost Breakdown for Low Head Hydro Developments

	Civil	Electromechanical	Transmission	Engineering and Approvals
Greenfield Sites	45%	35%	8%	12%
Existing Dams	25%	53%	12%	10%

Regional cost variations for hydropower developments were also explored. Canada is a large country where regional economics have the capacity to significantly influence prices in some areas. However, the variability in hydropower development costs for most regions were very small when compared to the variability due to the uniqueness of each development.

The one major exception to the regional homogeneity in hydropower development costs was in northern Canada and similarly remote areas. The costs for development in remote areas could be 50% to 100% higher, depending on travel distances, mode of transportation, and whether winter construction is required. However, as discussed below, energy is traditionally generated in many remote areas through very expensive, imported diesel generation. Even with the inflated construction costs, low head hydro may provide an overall cost savings in remote locations.

5.2 Cost of Other Generation Technologies

In this section, the low head hydro costs are placed within the context of the other options available for generation. The cost comparisons are based on a review of internal Hatch studies as well as outside publications.

Large conventional power stations account for the vast majority of electricity generation in Canada. These plants are largely base load and are the major determinants of the wholesale electricity prices in their respective markets. Low head hydro projects must bid into these markets, and because of their higher costs, run the risk of not being dispatched. Standard offer programs in several provinces present an alternative to direct market participation and provide low head hydro with a grid outlet at a reasonable price.

The unique nature of the low head hydro project in a remote location presents another alternative. In this case, there is frequently no grid system. Unfortunately, this can also mean that there is also no market. Typically, the only competition to a small, remote low head hydro plant would be a diesel generator with associated fuel supply problems. In these cases, a hydro plant with storage offers an assured supply without the costs and environmental risks of fuel supply and fuel spills.

5.2.1 Conventional Technologies

- Hydro – Hydro generation is the principal component of the electricity supply mix in British Columbia, Manitoba, Quebec and Newfoundland and Labrador as well as a major contributor in Ontario. Unit sizes are usually many hundreds of megawatts; however, the use of an established technology allows costs to be among the lowest in the world. The size of these plants offsets the extra costs associated with site-specific construction requirements.

- Thermal – Thermal generation based on oil, coal or natural gas dominate the Alberta and Saskatchewan markets and are major contributors in Ontario and many other provinces. As in the case of conventional hydro, these plants are large and the use of well-established technology and nearby fuel supplies maintain low costs.
- Nuclear – Nuclear generation dominates the electricity market in Ontario. These plants offer relatively low cost energy; however, they face a long decommissioning cycle which must be included in the evaluation of their costs.

Among the conventional power plants, there is no typical configuration upon which to develop a cost comparison. Plants vary by size, site-specific costs and fuel handling capabilities as well as service expectations. Table 5.3 outlines indicative costs associated with a number of different technologies that can be considered either as conventional or as having evolved from conventional plants. It should be noted that the capital cost estimates are overnight rates, that is, they do not include the effect of the interest during construction.

5.2.2 Other Technologies

Other technologies which might compete with low head hydro at specific sites or in specific applications include fuel cells, biomass, landfill gas, geothermal, wind, and solar (thermal and photovoltaic). Table 5.4 presents indicative capital and operating costs for these types of plant.

5.3 Unit Energy Prices

On the basis of the capital and operating costs listed in Tables 5.3 and 5.4, the levelized unit electrical prices were calculated. There are a number of steps involved in the calculation of the levelized unit electricity costs. The capital cost estimate is first annualized over the expected project life. This has been calculated at an 8% discount rate. The annualized capital plus the fixed operations and maintenance (O&M) costs is then divided by the expected annual production level. This converts the capacity values expressed in dollars per kilowatt into the equivalent energy values expressed in dollars per kilowatt-hour. The additional annual allowances, particularly the decommissioning costs of the nuclear facilities are divided by the annual production to determine its value in energy terms. Finally these two figures are added to the variable O&M and the fuel costs which are already in energy terms. The final value is the unit energy cost.

Within these calculations, lower capacity factors will increase the unit costs because there are fewer energy units to absorb the same capital cost. Similarly, increasing the discount rate will raise all annualized costs. It should be noted that annual O&M and fuel costs have not been escalated in this analysis. They have been held at current levels.

As expected, the large conventional generation plants all have the lowest unit energy costs. New technologies, particularly those including carbon sequestration, have higher costs and the small renewable technologies generally have the highest, with the exception of diesel generation in remote areas.

Table 5.3[XV]
Indicative Costs – Conventional Technologies

No.	Technology	Size (MW)	Capital Cost ($/kW)	Variable O&M ($/MWh)	Fixed O&M ($/kW)	Additional Costs ($x10^6)	Life (yrs)	Capacity Factor (%)	Levelized Unit Electricity Cost ($/kWh)
1	Coal	500	1,938	5.6	44.7	0	30	85%	0.0624
2	Natural gas	580	861	3.7	18.6	0	30	85%	0.0681
3	Nuclear ACR-700	703	2,843	0.0	13.1	18	30	85%	0.0471
4	Nuclear CANDU	673	3,600	0.0	15.6	18	30	85%	0.0541
5	Integrated coal-gasification combined cycle (IGCC)	550	1,631	3.0	39.8	0	20	85%	0.0562
6	IGCC with carbon sequestration	380	2,334	4.6	46.8	0	20	85%	0.0727
7	Conv gas/oil combined cycle	250	659	2.1	12.9	0	20	85%	0.0982
8	Adv gas/oil combined cycle (CC)	400	649	2.1	12.0	0	20	85%	0.0926
9	Adv CC with carbon sequestration	400	1,296	3.0	20.5	0	20	85%	0.1253
10	Conv combustion turbine	160	459	3.7	12.5	0	20	30%	0.1059
11	Adv combustion turbine	230	435	3.3	10.8	0	20	30%	0.0918
12	Conventional hydropower	500	3,000	3.6	14.4	0	50	60%	0.0530
13	Distributed generation - base	2	939	7.3	16.5	0	20	85%	0.0924
14	Distributed generation - peak	1	1,129	7.3	16.5	0	20	20%	0.1607

Note: All dollar amounts are adjusted to 2008 dollars.

XV Table 5.3 data sources:
No. 1, 2, 3 & 4 – CERI 2003 dollars escalated at ENR Construction Cost Index to 2008 dollars.
No. 5 to 14 – EIA Annual Energy Outlook, 2005 dollars escalated at ENR Construction Cost Index to 2008 dollars.
No. 12 – Hatch internal files for capital cost estimate and capacity factor.

Table 5.4[XVI]
Indicative Costs – Other Technologies

No.	Technology	Size (MW)	Capital Cost ($/kW)	Variable O&M ($/MWh)	Fixed O&M ($/kW)	Additional Costs (x10^6$)	Life (yrs)	Capacity Factor (%)	Levelized Unit Electricity Cost ($/kWh)
15	Fuel cells	10	4,943	49.3	5.8	0	20	85%	0.1757
16	Biomass	80	2,044	3.2	54.9	0	20	85%	0.0386
17	MSW - landfill gas	30	1,744	0.0	117.6	0	20	85%	0.0397
18	Geothermal	50	2,056	0.0	169.4	0	20	85%	0.0509
19	Wind	50	2,500	0.0	31.2	0	20	30%	0.1088
20	Solar thermal	100	3,444	0.0	58.4	0	20	30%	0.1557
21	Photovoltaic	5	7,000	0.0	12.0	0	20	13%	0.6366
30	Remote diesel	1	3,000	10.0	60.0	0	20	40%	0.3216
31	Small hydro	10	3,750	5.0	75.0	0	50	60%	0.0776
	Low Head Hydro[XVII] Greenfield Developments								
22	0 to 5 MW	2.5	7,000	5.0	140.0	0	50	60%	0.1405
23	5 to 10 MW	7.5	6,000	5.0	120.0	0	50	60%	0.1211
24	10 to 20 MW	15	5,375	5.0	107.5	0	50	60%	0.1091
25	20 to 50 MW	30	4,750	5.0	95.0	0	50	60%	0.0970
	Low Head Hydro[XVIII] Existing Structure								
26	0 to 5 MW	2.5	4,500	5.0	90.0	0	50	60%	0.0921
27	5 to 10 MW	7.5	3,750	5.0	75.0	0	50	60%	0.0776
28	10 to 20 MW	15	3,500	5.0	70.0	0	50	60%	0.0728
29	20 to 50 MW	30	3,125	5.0	62.5	0	50	60%	0.0655

Note: All dollar amounts are expressed at 2008 prices.

XVI Table 5.4 data sources:
No. 15 to 21 – Costs - EIA Annual Energy Outlook, 2005 dollars escalated at ENR Construction Cost Index to 2008 dollars.
No. 15 to 20 – Capacity Factors - OPA Supply Mix Analysis Report.
No. 20 – Capacity Factor – Hatch internal files.
No. 19 & 20 – Capital Costs - Hatch internal files.
No. 22 to 31 – Hatch internal files (fixed O&M at 2%).

XVII Size and capital costs represent a midpoint of range.

XVIII Size represents a midpoint of range.

Based on Ontario experience, recent wholesale electricity prices range from approximately $0.042/kWh to $0.100/kWh. The costs of large generators all fall within this range while the costs of remote diesel and renewable energy, particularly wind and solar, are higher.

The low head hydro costs in Table 5.1 are also converted to unit electricity prices. The costs in Table 5.1 are only for the construction expenditures for each category of installation. An estimate of variable O&M costs at $5/MWh plus a fixed O&M cost calculated at 2% of the capital cost per year are included in the analysis.

The generation costs for low head and small hydro are based on a capacity factor of 60%. This is thought to represent an average low head hydro development. However, capacity factors can vary significantly from site to site. A site with a higher capacity factor will generate more energy, thus rendering the project more economical for a given turbine/generator size. Conversely, a site with a lower capacity factor will generate less energy and therefore be less economical. Hydropower sites with usable storage typically have capacity factors ranging from 50% to 80% and occasionally much higher. ROR sites typically have smaller capacity factors. An advantage of hydropower (including low head hydropower) is that a developer can install a smaller unit at a site and raise the capacity factor of the project. This reduces the total amount of energy generated, but has the potential to improve the overall project economics for an installation by decreasing the capital cost.

Of the hydropower options, large conventional hydropower is the most cost effective at about $0.05/kWh. Small hydropower costs approximately $0.07/kWh to $0.08/kWh while low head hydropower costs between $0.07/kWh and $0.15/kWh, making it the most costly hydropower option.

Of the non-conventional energy technologies (Table 5.4), low head hydropower at greenfield sites is extremely cost effective when compared to remote diesel and solar photovoltaic (PV) generation and can compete with wind, solar thermal and fuel cells. Low head hydropower at existing sites compare favourably to most of the other technologies, especially at the larger sizes.

These relationships are displayed in Figures 5.2 and 5.3.

5.4 Project Economics

The cost analysis shows that the unit cost of energy generation at low head hydro sites is generally higher than for conventional generation technology. This is due primarily to high initial site-specific costs that generally do not have the same magnitude of impact on the larger hydro stations. However, low head hydro can compete favourably with other renewable generation technologies, especially at existing sites and at large capacities.

Current provincial programs, for example, the Standard Offer program in Ontario, are prepared to pay up to $0.145/kWh for energy during peak periods. Many of the low head hydro sites are economic at that rate. The same program offers $0.42/kWh for solar power which suffers from the same high initial cost, and even lower capacity factors, than low head hydro.

The costs for all the low head alternatives are less than the present rates for northern diesel generation. Thus, low head hydro may be economic in northern communities where the cost of diesel generation has risen drastically in the last few years due to the rising price of oil.

Figure 5.2: Unit Electricity Prices for Traditional Energy Generation

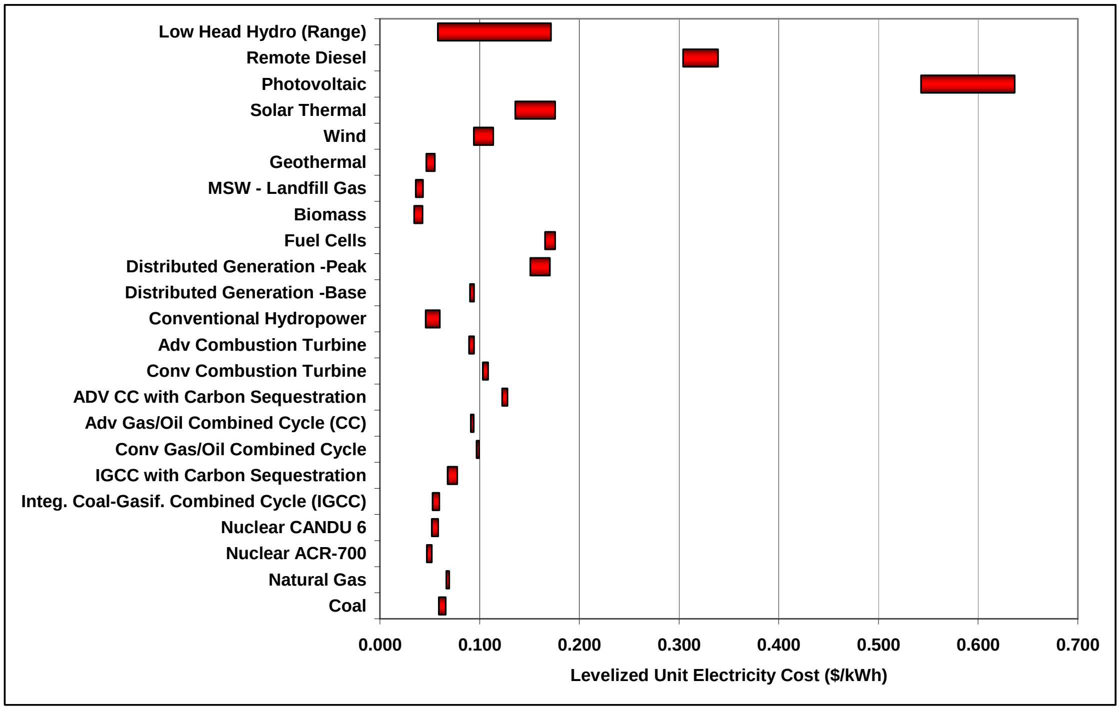
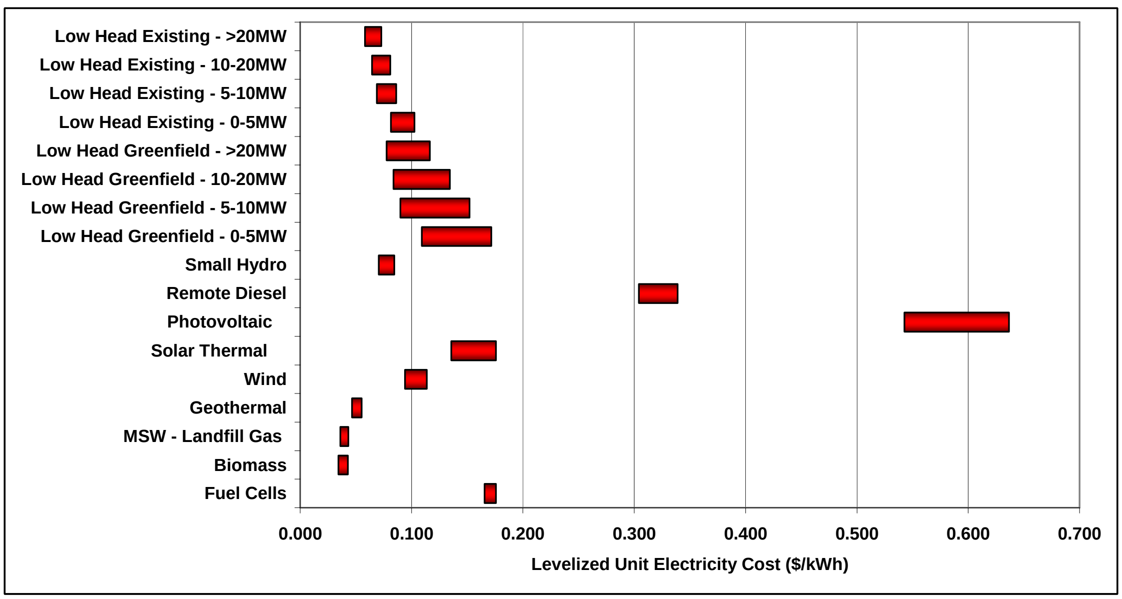


Figure 5.3: Unit Electricity Costs for Non-Conventional Energy Generation



5.5 Green Power Incentives

Incentives to develop clean, renewable or green power typically take one of four basic forms: tax incentives, requests for proposal, standard offer programs or net-metering. The application and availability of these programs varies from province to province and are subject to frequent updates and adjustments. They are usually applicable to solar, biomass, wind and hydro but are often subject to restrictions on size and location.

5.5.1 Federal Incentives and Tax Measures

Tax incentives are granted at two levels. Federally, the purchase of clean energy generation equipment, such as solar, wind and small hydro, qualifies for the accelerated Capital Cost Allowance in Class 43.2. This allows a developer to write off the equipment against the tax liability much faster than in earlier regulations. Provincially, the purchase of renewable energy equipment is exempt from provincial sales tax in British Columbia and Ontario.

While not a tax incentive program, the ecoEnergy initiative does provide a $0.01/kWh incentive for up to 10 years to eligible low-impact, renewable electricity projects commissioned between April 1, 2007 and March 31, 2011. This incentive remains the same over the entire period and is not subject to escalation.

5.5.2 Requests for Proposal

A request for proposal (RFP) usually involves a specific acquisition target in terms of energy or power, a fixed term, minimum and maximum plant size restrictions and defined commercial operation dates. The proponent is expected to bid energy according to a fixed delivery schedule and defined tariff rates which may or may not include escalation.

5.5.2.1 British Columbia

The 2008 Clean Power Call is for projects where the entire output must qualify as clean energy as defined by guidelines published by the British Columbia Ministry of Energy, Mines and Petroleum. BC Hydro hopes to attract up to 5000 GWh of firm clean energy.

It should be noted that these guidelines have yet to be published and are referenced as “forthcoming” guidelines on the BC Hydro Clean Power Call website.

The projects are to be located in British Columbia in areas that do not require BC Hydro to transmit power through another jurisdiction. The projects must use generation technologies which are readily available in commercial markets and which have been in commercial use for at least 3 years and used in at least three generation plants. Nuclear and biomass technologies do not qualify. Biomass is to be the subject of a separate call.

Projects can be new, refurbished, incremental or, with some restrictions, existing generation. New generation at an existing site is also eligible. The minimum project size is 25 GWh/yr. The project must have an interconnection point with either the British Columbia Transmission Corporation (BCTC) transmission grid or the BC Hydro distribution system. The connection need not be direct; indirect connections through private or other utility transmission services are eligible. Regardless of the connection type, the project must be able to clearly identify its production, through separate metering or other means. The project will also require a BCTC interconnection study which must be submitted with the tender. Finally, energy which is currently part of an existing contract with either

BC Hydro or another purchaser is not eligible unless that contract can be legally terminated shortly after the call is issued.

The terms of the proposed Clean Power Call EPA are still tentative. The draft documents outline the principal terms under consideration at this time.

- **Term:** 15 to 40 years in any whole integer starting at the Commercial Operations Date (COD)
- **COD:** Between November 1, 2010 to November 1, 2016.
- **Firmness Election:** Bidder may tender all or a portion of output as firm energy. All firm energy must be designated as either seasonal firm or hourly firm, where seasonal firm is to be based on four periods:
  - winter (November 1 to January 31)
  - spring (February 1 to April 30)
  - system freshet (May 1 to July 31), and
  - fall (August 1 to October 31).

  "Firm" means that a failure to deliver the tendered quantity of energy during a season or an hour, as elected by the bidder, will result in liquidated damages payable by the bidder with specified exceptions such as planned outages.
- **Firm Energy Price:** Firm energy is bid at a price expressed as at January 1, 2008 and escalated based on the consumer price index (CPI) to the time of sale.
- **Firm Price Escalation:** Seller can select 0% to 200% of bid price to escalate at CPI from January 1, 2008 to COD, and 0% to 100% of bid price after COD.
- **Firm Energy Profile:** Bidder must tender a firm energy profile. The profile will determine the amount of firm energy the bidder will be required to deliver on a seasonal or hourly basis.
- **Total Energy Profile:** Bidder must submit a total energy profile, inclusive of firm energy and expected non-firm energy. For each period, firm energy must be less than or equal to total energy.
- **Non-Firm Energy Price:** Bidder can choose between a fixed price expected to range from $50/MWh to $80/MWh escalated to the time of sale or a formulation based on the appropriate mid-C price and adjustments for line losses and wheeling charges.
- The draft Electricity Purchase Agreement (EPA) terms apply a **monthly time of delivery factor** to the bid prices for both firm and non-firm energy. These factors reflect the fact that energy is worth more to BC Hydro in the winter when production is low than in the system freshet when energy is abundant. The factors also vary between heavy load hours and low load hours.

The draft call documents were issued on November 14, 2007 and presented at stakeholder meetings in late November and early December 2007. Written comments from those meetings are currently being reviewed and the revised documents are expected in the first quarter of 2008. They will be submitted to and reviewed by British Columbia Utilities Commission (BCUC) and the call will be issued in spring 2008.

There is also a companion call for bioenergy in British Columbia. This call is intended to support generation based on wood waste and the utilization of mountain pine beetle-impacted trees.

5.5.2.2 Ontario

The Ontario Power Authority (OPA) is engaged in a RFP process to procure 2000 MW of renewable energy supply for projects that are greater than 10 MW in size. This process is expected to be undertaken in multiple phases.

On November 20, 2007, the OPA released a Request for Expressions of Interest for Renewable Energy Supply ("RES III RFEI"). This process is now closed, and the OPA is currently developing the next phase for procuring new renewable energy supply. Responses are currently being reviewed and next steps in this process will be communicated shortly. An RFP (RES III RFP) is expected to be released in the first quarter of 2008.

The purpose of the RES III RFEI is to identify potential projects and collect information on viability and status with respect to any subsequent RES procurement. The OPA is considering projects which

- are based on renewable energy
- are located in the province of Ontario
- have a capacity in excess of 10 MW
- can attain commercial operation on or before 2015
- be electrically connected to the IESO-controlled grid, and local distribution company or an end-user
- are not an existing generating facility, and
- is not an upgrade.

At this point, potential contract term and prices have not been identified.

5.5.3 Standard Offer Programs

The standard offer programs for renewable generation involve the purchase of energy using a guaranteed minimum price over a long-term contract. The price is often modified by technology and/or the size of the generator. Unlike the RFP, the standard offer price is available to all qualified proponents and may be modified by a defined escalation rate over its term. Typically, standard or standing offer programs are aimed at small projects of less than 10 MW.

5.5.3.1 British Columbia

The BC Standing Offer Program is to encourage the development by independent power producers of clean energy projects throughout British Columbia. The projects must be greater than 0.05 MW but not more than 10 MW. There are two elements to the program price: the energy price and the environmental attributes price.

The price to be paid for electricity is based on a 2007 dollars per megawatt-hour figure which varies according to the region of the installation. The base price range is from $65/MWh in the Peace Region to $79/MWh on Vancouver Island. These base prices are escalated annually at 100% of the CPI up to the year that the project EPA is signed. After the EPA is signed, 50% of the escalated base price is further escalated at CPI annually.

The escalated price is further adjusted based upon the time of day (high load hour or low load hour) and the month when the energy is delivered.

It is mandatory for developers to transfer an environmental attributes price for the energy delivered under the project EPA to BC Hydro. The value of these attributes is set at $3.05/MWh for each megawatt hour of project energy that receives environmental certification. One hundred percent of the environmental attribute price will be escalated at CPI annually.

The draft program rules for the BC Standing Offer Program were issued on January 18, 2008.

5.5.3.2 Ontario

The intent of the Ontario Renewable Energy Standard Offer Program is to make it easier for the operators of small renewable energy generating facilities to contribute to Ontario's electricity supply by providing power to their local distribution company and receiving payment for the power they provide. The contract is to be for a period of 20 years.

An eligible renewable energy project must be located in Ontario, must have a gross nameplate capacity of no more than 10 MW, must be connected (directly or indirectly) to a distribution system licensed by the Ontario Energy Board (OEB), must have a connection voltage of no more than 50 kV and must be metered at the generator’s expense in accordance with distribution system code requirements. Many small remote hydro facilities are not able to connect to a local distribution system. The OPA is recommending to the Minister of Energy that these facilities still be allowed to participate in the standard offer program if they are technically able to connect directly to the transmission system.

Applicants are cautioned that certain areas of the transmission grid are limited in their ability to accept incremental power. For this reason, the OPA may be required to restrict or decline project applications in certain designated areas.

The base year rate for all generators, except PV[XIX], will be $0.11/kWh for electricity actually delivered under the contract. In subsequent years, 20% of the base rate will be indexed for inflation according to the year-over-year change in the CPI. Projects that can reliably operate during on-peak hours (11 a.m. to 7 p.m. eastern standard time) will be eligible for an additional $0.0352/kWh for electricity actually delivered during those on-peak hours.

In the case that the generator is connected to a load customer, contract payments will be reduced to account for the portion of the total generation that is consumed by the load customer. The amount of the reduction will be determined by the product of the amounts of generation consumed by the load customer and the hourly Ontario energy price. This adjustment is required to establish compliance

[XIX] PV projects will be paid $0.42/kWh but will not be eligible for inflation indexation or the peak-hour premium.

with OEB codes for distributed generation connected "behind" the load customer's meter. Where the resulting contract payment amount is negative, payments shall be made by the generator to the OPA.

Wind power production incentive (WPPI) payments (replaced by the broad-scoped ecoEnergy for renewable power program) will be shared equally between the generator and the OPA.

There is also a similar clean energy standard offer program available in Ontario. This program, however, targets power derived from burning natural gas or from the capture and use of by-product fuels or under-utilized energy.

5.5.4 Net-Metering

Net-metering allows small renewable generators to send electricity excess to their own use into the grid. This significantly reduces the costs associated with wind and solar applications as there is no battery or other storage device required. Small hydro with limited reservoir capacity would also benefit from net-metering.

Net-metering is available in Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia and Prince Edward Island.

5.6 Capital Cost and Incentive Impact Analysis

It is very difficult to accurately predict the impact that a particular incentive package may have on an entire market area. This is particularly true in the hydropower sector where each site is unique with a set of challenges that can only be properly assessed on a case by case basis. However, the following is a broad-brush attempt to estimate the impact two incentive packages would have on the viability of low head hydropower projects in Canada. It is important to note that this is by no means an in-depth study and represents only a rough estimation.

The economic viability of a low head hydro facility, as with most other investments, is dependent upon a large number of costs and other variables. These include not only the capital and operating costs and the operating characteristics of the plant, but also the expected value of electricity in the market. One developer supplying electricity to the grid may face an energy value that is dominated by the base load plants on the system, another may be bidding into a standard offer program with a fixed and known energy value, while a third developer may be proposing a small hydro facility to displace diesel generation in an isolated northern community. Each faces a different threshold energy value below which their project are viable. If the cost of producing energy (including any required rate of return) is above the price they can receive, the project is not economically viable.

The economics of developing low head hydro sites can be manipulated by two basic means:

- The first takes the form of an energy incentive which could be associated with a low-interest loan or a straight per kilowatt-hour payment program to encourage small or low head hydro development. For the purposes of this incentive impact analysis, an incentive of $0.05/kWh is assumed.
- The other area is associated with technical developments which could lower the initial costs of small or low head hydro. These would include the reduction of civil/mechanical costs through innovative design such as VLH turbines, or research that would allow PMG connection to the

grid. For the purposes of this incentive impact analysis, it is assumed that a capital cost reduction of 25% is achieved.

On the basis of the database assembled in this study, 2329 low head hydro sites with a combined capacity of 4866 MW were identified in Canada. An estimated 17% of these sites include existing structures. The sites are distributed by size and province as listed in Table 5.5.

Table 5.5: Distribution of Low Head Hydro Sites in Canada

	0 to 5 MW		5 to 10 MW		10 to 20 MW		20 to 50 MW		All Sites	
Province	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**
Newfoundland & Labrador	49	27	–	–	–	–	–	–	49	27
Prince Edward Island	6	2	–	–	–	–	–	–	6	2
Nova Scotia	5	11	–	–	–	–	–	–	5	11
New Brunswick	45	96	7	47	2	33	–	–	54	176
Quebec	1485	772	46	307	42	651	11	271	1584	1991
Ontario	433	966	55	388	27	359	11	334	526	2047
Manitoba	9	33	13	97	9	133	3	74	34	337
Saskatchewan	17	25	3	24	8	129	–	–	28	178
Alberta	18	21	2	20	2	34	–	–	22	75
British Columbia	10	11	–	–	–	–	–	–	10	11
Yukon	–	–	–	–	–	–	–	–	–	–
Northwest Territories	10	2	1	10	–	–	–	–	11	12
Nunavut	–	–	–	–	–	–	–	–	–	–
TOTAL	**2087**	**1966**	**127**	**893**	**90**	**1329**	**25**	**679**	**2329**	**4867**

The above cost analysis defined energy cost ranges for each of the size categories for new developments and developments on existing structures. For the purposes of this analysis, it is assumed that the total number of sites (and the associated capacity) are evenly distributed over the energy cost range. Thus, if the cost range is from $0.10/kWh to $0.14/kWh and there are five sites, there would be one site at each $0.01 cost point. If an input threshold level is assumed, one can postulate the number of sites that might fall below that threshold and are therefore economically viable. In the simple example above, a threshold of $0.12/kWh would result in three sites equal to or below the threshold and therefore economically viable to develop.

The number of sites that would fall below each of three thresholds ($0.10/kWh, $0.15/kWh and $0.20/kWh) for both of the incentive options listed above are listed in Tables 5.6 through 5.8.

At a $0.10/kWh threshold, without incentives, 405 of the sites would be considered economically viable. A capital cost reduction of 25% would render 908 sites economically viable, almost doubling the economic installed capacity. A $0.05/kWh energy incentive would make 1723 sites, totalling nearly 4300 MW, economically viable. At this low threshold value, the energy incentive appears to have a much more significant effect on project viability than the capital cost reductions.

At a threshold energy price of $0.15/kWh, most of the larger scale projects are viable without incentives or cost reductions. Both the energy incentives and cost reductions rendered nearly all of the identified projects viable.

At the highest threshold energy price, the incentives had no impact; at $0.20/kWh, the majority of sites, nearly 5000 MW of low head hydro, would potentially become economically viable. Of course this is subject to market conditions and site conditions that would affect costs of construction, thus this simple economic analysis may not be applicable at many sites; therefore, some of these sites may not be viable at $0.20/kWh and further incentives would help to promote development.

Table 5.6: Viable Sites With a Threshold of $0.10/kWh

	0 to 5 MW		5 to 10 MW		10 to 20 MW		20 to 50 MW		All Sites	
	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW
New Developments										
No Incentives	0	0	17	119	24	354	12	326	53	799
Capital Reduction (25%)	373	351	57	405	61	896	21	564	512	2216
Energy Incentive ($0.05/kWh)	1130	1065	101	714	75	1102	21	564	1327	3445
Existing Dams										
No Incentives	311	293	22	152	15	226	4	115	352	786
Capital Reduction (25%)	355	334	22	152	15	226	4	115	396	827
Energy Incentive ($0.05/kWh)	355	334	22	152	15	226	4	115	396	827
All Sites										
No Incentives	311	293	39	271	39	580	16	441	405	1585
Capital Reduction (25%)	728	685	79	557	76	1122	25	679	908	3043
Energy Incentive ($0.05/kWh)	1485	1399	123	866	90	1328	25	679	1723	4272

Table 5.7: Viable Sites With a Threshold of $0.15/kWh

	0 to 5 MW		5 to 10 MW		10 to 20 MW		20 to 50 MW		All Sites	
	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW
New Developments										
No Incentives	1130	1065	101	714	75	1102	21	564	1327	3445
Capital Reduction (25%)	1732	1632	105	741	75	1102	21	564	1933	4039
Energy Incentive ($0.05/kWh)	1732	1632	105	741	75	1102	21	564	1933	4039
Existing Dams										
No Incentives	355	334	22	152	15	226	4	115	396	827
Capital Reduction (25%)	355	334	22	152	15	226	4	115	396	827
Energy Incentive ($0.05/kWh)	355	334	22	152	15	226	4	115	396	827
All Sites										
No Incentives	1485	1399	123	866	90	1328	25	679	1723	4272
Capital Reduction (25%)	2087	1966	127	893	90	1328	25	679	2329	4866
Energy Incentive ($0.05/kWh)	2087	1966	127	893	90	1328	25	679	2329	4866

Table 5.8: Viable Sites With a Threshold of $0.20/kWh

	0 to 5 MW		5 to 10 MW		10 to 20 MW		20 to 50 MW		All Sites	
	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW
New Developments										
No Incentives	1732	1632	105	741	75	1102	21	564	1933	4039
Capital Reduction (25%)	1732	1632	105	741	75	1102	21	564	1933	4039
Energy Incentive ($0.05/kWh)	1732	1632	105	741	75	1102	21	564	1933	4039
Existing Dams										
No Incentives	355	334	22	152	15	226	4	115	396	827
Capital Reduction (25%)	355	334	22	152	15	226	4	115	396	827
Energy Incentive ($0.05/kWh)	355	334	22	152	15	226	4	115	396	827
All Sites										
No Incentives	2087	1966	127	893	90	1328	25	679	2329	4866
Capital Reduction (25%)	2087	1966	127	893	90	1328	25	679	2329	4866
Energy Incentive ($0.05/kWh)	2087	1966	127	893	90	1328	25	679	2329	4866

6 Environmental Impacts of Low Head Hydropower Developments

6. Environmental Impacts of Low Head Hydropower Developments

> *"Perhaps the biggest hurdle of small hydro development is the regulatory approval process, or more specifically, the environmental approval process. Regulations focus more on large-scale hydroelectric issues than on small-scale hydroelectric issues, and the regulatory requirements are the same, regardless of the size or configuration of the project. This can impose disproportionate demands on small hydroelectric developers. A small project cannot support the comprehensive studies and infrastructure assessments that government typically demands from a 500-MW facility, which creates a barrier for small hydro projects."*
> (National Energy Board, March 2006)

Hydropower is a renewable energy source because it relies on natural water cycling. In addition, it does not emit sulphur oxides (SO_X), nitrogen oxides (NO_X) or particulate matter, and removing vegetation from the reservoir area minimizes the production of greenhouse gases (GHG) and methylmercury from decaying vegetation. Based on these positive characteristics, many believe power produced by small and low head hydro should command a premium as green power.

However, a greenfield small hydro site may have impacts from dam construction and operation and flooding of the upstream river other than the impacts of decomposing of flooded vegetation. By contrast, flooding is not an issue with small hydro developments at existing dams, but the installation of a hydro development, if not operated as ROR, can change the flow regime and affect fish and other wildlife and their habitats above and below the dam.

In most cases, compared to large hydro, small hydro generating stations have relatively low environmental impacts because they are constructed in a small area and rarely cause significant shoreline flooding or require large river diversions. Additionally, most of the negative environmental impacts of small hydro development can be mitigated by good design and operating practices. The current trend in certified green power, including renewable low-impact electricity, as defined by Canadian EcoLogo[20] criteria, is to recognize hydro projects only if they do not interfere with seasonal water flows and if they minimize impacts on fish and flooding patterns.

Low head hydroelectric development has the potential to affect a number of valued physical environmental components (e.g., air quality, soils, surface water, groundwater) and valued ecosystem components (e.g., terrestrial and aquatic habitat and biota). The construction and operation phases of the project typically have different environmental effects. Table 6.1 summarizes the potential effects of low head hydroelectric development on the environmental parameters noted above, differentiating between those effects occurring during the construction phase of the project and those occurring during the operational phase.

20 An official certification symbol for Environment Canada's ecolabelling Environmental Choice Program. In order to be certified, a product or service must be made or offered in a way that improves energy efficiency, reduces hazardous by-products, uses recycled materials, is re-usable or provides some other environmental benefit.

Table 6.1
Potential Environmental Impacts Associated With Low Head Hydroelectric Developments

Environmental Component	Potential Impacts During the Construction Phase	Potential Impacts During the Operational Phase
Air Quality	• Increased airborne dust levels • Increased airborne pollutants due to vehicle and machinery emissions or burning of brush/waste	• Temporary increases in greenhouse gases due to decomposition of organic matter in the headpond • Minor emissions due to maintenance vehicles and machinery or backup generator use
Geology	• Bedrock excavation and disposal • Alteration of rock formations due to blasting	• No impacts
Soils	• Loss of soil due to erosion and sedimentation • Soil compaction and mixing of surface/subsoils • Contamination due to accidental spills	• Contamination due to accidental spills (transformer fluids) • Erosion of shoreline soils due to changes in water level and/or flow
Groundwater	• Decreased local groundwater levels in vicinity of excavations • Contamination due to accidental spills	• Increased groundwater table adjacent to headpond • Contamination due to accidental spills
Surface Water Hydrology	• Alterations in flow due to water diversion requirements • Alterations in flow due to headpond filling • Alterations in local flow hydraulics due to use of cofferdams, intake and tailrace excavations	• Long-term alteration in hydrology in bypass reach • Changes in hydraulics (velocity and vector) downstream from powerhouse • Alterations in hydrology if peaking mode of operation utilized • Alterations in hydrology due to increased impervious surfaces
Surface Water Quality	• Increased turbidity due to erosion and sedimentation • Adverse impacts due to accidental spills or contamination	• Short-term change in water quality due to decomposition of organic matter in headpond (e.g., increased nutrient concentrations, altered physical chemistry) • Potential for anoxic conditions in headpond • Short-term increases in methyl mercury due to headpond inundation • Increased temperature due to increased surface area in headpond • Adverse impacts due to accidental spills or contamination

Environmental Component	Potential Impacts During the Construction Phase	Potential Impacts During the Operational Phase
Aquatic Habitat	• Temporary loss/alteration of habitat due to in-water construction (cofferdams) and water diversion requirements • Altered habitat due to erosion and sedimentation • Permanent loss of habitat due to instream structures (e.g., dam, intake and tailrace channels) and decreased flow in bypass reaches • Alteration of habitat at access road water crossings and along transmission lines • Altered habitat conditions in headpond (e.g., loss of riverine habitat functions)	• Temporary loss of habitat and altered habitat dynamics due to water level fluctuations associated with peaking facilities • Alterations in normal biophysical process associated with decreased water level fluctuation in ROR plants (less spring flooding, limited normal shoreline drawdown) • Changes in habitat variables and availability downstream from the facility due to alterations in flow • Temporary impacts during access road and transmission line maintenance
Aquatic Biota	• Impacts on aquatic biota due to impaired water quality (erosion and sedimentation or contaminants) • Disturbance due to in-water construction • Stranding and disturbance of biota in dewatered areas • Mortality or disturbance due to blasting in or near water • Blockage of fish movement due to instream construction	• Blockage of fish movement due to the presence of the dam • Entrainment and turbine mortality • Stranding or entrainment downstream associated with up and down ramping for peaking operations
Terrestrial/Wetland Habitat	• Clearing of vegetation and associated loss of habitat • Alterations in wetlands and existing terrestrial habitat in flooded headpond • Alterations to remaining vegetation communities due to edge effects • Altered plant growth or mortality due to dust, contamination, soil compaction or altered topsoil condition	• Altered riparian vegetation communities in areas with increased water table adjacent to the headpond • Periodic disturbance to terrestrial habitat along transmission lines and access roads during maintenance • Potential for invasion of non-native species along new linear corridors
Terrestrial Biota	• Disturbance of wildlife due to construction noise, human presence • Disturbance or mortality of breeding birds due to vegetation clearing • Disturbance or mortality due to headpond flooding • Creation of barriers to movement (e.g., linear features such as transmission lines or access roads) • Altered wildlife communities due to habitat changes such as increased use by edge species	• Long-term impacts on wildlife movement and habitat use • Bird fatality due to collisions with transmission lines

7 Low Head Hydro Barrier Assessment

7. Low Head Hydro Barrier Assessment

Low head hydropower projects are generally thought to be "uneconomical". As part of this market survey, Hatch was tasked with identifying the barriers that cause low head hydro to be considered "uneconomical" as well as opportunities to counter these barriers. This was done in two steps. First, a screening exercise was performed by Hatch experts. A comprehensive range of topical areas surrounding potential barriers to, and opportunities for, the development of low head hydropower projects were identified and screened to come to a manageable number of areas to be addressed. Second, a questionnaire was developed to poll industry stakeholders (i.e., consultants, contractors, developers, government agencies, manufacturers, utilities, etc). Respondents were asked to propose solutions to each barrier (or methods to exploit the opportunities) and then rate these propositions in terms of their ease of implementation and the amount of impact they would have on reducing the barrier (or exploiting the opportunity). The questionnaire was also used to accumulate information about the state of the low head hydropower market.

7.1 Screening Exercise

The following 16 focus areas (including both potential barriers to, and opportunities for, low lead hydro developments in Canada) were identified by Hatch's in-house experts:

- Cost Reductions
  - structures
  - turbines
  - power train
- Technology Innovation
  - structures
  - turbines
  - power train
- Manufacturing and Construction
  - structures
  - turbines
  - power train
- Market Mechanisms
  - power purchase agreements
  - incentives
  - taxes
- Regulatory Approvals and Permitting
  - environmental
  - technical
- Standards and Codes
- Site Availability.

Through discussions, some categories were condensed or eliminated to focus on the areas of the most concern. For example, three barriers/opportunities were identified with regard to turbines: technological innovation, manufacturing and construction improvements and general cost reductions. It was decided that all three categories had the potential to reduce turbine costs; therefore, they were combined into one category: turbine cost reductions. Furthermore, it was noted that in many low head hydro cases, the turbine and power train are intimately linked, so the barrier was further condensed to be electromechanical cost reductions.

Of the 16 barriers/opportunities initially listed, five broad categories of barriers to and opportunities for low head hydro developments in Canada were identified. They are

- cost reductions, including those due to technology and innovation as well as manufacturing and construction improvements. This category was further subdivided into the two areas driving the physical costs of development:
  - civil structures, comprised primarily of the cost of a new dam, but including the powerhouse and any other structures required
  - electromechanical equipment, including the turbine, generator, exciter and all other electromechanical works.
- market mechanisms, including all taxes and incentives that are applicable to the project as well as any power purchasing agreements in place. Market mechanisms can be both barriers (taxes) and opportunities (incentives); both were assessed equally.
- regulations, including all approvals and permitting required for the development of a site. This was subdivided into two categories:
  - environmental permitting
  - technical permitting

7.2 Questionnaire

Based on the results of the screening exercise, a list of five propositions was generated. The five propositions are as follows:

NRCan can support low head/small hydro projects through

1. expansion of financial incentive programs by specifically targeting low head/small hydro projects
2. streamlining provincial and federal environmental assessment screening processes and supporting research into environmental impacts and mitigation
3. streamlining the electrical interconnection approvals for emerging generator technologies, i.e., variable speed, brushless excitation, permanent magnet generators, etc
4. research, development and deployment of structural technologies to reduce cost
5. research, development and deployment of electromechanical technologies to reduce cost or increase efficiencies.

7.2.1 *Proponent/Reviewer Format*

A proponent/reviewer format was used for the questionnaire. This involves having one person (the proponent) address a proposition in detail, then having many people (the reviewers) evaluate the proponent's responses to express agreement or disagreement, share their own insight and to add to any discussion that they feel has not yet been addressed. The proponent/reviewer format was used very successfully in the Canadian Academy of Engineering study "Energy Pathways Task Force, Phase 1".[XXI]

Completing a poll with a questionnaire of this format follows the following steps:

1. Proponent Selection

   One proponent is selected to address each of the propositions. The proponents are drawn from industry professionals and must have experience with the subject of the proposition. The selected proponents are listed in Appendix C.

2. Proposition Summary - Proponent

   The proponents are asked to complete the proposition summary. The proposition briefs developed by Hatch are used as a starting point for the proponents. For example, while financial incentives can be used to support low head hydro (Proposition 1), it was left to the proponent to define specific methods to achieve this.

3. Proposition Evaluation - Proponent

   The proponents are then asked to assess the viability of the proposition as detailed. This was done by addressing questions in ten areas, organised into two parts, as listed in Table 7.1.

   - Part A – Proposition Assets deals with the ease of implementation of the proposition.
   - Part B – Proposition Impacts addresses the expected impacts of implementing the proposition on the low head hydro sector.

Table 7.1: Questionnaire Layout

Part A – Proposition Assets	Part B – Proposition Impacts
Fundamentals/Background/Underlying Science	Economic Impacts
Technology/Strategy Validation/ Precedence/Application	Environmental Impacts
Proposition Integration/Synergy	Schedule Impacts
Societal Acceptability	Canadian Capacity
Sustainability/Self-Perpetuation/ Resource Requirement	Enabler of Low Head Hydro/Promoted With Respect to Other Generation Forms

[XXI] "Energy Pathways Task Force Phase 1 – Final Report", © Canadian Academy of Engineering, 2007.

Each question is laid out as a "language ladder", as seen on the sample questionnaire in Appendix D. A "language ladder"[XXII] allows for a common language between the proponents and the reviewers and ensures an even ground between each of the propositions. Respondents were also encouraged to support their answer by including a space for a written discussion following each question.

Space was also left for proponents to add further questions in each part. Respondents were encouraged to write additional questions and answer them, if they felt that the ten questions did not cover all of the key factors that would define the importance and practicality of the propositions.

4. Reviewer Selection

   Over 60 reviewers were invited to participate in the questionnaire process. These were drawn from stakeholders in the hydropower industry and included representatives of consultants, contractors, developers, government agencies, manufacturers, utilities, etc. Reviewers were also selected such that representatives from all regions of Canada were included to provide a true cross-section of the industry. The selected reviewers are listed in Appendix E.

5. Proposition Evaluation - Reviewers

   Once the five questionnaires were completed by the five proponents, the completed questionnaires were distributed to the reviewers. The reviewers were invited to review each of the propositions with which they had experience. They were given the opportunity to review the proponents' comments and selections on the language ladder and either agree with their selection, or provide a higher or lower rating. The questionnaires distributed to the reviewers are included in Appendix F.

6. Questionnaire Output Assessment

   The completed questionnaires were then compiled and assessed. A one-page report was generated for each proposition to summarize the ratings given by both the proponent and the reviewers. The output processing is discussed below.

7.2.2 *Questionnaire Evaluation*

The questionnaires were developed to fulfill a threefold purpose:

- to quantify the opinions of hydropower stakeholders with respect to the propositions
- to initiate discussion about low head hydropower, barriers to low head hydropower development and potential solutions to these barriers
- to gather information about the low head hydropower sector.

XXII A questionnaire using a "language ladder" format provides a series of answers to each question posed. The respondent is asked to select the statement that best represents their opinion on the answer to the question. This format allows a quantitative analysis of the answers to be performed while avoiding some of the bias that could result if the questionnaire used a simple numerical scale for responses. In this questionnaire, four possible answers were listed for each question. It was thought that an even number of answers prevents the respondents from choosing the central answer and causes them to give more thought to their responses.

The questionnaire results were analyzed using the following criteria to quantify the opinions of hydropower stakeholders with respect to the propositions:

- the ten questions on the questionnaire were weighted equally
- the four language ladder ratings for each question (A, B, C and D) were expressed on a linear scale
- ratings from Part A – Proposition Assets were allocated to the x-axis of the proposition evaluation chart. Ratings from Part B – Proposition Impacts were allocated to the y-axis of the proposition evaluation chart
- the proposition percent of maximum rating is a percentage that represents the promise of the proposition as expressed by the proponent and respondent, as discussed below.

A one-page summary was prepared for each proposition to summarize the responses to the questionnaires. An example summary sheet is illustrated in Figure 7.1. All summary pages are included in Appendix G. Each summary page has the following components:

- the proposition number, title and name of the proponent
- the proposition description, as provided by the proponent
- the number of reviewers who completed the questionnaire for the proposition
- the proposition evaluation chart. The responses from the proponent and each respondent are summarized on the proposition evaluation chart. The net ratings from Part A – Proposition Assets were allocated to the x-axis and the net ratings from Part B – Proposition Impacts were allocated to the y-axis. High values for proposition assets indicate that the proposition is relatively easy to implement and maintain effectively. High values for proposition impacts indicate that the proposition would have a significant positive impact on low head hydropower development in Canada.

  The proposition evaluation chart illustrated in Figure 7.1 includes 9 points, one for the proponent and one for each of the eight reviewers. Most points fall just beneath the half mark (5 out of 10) on the proposition impacts scale indicating that in general, the respondents thought the impacts of this proposition were relevant but not highly significant. However, on the proposition assets scale, most points fell just above the half mark. This indicates that the respondents felt the proposition would be relatively easy to implement and maintain.
- the proposition percent of maximum rating is a percentage that represents the promise of the proposition as expressed by the proponent and respondent. This is calculated as the percentage progress in achieving the maximum rating on both the x- and y-axes. The rating for each response was calculated and averaged with equal weighting to achieve the overall proposition percent of maximum rating.

  The proposition percent of maximum rating for the proposition illustrated in Figure 7.1 was calculated to be 51%. To calculate this, the linear distance of each response point on the proposition evaluation chart from the maximum rating (10 on each axis) is calculated. These

Figure 7.1: Example Questionnaire Summary Sheet

Proposition Number: 1 **Proponent:** Clark Smith

Proposition Title: NRCan can support low head / small hydro through expansion of financial incentive programs by specifically targeting low head / small hydro projects.

Proposition Description:

Hydro in general but low head hydro in particular suffers a distinct disadvantage to most other forms of energy generation -- location. The magnitude of hydraulic energy at a specific site may be entirely predicable but it only exists at that one location and is only transportable over a very short distance. Here we are addressing the topographic elements of location rather than the fact that the site may be simply remote and does not allow the efficient evacuation of power beyond local supply.

This disadvantage translates into a significant site specific largely civil cost component which will threaten project viability.

In those cases where a local market exists or the transmission of power to a more distant market is feasible, NRCan could provide a credit to energy production to offset the incremental site-specific civil costs. This credit mechanism would tend to bring small hydro projects to a common base.

Number of reviewers: 8

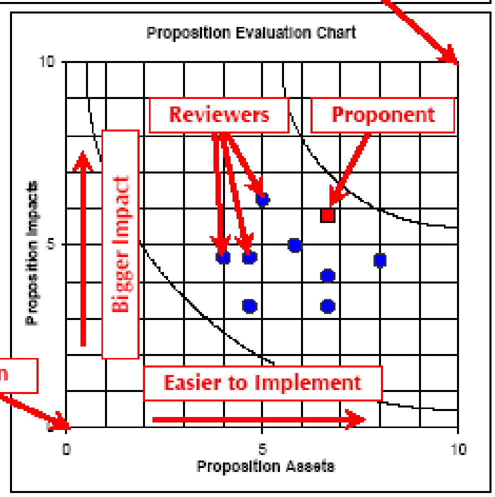
Proposition Evaluation Chart

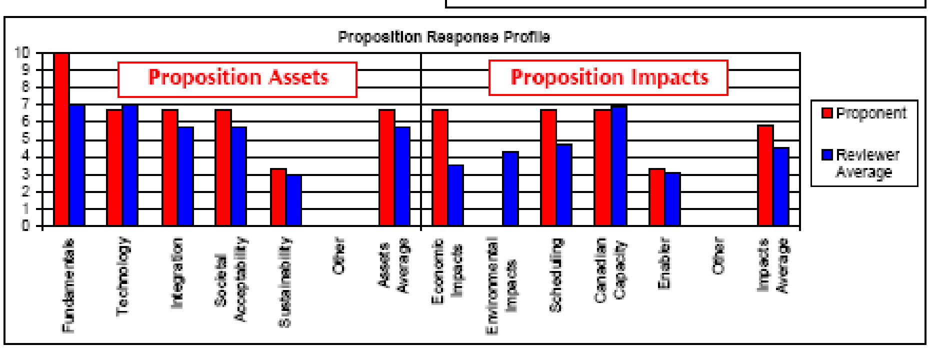
The responses of the proponent and reviewers are shown in the Proposition Evaluation Chart. High values for Proposition Assets indicate that the proposition is relatively easy to implement and maintain effectively. High values for Proposition Impacts indicate that the proposition would have a significant positive impact on Low Head Hydro development in Canada.

Proposition Response Profile

The breakdown of the responses to this proposition are illustrated in the Proposition Response Profile. The responses of both proponent and the average of the reviewers are included.

Percent of Maximum Rating: 51%





were then averaged and expressed as a percentage of the progress in achieving the maximum rating.

- the proposition response profile. This chart illustrates the responses to the individual questions on the questionnaire. Both the proponent responses and the average of the reviewer responses are included. Also included are the averages of the proposition assets and proposition impacts.

  The proposition response profile illustrated in Figure 7.1 shows the proponent responses and the average of the reviewer responses to each of the questions on the questionnaire on a scale of 0 to 10. Where no data is listed, no response was given. Neither the proponent nor any of the reviewers chose to answer the optional "Other" questions and the proponent did not respond to the "Environmental Impacts" question. Had the response been 0, a small bar would be present to indicate a response was given. The average of the responses to the proposition assets and the proposition impacts questions are also shown. It is these values that are plotted on the proposition evaluation chart.

In addition to the quantitative analysis of the questionnaires, significant discussion about low head hydropower, barriers to low head hydropower development and potential solutions to these barriers was generated. A summary of the comments that came through the questionnaire process is included in Section 9.

8 Workshops

8. Workshops

Two internet-based workshops were held for industry stakeholders on March 26, 2008 and March 28, 2008. The reason two workshops were held was to accommodate as many hydropower stakeholders as possible. Attendees were provided with draft copies of this report containing the results from the questionnaire prior to the workshop.

The workshops were run by Hatch and consisted of a brief presentation of the background information gathered by Hatch for the draft report and an in-depth discussion of the questionnaire results. Each proposition was discussed in detail, including a summary of the responses from the questionnaires. This allowed the thoughts and opinions of the attendees to be recorded and compiled into the final report.

A list of the workshop attendees is included in Appendix H.

9 Questionnaire/Workshop Results

9. Questionnaire/Workshop Results

The questionnaires and workshops were designed to initiate discussion around the five propositions. The following sections list some of the thoughts and ideas that came about through those discussions.

9.1 Proposition 1 – Market Incentives

Proposition 1 is "NRCan can support low head/small hydro projects through expansion of financial incentive programs by specifically targeting low head/small hydro projects."

A one-page summary page for the questionnaire dealing with this proposition is included in Appendix G. The sections of the summary page are described in Section 7.2.2.

Through both the questionnaire and workshops, several points were raised with respect to this proposition, including

- many of the issues associated with low head hydro are not unique to low head hydro, including
  - transmission costs
  - high upfront costs with long payback periods
  - potential benefits from a CO_2 market.

  If a program is to target these issues, it must target all generation types that would benefit. Specifically targeting low head hydro to the exclusion of all else would likely not be well received.
- The establishment of a market for carbon credits may go a long way in making low head hydro more economically viable without additional market mechanisms.
- Transmission can represent a significant fraction of the cost associated with any hydropower project, including low head developments, but most financial incentive programs are tied to generation. While the cost of energy transmission is somewhat tied to the size of the generating station (a larger station will require heavier lines), the biggest variable is simply the distance of the resource from the load center or grid interconnection point. It has been suggested that any incentive programs should help defray transmission costs in order to make more developments, especially those in remote areas, more economical.
- Hydropower projects (including low head hydro) are characterized as having very large upfront costs and low operational costs. Per kilowatt-hour incentive programs distribute the credit given over a long time period (say, 10 to 20 years). This means that a very large incentive may be needed to defray the initial costs. Benefits that manifest themselves at the project onset may be more influential than distributed payments in rendering low head hydropower sites economical.
- One option to address the large up-front expenditures with long payback periods of low head hydro (and most other renewable energy technologies) is to support low interest loans for renewable energy developments. This takes some of the risk off the developer and provides finances when needed.

- Any financial incentive program should keep the ownership structure of low head hydro projects in mind. Likely, it is not big utilities or other large companies that are developing small, renewable projects, but municipalities and smaller organizations. These small groups would benefit from different subsidies than large organizations. Low interest loans or loan guarantees would be particularly helpful for small owners/developers so that the initial capital outlay is not as burdensome.
- Many low head hydro projects are ideally situated to service remote, off-grid communities. Because the power needs of these communities is small (often less than 1 MW), a per kilowatt-hour power incentive will likely not be sufficient to offset the up-front development costs for these small projects. For larger projects (5 to 50 MW), such an incentive might be adequate. For projects serving remote communities, any incentive should scale inversely with the project size, i.e., very small capacity developments should receive a large subsidy relative to the cost of the project.
- The larger scale economic impacts of direct subsidies must be given careful thought before instituting such a program. Financial incentives do not change the cost of energy, only who pays for it. It can be argued that incentive programs can have an inflationary effect on development costs. The cost of development could increase as developers, manufacturers, contractors, etc, learn that government money is available and raise their prices accordingly.
- In some jurisdictions (Manitoba specifically, but likely British Columbia and Quebec as well), there are high head and/or large hydro sites available for development. In these cases, it may not make sense to encourage low head/small hydro over the larger developments.
- Low head hydro appears to be the most economically viable in remote, off-grid communities where currently electricity is generated with imported diesel. Low head hydro in these areas would offset the cost of the diesel; however, the diesel generating station must remain to supply power at times of low flow. This reduces the benefit of constructing a low head hydro plant.
- For some remote, off-grid communities, it may be more cost effective to run transmission lines to serve the community than to build new low head hydro plants.
- Ontario has the Renewable Energy Standard Offer Program (RESOP) that works very well at promoting renewable energy development by offering increased energy prices for renewable generation technologies. This program does specifically target solar photovoltaic generation with a premium energy price. With this as a precedent, a similar energy price could be offered for low head hydro and other emerging technologies (kinetic hydro, for example).
- Hydropower provides firm reliable power. For low head ROR sites, the firm power is typically only a fraction of the installed capacity. Financial recognition of this benefit would make more sites viable. Ontario's RESOP does recognise this benefit by providing additional revenue for sites which can guarantee generation during the peak demand periods, but limits this benefit to sites which are very reliable.
- Tax write-offs for green power were discussed. Small hydropower (including low head hydro) qualify under Class 43.1 for accelerated write-off of capital assets and resource-related expenditures.

- Policy makers need to assess the actual value of "clean" energy generation. The market can set a price on electricity, but factors such as human health do not get taken into consideration in an open market.

  The 2005 report "Cost Benefit Analysis: Replacing Ontario's Coal-Fired Electricity Generation"[XXIII] attempted to place a net monetary value on energy generation in Ontario by considering both the direct financial costs of various generation technologies and the human health costs associated with illness and death resulting from air pollution caused by electricity generation. 688 annual deaths were attributed to continuing to generate electricity with coal-fired plants in Ontario. By continuing this analysis, one can calculate that a 10-MW ROR small hydro development can save, on average, one human life per year. If policy makers were to place a dollar value on this benefit, more sites would become economically feasible.

9.2 Proposition 2 – Environmental Assessment

Proposition 2 is "NRCan can support low head/small hydro projects can be supported through streamlining provincial and federal environmental assessment screening processes and supporting research into environmental impacts and mitigation."

A one-page summary page for the questionnaire dealing with this proposition is included in Appendix G. The sections of the summary page are described in Section 7.2.2.

Several methods of achieving this proposal were suggested. These included

- creating a joint provincial/federal guidebook for developers of hydropower sites
- standardizing an instream flow assessment methodology
- supporting research into new technologies that reduce the environmental impact of developments and hence ease the environmental permitting process. Some examples of this technology are
  - fish-friendly turbines
  - VLH turbines that reduce the visual impact, noise and civil work required at a development.

Through both the questionnaire and workshops, several points were raised with respect to this proposition, including the following:

- Any proposition that requires coordination on a national scale of the federal and all provincial governments is unlikely to be successful without legislative change both provincially and federally. This is not an easy task.

[XXIII] DSS Management Consultants Inc. and RWDI Air Inc. for Ontario Ministry of Energy, "Cost Benefit Analysis: Replacing Ontario's Coal-Fired Electricity Generation", April 2005.

- A joint guidebook to both the provincial and federal environmental assessment (EA) processes would help a developer understand the process from the outset. This would assist developers in identifying what is required and the associated timetable, avoiding uncertainty and duplication. This in turn would allow for more informed "go/no-go" decision making earlier in the planning process.
    - This exists for Ontario and possibly for other jurisdictions as well.
- It was proposed that more coordination between provincial governments and the federal government with respect to environmental permitting and the EA process would be valuable. This generated some discussion, including
    - Ontario and Alberta (and possibly other jurisdictions) have coordinated provincial and federal EA processes. However, in the opinion of the participants, this doesn't do much to speed up the overall EA process.
    - the provincial and federal agencies have different priorities, e.g., number of fish species vs. habitat loss. This means that coordinated processes do not necessarily help.
- Environmental permitting can be a major hurdle for many small hydro developments. A standardized approach to EA would be of great benefit to developers by streamlining the process and clarifying the requirements. However, such a system would face many challenges before becoming viable.
    - The environmental concerns with hydro developments can vary greatly from site to site; therefore, a unified process may not be readily applicable to all sites. It may have the potential to miss some significant impacts, or be so restrictive that nothing can meet the criteria.
    - It would be very difficult to set up and administer such a project. Getting each jurisdiction to agree to a common set of guidelines would likely be extremely difficult.
- A maximum time limit to cap the environmental permitting process (6 months, for example) would have a two-fold benefit. It would limit the time (and cost) of environmental permitting to the developer and allow for proper budgeting, but would also likely speed up the project. Regulators would be motivated to move through the process more quickly, highlighting key concerns and looking for solutions. The current system, some believe, does not motivate regulators to approve any development at all. At least British Columbia and Ontario have time limits on portions of the EA process (government reply times), but not on the process as a whole. Implementing time limits was not thought by all stakeholders to be practical/particularly helpful.
- The environmental benefits of many small sites over one large site are debatable at best. Therefore, in jurisdictions with available large hydro, it may be more reasonable to support large hydro than small and low head hydro.
- An accelerated EA process for the development of existing damsites would be extremely beneficial. These sites are already the most economical and would benefit from a streamlined process. There will generally be fewer environmental concerns at existing sites than at greenfield sites because there is no new inundation; the EA process should reflect this.

- Research into the effects of hydropower might be beneficial in simplifying the EA process. Some potentially helpful areas for research are
    - methylmercury production in headponds
    - the effects of fish passage through turbines (fish-friendly turbines).
- The science of fishery concerns is poorly understood. More research into fisheries and fish habitat is needed to accurately assess and predict the impact on hydropower developments on fisheries. This would enable developers and regulating agencies to
    - more effectively mitigate any fisheries disruption caused by developments
    - avoid development in any particularly sensitive areas, and
    - move through the environmental screening process more quickly and effectively.
- Research into the effects of low head hydro on fish passage in rivers would be useful. New "fish-friendly" turbines are being developed, but are not yet recognized by regulating authorities. Research into fish migration through turbines, with respect to the required fish passage at development sites, would be beneficial.

9.3 Proposition 3 – Electrical Interconnection Permitting

Proposition 3 is "NRCan can support low head/small hydro projects through streamlining the electrical interconnection approvals for emerging generator technologies, i.e., variable speed, brushless excitation, permanent magnet generators, etc."

A one-page summary page for the questionnaire dealing with this proposition is included in Appendix G. The sections of the summary page are described in Section 7.2.2.

This proposition had some overlap with Proposition 5. All discussion of the development of permanent magnet generators (PMGs) and associated technology is included in Section 9.5.

Much of the discussion of this proposition focused on developing the technology required for PMGs. It was felt that the interconnection approvals process for PMGs would become a non-issue if the technology were further developed. Once projects using PMGs have the level of electrical protection required by electrical authorities to connect to the grid, this proposition will be realized.

Some other points raised through both the questionnaire and workshops included the following:

- individual local authorities may have different standards for frequency, voltage regulation and electrical protection which must be satisfied before interconnection. If PMGs are to become widely accepted, it will likely be important to standardize the requirements in order to streamline the approvals process.
- any interconnection permitting simplification would benefit all new distributed generation, not just low head hydropower
- more information about the impacts of new technologies on grid stability would help with interconnection. Some grid operators are reluctant to allow PMGs with direct current (DC) to

alternating current (AC) inverters to connect to the grid because the effects of interconnection have not been extensively tested.

- a two-tiered interconnection permitting system might be valuable. Currently, small developments need to meet the same requirements as large developments. On a small project, this can be a significant burden.

9.4 Proposition 4 – Structural Cost Reductions

Proposition 4 is "NRCan can support low head/small hydro projects through research, development and deployment of structural technologies to reduce cost."

A one-page summary page for this proposition is included in Appendix G. The sections of the summary page are described in Section 7.2.2.

Through both the questionnaire and workshops, several points were raised with respect to this proposition, including the following:

- Low head hydropower developments can fall into two broad categories with respect to civil works: greenfield sites and existing damsites. Greenfield sites require the construction of a dam and spillway, penstocks, a powerhouse and a tailrace. Existing damsites generally have an acceptable dam and spillway in place. The financial ramifications of this difference in terms of civil costs mean that greenfield sites are rarely economical to develop while existing damsites can be attractive.
- It is unlikely that the civil costs associated with dam construction will be reduced without direct cost subsidies, which would be extremely costly to implement. Again, this would not affect the cost of the development, just who pays.
- Civil costs associated with other aspects of low head hydro developments could be reduced through other innovation, especially for very small plants. Some examples are
  - kinetic energy turbines that do not require impoundments (not part of this study)
  - siphon penstocks
  - penstocks constructed from plastics.
- Pre-packaged plants have been tested successfully in Canada; work is required to apply new technologies in penstocks to the concept.
- Reducing the civil costs associated with developing low head hydropower sites would be tremendously effective at rendering more development economical (especially for greenfield sites).
- The engineering component to civil costs is considerable. If this could be eliminated by using off-the-shelf components that are standardized between sites, costs could be significantly reduced. This is challenging due to the site-specific nature of hydropower developments, but might be possible for small low head hydro sites.
- The costs associated with dam ownership are very large and are poised to increase. In Quebec, Bill C93 will require dam owners to provide a higher degree of protection for their dams than is

currently required. Similar trends are noted in other parts of Canada; dam ownership is becoming more expensive. This is going to have a negative impact on the viability of hydropower projects, especially low head and small hydro.

- Rubber dams were suggested as an alternative to traditional dam construction to reduce cost. Many participants of the workshop disagreed because
  - rubber dams are often more expensive than traditional dam structures, and
  - one of the two major manufacturers of rubber dams (Bridgestone) is pulling out of the market (Obermeyer is the other major manufacturer).
- It is well known that in the north, construction is more expensive than in other, more populated areas of Canada. However, this is not due to the cost of the materials themselves (such as concrete), which is relatively constant from one location to another. Increased labour and transportation costs are generally the main drivers of increased costs for construction in remote areas. Therefore, if local labour was used, costs might be reduced. Some thoughts with regards to this proposition are as follows:
  - there might be some problems with the training and/or willingness of the local population
  - government-funded training programs could facilitate partnerships of this nature
  - this could provide opportunities for partnerships in small northern communities.
- There is some work being done with alternate construction methods and/or materials:
  - the Sidney A. Murray generating station on the Mississippi River (mostly owned and operated by Brookfield Power) is a 192-MW, low head, ROR power station. The plant structure was prefabricated at Avondale Shipyards in New Orleans and was floated 208 miles upriver to its final destination, making it the largest prefabricated powerplant in the world.
    - This might or might not have been cost effective; there were problems during construction that meant traditional construction methods might have been approximately the same cost.
    - This technique requires very good barge access to the site. The Mississippi River is ideal for barge access; most sites do not have such good access.
  - a dam in western Canada was mentioned that used prefabricated sections for parts of its construction.
- Small pre-packaged systems that could be dropped in headponds of existing dams could be worth exploring. A workshop participant discussed his involvement with the development of low head hydro sites in remote areas. Two of the sites are still operational after approximately 20 years. Some of the features of the sites are
  - a pre-packaged steel box unit, containing the turbine and generator, is placed directly in a river
  - a 40- to 50-m long polyethylene tailrace extends downstream

- the need of both the dam and powerhouse is eliminated, dramatically saving on structural costs
- all four sites were very small (in the order of 100 kW); this type of development would be very difficult for plants of 1 MW or more
- this technology might have applications in the far north or internationally, in developing nations
- waste heat from the turbine and generator keeps the unit ice-free down to temperatures of about -40°C
- flood protection is needed; without a dam, a large freshet might wash the unit away
- remote monitoring and control would render this design more effective.

9.5 Proposition 5 – Electromechanical Cost Reductions

Proposition 5 is "NRCan can support low head/small hydro projects through research, development and deployment of electromechanical technologies to reduce cost or increase efficiencies".

A one-page summary page for the questionnaire dealing with this proposition is included in Appendix G. The sections of the summary page are described in Section 7.2.2.

This proposition had some overlap with Proposition 3. Therefore, the discussion of this proposition will include all discussion of the use of PMGs in low head hydropower developments.

Low head hydro installations are almost always characterized by a large variation in either the head, or the flow. Such variations require generation equipment designed to accommodate the variations should regulation of frequency (speed) and control of voltage be required, double regulation and external excitation systems are often needed. This results in turbine and generator complexity and a considerable expense to the developer.

Emerging technologies proposed for such installations often include a "fish-friendly" fixed blade position, unregulated turbines that vary speed with head or flow variations and permanent magnet type excitation generators which produce an output voltage that varies with speed, that is, with head and flow variations as well. The primary objective of such a design is to keep the unit physically small, use standard components and hence be cost effective.

Unfortunately, such a system cannot be connected directly to the electrical grid as it is not possible to establish the control of frequency and voltage necessary for successful parallel operation. Such a system is more suited to the production of DC electricity, than to the production of AC electricity.

To connect to the grid, the use of a DC to AC inverter is necessary. DC to AC inverters do exist; however, the traditional approach has been to provide a battery bank between the hydro DC generation and the inverter. Hence, the inverter is designed to operate on a relatively constant DC voltage. In addition, grid interconnection requirements include the provision of electrical protection which results in the addition of external components.

It would be advantageous to the low head, small hydro market, if NRCan could stimulate the development of a "Made in Canada", DC to AC inverter that

- could accommodate the potential large DC voltage swings of a variable speed, PMG
- would not require an intermediate battery, and
- could provide the level of protection required by the electrical authorities to allow interconnection to the grid.

Through both the questionnaire and workshops, several points were raised with respect to this proposition, including

- PMG can eliminate the need for speed-increasing gearboxes. This can reduce downtime and maintenance issues and decrease the required footprint of the powerhouse.
- PMG are well understood and are widely used in other industries. Wind power, for example, uses this technology extensively. However, PMGs are not yet widely used in hydropower and require more testing and development.
- AC/DC inversion is also well understood, but not yet used extensively in hydropower applications. Further development and testing is required in this area as well. The proponent for the questionnaire proposed a made in Canada DC/AC inverter to provide adequate grid protection to allow for interconnection. This discussion about this proposition included
  - electronics often have a short (5- to 10-yr) shelf life. Developers may be hesitant to use power electronics that have the potential to become obsolete (and, therefore, difficult to repair or replace) early in the life of a development.
    - This view was not shared by all participants.
- Canadian companies are exploring PMG technology with laboratory testing and prototype installations in Europe. A demonstration plant in Canada would be of tremendous use.
  - A pilot plant was planned for Canada (supported by NRCan) but fell through. Now, a site is needed to host the 300-kW, 300-rpm, 9-m head machine.
  - Some PMGs are made in Canada; sizes vary from very small to several hundred MW.
- the implementation of a project to develop this technology need not be limited to hydropower. Rather, it may be applicable to any varying generation method (wind, solar, hydro, etc). It may require significant investment, but should be able to serve multiple markets if successful.
- Hydro One (the grid regulator in Ontario) currently does not allow for direct connection of variable speed turbines with PMGs to the grid, regardless of whether inverters are used. It is assumed that other jurisdictions have similar interconnection rules.
  - There are currently two hydropower sites developed in Ontario using PMG technology. However, both had extenuating circumstances at the time of development that are not likely to be reproduced.

  - An inverter can provide the required level of grid protection; however, little is known about how inverters will react to grid instability. More research is needed to demonstrate to the grid regulators that this is viable and stable technology.

Other emerging electromechanical technologies were also discussed as part of the questionnaire process and at the workshops. Some of the points raised through this discussion include the following.

- Some examples of research areas that could reduce cost and/or increase generation efficiencies are
  - tolerance of frazil ice
  - fish friendliness of turbines
  - protection against floating ice
  - operation under extremely cold temperatures
  - lifting mechanisms
  - fabrication methods, materials, tooling, etc.
- It was suggested that low head hydro needs the development of an inexpensive generator. A DC generator was suggested as a possible solution to this.
- VLH turbine is a new turbine design being developed by MJ2 and Atelier Onmec Inc. with support from NRCan (http://www.vlh-turbine.com). This is a large turbine with a direct-drive, variable-speed, permanent-magnet generator that is placed directly in a flow channel with between 1.4- and 2.8-m head. This dramatically reduces the civil works required and can result in overall project cost reductions. Further discussion is included in Section 4.2.2.
- NRCan is supporting research into fish-friendly turbines, one of which is discussed in Section 4.2.4.
  - It was mentioned that fish-friendly turbines must be recognized by regulators. In many cases, regulators are not concerned with fish mortality in the turbines. However, this might change if large low head applications are developed and the turbine is designed to be the primary means of fish passage through the development.
  - There is more of a market for fish-friendly turbines in the United States than in Canada. In the United States, the environmental regulators are more concerned with fish mortality than their Canadian counterparts.
- One emerging technology discussed was a turbine with two or three interchangeable runners. Each runner would be designed for a specific flow and head range. As the flow and head on the plant seasonally change, the runners can be exchanged to maintain efficient operation. This replaces the need for double regulation in the turbine and may result in a cheaper turbine, for small unit sizes (up to about 150 kW).
- Remote control of low head hydro plants was discussed as a potentially valuable development area. Many small plants would not be cost effective to staff and would benefit from being

operated remotely. Some work is needed, however, to improve the reliability and decrease the cost of remote monitoring and control of sites.

- This is particularly true in the far north, where it is impractical to bring experts to the site for maintenance. Remote operation allows this for little cost.
- However, because remote control and operation means that no local operator is required, local support for a development may diminish.

9.6 Discussion

As discussed in Section 7.2.2, the questionnaires were evaluated quantitatively to determine the viability of the propositions. The resulting summary pages are included in Appendix G and are briefly discussed below.

Table 9.1 lists the percent of maximum ratings achieved by each of the propositions, as defined in Section 7.2.2.

Table 9.1: Proposition Ratings

Proposition	Description	Percent of Maximum Rating
Proposition 1	Market mechanisms	51%
Proposition 2	Environmental assessment	43%
Proposition 3	Electrical interconnection permitting	43%
Proposition 4	Structural cost reductions	51%
Proposition 5	Electromechanical cost reductions	53%

Proposition 5, dealing with electromechanical cost reductions, appears to be the most promising area for investment. There are several emerging technologies that show promise in reducing the development cost of low head hydro projects. These include PMGs, VLH turbines, fish-friendly turbines and a variety of other new designs that help to reduce development costs. Not only can electromechanical costs be directly reduced, but the civil costs associated with development can also be reduced by reducing the required civil works (for example, by decreasing the required footprint of the powerhouse or entirely eliminating the need for a dam).

Proposition 4, dealing with reducing the cost of civil works, also appears to be attractive. Civil cost reductions are generally a bi-product of innovative electromechanical designs rather than advancements in the civil works themselves. For example, reducing the size of a powerhouse or eliminating it entirely through the use of innovative turbines (VLH turbine technology, for example) reduces the civil costs. The same can be said for eliminating the costs associated with dam construction by using a displacement motor or another pre-packaged unit technology. If these emerging technologies were to become more widely accepted and utilized, the civil cost savings could have a significant impact on the overall project economics and the low head hydropower industry as a whole.

Proposition 1, dealing with market mechanisms, also appears to be a promising area for investment. By subsidizing low head hydropower developments directly, more sites will become economical. However, careful thought must be directed towards determining what subsidies would best achieve the goals of the program. Per kilowatt-hour incentives, low interest loans or loan guarantees and transmission subsidies were all mentioned as potential market incentives. It was also mentioned that a carbon credit trading system or recognition of the potential firm power would benefit low head hydro development.

It appears that Proposition 3, dealing with electrical interconnection permitting of innovative turbine/generator design, is an unattractive place to focus development resources. Electrical interconnection permitting is a significant hurdle for many small developments, but this is generally due to a lack of testing of emerging technologies and not due to overly burdensome interconnection requirements. Once new technologies become widely accepted, it is thought that grid interconnection will not be an issue.

Proposition 2, dealing with environmental permitting, also appears to be a relatively unattractive place for NRCan investment. A reduced, streamlined or standardized EA process would be of great benefit to low head hydro development; however, this would be very difficult for NRCan to achieve. Even with a simplified process, other significant barriers would still exist for low head hydro. This is not to say that environmental permitting should not be simplified, only that NRCan would likely find it difficult to achieve this. However, providing information on the environmental benefits of hydropower, and supporting environmental research could provide immeasurable benefits to the hydropower industry.

10 Conclusions

10. Conclusions

Hydropower is the most predictable of the renewable energy sources, with highly efficient systems and extremely low maintenance costs. It is clean and renewable, with zero greenhouse gas emissions during operation.

Canada has a vast untapped potential for low head hydropower development. At least 5000 MW of potential have been identified, but the actual potential is likely significantly higher. A large portion of this potential lies in dams constructed for other purposes and other existing structures.

Currently, most of the electromechanical technology used to develop small, low head sites was originally designed for larger, higher head applications. This technology is often not economically viable in comparison with other generation technologies. However, there are several emerging technologies designed specifically to exploit these low head sites. These technologies, should they become widely accepted by developers, regulators and utilities, could become economically viable and have a significant impact on the low head hydro sector.

Promoting the development of low head hydropower is promoting reliable, environmentally friendly, distributed energy generation.

10.1 Low Head Hydro Potential

In Canada, there is currently almost 3500 MW of small hydropower installed across over 350 sites. Current statistics for low head hydro are not available, but as of 1986, 560 MW of low head hydro were installed at almost 100 sites in Canada.

There is a large potential for low head hydro development in Canada. A review of past hydropower studies and databases yielded over 2300 small (under 50 MW), low head hydropower sites with a combined potential capacity of almost 5000 MW. Twenty-one low head sites with individual capacities of over 50 MW were identified in Ontario and Manitoba with a combined capacity of over 3000 MW. It must be kept in mind that this estimation was based on information that was, in some cases, several decades old and that did not specifically identify low head hydro. The actual low head potential in Canada might be much larger.

10.2 Technology

The conventional technology used to develop low head hydropower sites is dominated by axial flow turbines, with horizontal Francis type turbines towards the higher heads. Several large turbine manufacturers are active in the Canadian small hydro sector providing a wide range of conventional technologies. If the low head hydropower market in Canada were to become more economically viable, it is estimated that the demand for units would be easily met with the current market capacity.

However, conventional technologies are often not economically viable for many low head installations. In the last 25 years, a number of improvements have been made to reduce costs and improve the environmental performance of low head hydro developments. Some of the promising emerging technologies include

- PMGs
  - reduced electromechanical equipment cost
  - slightly reduced civil cost by reducing the required powerhouse size
  - moderate environmental benefits from reduced lubricating oil use
- VLH turbines
  - significantly reduced civil costs
  - enhanced environmental properties (low noise, low fish mortality)
- displacement motor
  - significantly reduced electromechanical cost
  - significantly reduced civil cost
- "vaneless" turbines
  - significantly enhanced environmental characteristics (very low fish mortality).

10.3 Economics

Economic feasibility is the most important aspect influencing the development of a waterpower site. The economic feasibility of a small hydro development is provided by a favourable combination of site topography, hydrology, location and market conditions. Low head hydro developments are generally fairly expensive, on a unit cost ($/kW) basis, in comparison to higher head developments.

The cost of developing a site can be divided into three main categories:

- Civil costs
  - includes a dam (if needed), water passage, gates and valves, fish passage, a powerhouse, environmental mitigation
  - can amount to over 50% of a project cost if a dam is needed
  - dam costs (and the associated environmental mitigation costs) alone can render a project uneconomical
  - little cost savings can be expected from improved civil techniques or technologies. Cost savings will result from a reduction in the amount of civil work required.
- Electromechanical costs
  - includes the turbine, generator, transformers and all other mechanical and electrical equipment
  - turbine costs for a defined capacity increase dramatically with decreasing head due to the required equipment size
  - can amount to over 50% of a project cost for projects with little civil work

- innovative turbine and generator designs have the potential to significantly reduce electromechanical costs. These designs also have the potential to significantly reduce civil costs because they require less civil work.

- Transmission and interconnection
  - includes electricity transmission to the load center or to an interconnection point on the electrical grid
  - transmission over long distances can render small projects uneconomic by doubling project costs
  - long transmission distances also result in electrical (and financial) losses
  - little can be done about the required transmission distance for a hydropower development, hydropower relies on the specifics of a site and cannot be moved.

In comparison to conventional large-scale electricity generation technologies, greenfield low head hydro developments are typically uncompetitive. However, low head hydro developments compare well with other renewable generation technologies, especially at existing damsites and at the larger capacities.

Of the hydropower generation technologies, large conventional hydropower is the most cost effective at a levelized cost of about $0.05/kWh. Small hydropower costs approximately $0.07/kWh to $0.08/kWh while low head hydropower costs between $0.07/kWh and $0.15/kWh, making it the most costly hydropower option.

Low head hydro developments are often more cost effective than diesel generation in remote, off-grid areas, notwithstanding the fact that low head hydro development costs will also be larger in remote locations. However, if low head hydro were to replace diesel generation in off-grid communities, the diesel plants would need to be retained to ensure electricity supply at times of low flow. In some situations, low head hydro is still economically attractive.

Low head hydro development costs fall within the range of the costs of other renewable energy sources. Greenfield low head hydro sites can be more costly to develop than many other alternatives but are competitive with fuel cells and solar thermal and more cost effective than solar PV installations. The cost of developing low head hydropower at existing sites is comparable to the cost of many other renewable electricity sources.

Green power incentives are in place in many Canadian provinces to encourage the development of renewable power; most include low head hydropower in their scope. Ontario and British Columbia have each issued requests for proposals for renewable energy developments and both have standard offer programs that guarantee minimum electricity purchase prices for energy from renewable sources over a long term. Net-metering programs that allow small renewable generators to sell excess electricity to the grid are available in six provinces.

The impact of two types of incentive packages on the low head hydropower market was estimated with a simple economic model. The two incentive packages modeled were: reducing the capital cost of installing low head hydropower by a factor of 25%, and adding an incentive of $0.05/kWh to the price of electricity generated from low head hydro projects. At a threshold energy price of

$0.10/kWh, the capital cost reduction over doubled the number of viable sites while the energy incentive yielded over a four-fold increase. At a threshold of $0.15/kWh, the increase in economic sites was not as dramatic, but still significant, mostly due to an increase in the number of viable small projects. At the high threshold energy price, the incentives had no impact; at $0.20/kWh, the majority of sites are already viable. This is shown in Table 10.1.

Table 10.1: Impact of Incentives at Varying Energy Prices

	$0.10/kWh		$0.15/kWh		$0.20/kWh	
	Sites	MW	Sites	MW	Sites	MW
No Incentives	405	1585	1723	4272	2329	4866
Capital Reduction (25%)	908	3043	2329	4866	2329	4866
Energy Incentive ($0.05/kWh)	1723	4272	2329	4866	2329	4866

10.4 Environment

Low head hydro is a renewable energy source that depends on the natural water cycling. There are minimal GHG emissions during operation (especially if any newly flooded areas are properly prepared) and no emissions of NO_X or SO_X.

However, there are some environmental concerns regarding small and low head hydropower sites. If a new dam is required, there can be impacts associated with flooding of the upstream areas. If not properly treated, decomposing vegetation in the newly flooded areas can lead to GHG emissions and release methylmercury. Fish passage across the barrier of the dam is often also a concern. If the plant is not operated as a ROR plant, the re-regulation of flows downstream can have an impact on fish and other wildlife and their habitats downstream of the dam. Many of these concerns are not present if the project is a redevelopment of an existing dam, especially if the operation of the dam does not change after the redevelopment.

The environmental permitting process is a major hurdle in terms of cost and time for many low head hydro sites, for both greenfield sites and development of existing structures.

10.5 Propositions

Hatch experts identified five broad categories of barriers to, and opportunities for, low head hydro development in Canada. These were expanded into five propositions that formed the basis of a questionnaire to industry stakeholders and served as a starting point for discussion at two internet-based, low head hydro workshops. The five propositions were:

NRCan can support low head/small hydro projects through:

1. expansion of financial incentive programs by specifically targeting low head/small hydro projects
2. streamlining provincial and federal EA screening processes and supporting research into environmental impacts and mitigation
3. streamlining the electrical interconnection approvals for emerging generator technologies, i.e., variable speed, brushless excitation, PMGs, etc
4. research, development and deployment of structural technologies to reduce cost

5. research, development and deployment of electromechanical technologies to reduce cost or increase efficiencies.

Proposition 5, dealing with electromechanical cost reductions, appeared to be the most promising area for investment. By supporting the development of innovative turbines and generators, the capital costs of low head hydro projects can be reduced, rendering many more projects viable. There are several emerging technologies that show promise in reducing the development cost of low head hydro projects including PMGs, VLH turbines, fish-friendly turbines and a variety of other new designs. Not only can electromechanical costs be directly reduced, but the civil costs associated with development can also be reduced by reducing the required civil works (for example, by decreasing the required footprint of the powerhouse or entirely eliminating the need for a dam with innovative turbine design).

Proposition 4, dealing with reducing the cost of civil works, also appears to be attractive. Civil cost reductions are generally a bi-product of innovative electromechanical designs rather than advancements in the civil works themselves. For example, reducing the size of a powerhouse or eliminating it entirely through the use of innovative turbines (VLH turbine technology, for example) reduces the civil costs. The same can be said for eliminating the costs associated with dam construction by using a displacement motor or another pre-packaged unit technology. If these emerging technologies were to become more widely accepted and utilized, the civil cost savings could have a significant impact on the overall project economics and the low head hydropower industry as a whole.

Proposition 1, dealing with market mechanisms, also appears to be a promising area for investment. By subsidizing low head hydropower developments directly, more sites will become economical. However, careful thought must be directed towards determining what subsidies would best achieve the goals of the program. Per kilowatt-hour incentives, low interest loans or loan guarantees and transmission subsidies were all mentioned as potential market incentives. It was also mentioned that a carbon credit trading system or recognition of the potential firm power would benefit low head hydro development.

Proposition 3, dealing with electrical interconnection permitting of innovative turbine/generator design, appears to be an unattractive place to focus development resources. Electrical interconnection permitting is a significant hurdle for many small developments, but this is generally due to a lack of testing of emerging technologies and not due to overly burdensome interconnection requirements. Once new technologies become widely accepted, it is thought that grid interconnection will not be an issue.

Proposition 2, dealing with environmental permitting, also appears to be a relatively unattractive place for NRCan investment. A reduced, streamlined or standardized EA process would be of great benefit to low head hydro development; however, this would be very difficult for NRCan to achieve. Even with a simplified process, other significant barriers would still exist for low head hydro. This is not to say that environmental permitting should not be simplified, only that NRCan would likely find it difficult to achieve this. However, providing information on the environmental benefits of hydropower, and supporting environmental research could provide immeasurable benefits to the hydropower industry.

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