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Emerging Hydropower Technologies R&D in Canada: A Strategy for 2007-2011

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Date: December, 2007

Canada

DISCLAIMER

ISBN: M154-34/2009E-PDF 978-1-100-13931-9

ACKNOWLEDGEMENTS

This report was prepared by the Hydraulic Energy Group, Renewable Energy Technologies, CanmetENERGY, Natural Resources Canada (NRCan). In kind services were contributed by many organizations and people including CanmetENERGY representatives.

The following groups are specially thanked for providing valuable suggestions, comments and critique toward preparation of this report:

NRCan's Renewable Energy Technologies Group
NRCan's Renewable Policy group (Renewable and Electrical Energy Division, REED)
Hydraulic Energy Technical Advisory Committee 2007

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An Emerging Hydropower Technology (EHT) R&D strategy for Canada

Hydropower covers a wide range of technologies in a dynamic industry with significant growth potential but also with many technical challenges to overcome. Known traditionally for its large hydropower plants, hydropower energy also encompasses emerging hydraulic power technologies such as small hydro, low-head hydro and water current. These technologies, though not as commercially advanced as large hydro, offer significant benefits in terms of faster deployment, distributed generation, small business opportunities and significant future growth potential. In addition, with focused research and development, the challenges facing these technologies can be addressed over time to make them economically competitive sources of clean power.

Canada enjoys a solid reputation for expertise in hydropower, particularly because of its manufacturers, construction companies and operators, and is known internationally for its expertise and excellence in the hydroelectric energy field. With the significant potential available from emerging hydropower sources, research and development in this area presents a significant opportunity to maximize both the economic and the environmental benefits of our resources.

This strategy paper will centre on emerging hydropower technologies, which focus on small and low-head hydropower and water current and involve little or no use of water storage.

Vision

Perform key research and technology development activities supporting the growth of Canadian emerging technologies for small and low-head hydro and water current, based on commercially viable and low-impact extraction of energy from rivers, providing projects, technologies, services and expertise to domestic and global markets, and ensuring that these emerging hydropower technologies contribute to a key and growing component of Canada's renewable energy mix by 2020.

Executive Summary

Hydropower is clean and renewable, and it is the most predictable of the renewable energy sources. Run-of-river hydro plants capture the energy of flowing water with little or no storage and include small and low-head hydro. These types of developments can bring about environmental and socio-economic benefits through integrated design, multipurpose planning and community involvement. Small hydro is especially attractive as an alternative to highly polluting and very costly diesel generation that currently provides electric energy in most remote communities across Canada. There is also a growing interest in *water current* or *in-stream* potential in Canada and internationally for power production using 'zero head' turbines, which require no dams or barrages.

The small hydro subsector contributes $150 million to the Canadian economy annually through local and overseas projects. Annual addition to generation capacity from small hydro represents an estimated $200 million in investments. The typical investment cost ranges (in $Can) from $2,000 to $5,000[1] per installed kW, with an overall cost of energy of $0.04 to $0.10 per kWh.[2] However, capital costs for projects in remote areas are usually much higher and can exceed $6000 per kW. Water current technologies are expected to enter the market by 2010 with about five major international players, and capital costs are expected to decline to $1000-$4000 by 2015.

The current small hydro capacity in Canada is approximately 3400 MW, and new capacity is growing at a rate of 50-150 MW/y[3]. It is estimated that about 15% of the identified small hydro potential of 15,000 MW[4,5] would be strong candidates for development under current socio-economic conditions and with existing state-of-the-art technologies. There is also significant potential in Canada for low-head hydro, a portion of which could become economical with a reduction in equipment costs. A recent study in Ontario identified over 4000 MW of low-head hydro potential.[6] Water current potential in Canada is largely unknown.

The global potential for small hydropower is much greater and could also be exploited with beneficial economic and environmental payoffs. The World Energy Council (WEC) estimates that, under current policies, installed capacity of small hydro will increase to 55 GW by 2010, with the largest increase coming in China. Under the favourable case scenario developed by the World Energy Council (WEC), installed capacity will increase to about 75 GW by 2020. All regions of the world are experiencing significant increases in small hydro capacity, with China again showing the largest increase.[7]

In Canada, the recent calls for renewable energy RFPs, standard offer programs and net-metering in provinces across Canada have helped to strengthen interest in small hydropower development. There has also been a positive policy shift to improving relations with First Nations and including them as active hydro project partners. However, developers encounter long lead times required for approvals and projects can become arbitrarily derailed by opposition during the public participation process. The most common concerns about small hydro projects are the impact of civil works construction on stream flow and aesthetics and prevention of fish movement towards their natural habitat. In recent years, provincial governments have begun to address some of these issues/barriers using a more streamlined and sustainable watershed management approach, and the federal government has recently come on board as well.[8]

In Canada and internationally, the perception is that hydropower is a mature technology and has few R&D requirements. As a result, many governments, organizations and businesses have not kept up with new innovations or attracted or allocated new

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[1] Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.
[2] Natural Resources Canada. 2004. Deck on small hydro. Internal document. Prepared by the Renewable Energy Technology Group, NRCan.
[3] Statistics Canada 1996-2004. *Electric Power Generating Stations*. Catalogue 57-202-XIB.
[4] Canadian Hydropower Association. 2006. *Study of Hydropower Potential in Canada*. Prepared by EEM Inc.
[5] Natural Resources Canada. 2005. *Small Hydro Atlas*. www.small-hydro.com.
[6] Hatch Acres. 2005. *Evaluation and Assessment of Ontario's Waterpower Potential*. Hatch Acres, Oakville. 55 pp.
[7] World Energy Council, 2004.
[8] Hon. Gary Lunn, Minister of Natural Resources Canada 2006. Speech at the *Forum on Hydropower 2006*. Canadian Hydropower Association (CHA), October 26.

R&D funding. Another significant issue facing the hydropower industry in Canada and abroad is the aging workforce: it is estimated that there are only 10 years of expertise left in Canada.[9]

While some countries have moved away from emerging hydropower technologies R&D, the European Union (EU) continues to carry out R&D in small hydro, and there is renewed hope in the U.S. that their hydropower R&D program will be reinstated.[10] The EU has shown a keen interest in addressing aging hydro sites, particularly tapping into the large low-head potential of abandoned sites and water resources infrastructure.

Developing the Canadian potential requires advances in R&D to make development economically viable. While conventional small hydro is close to being competitive with other energy sources,[11] there are still a number of emerging technologies that need R&D, including economical and efficient low-head turbines, mitigation technologies and eco-engineering and protection of aquatic resources. In addition, water current technologies are at a similar R&D stage to that of wind 10 years ago.[12]

Standardization of equipment aids developers who have limited resources for custom design and allows small turbine manufacturers to become cost-competitive. Other equipment must be custom-designed for individual sites, and Canadian designers and manufacturers also require support to increase their R&D research capabilities. The International Energy Agency (IEA) identified manufacturers as the "best entities to initiate or sponsor" in the development of equipment and improvement for small hydro,[13] and public R&D programs support manufacturers by making results available, giving them the ability to "systematically develop an optimized laboratory design."[14]

Over the last 25 years, the federal government has been supporting small-scale hydro emerging technologies. The Hydraulic Energy Group (HEG) is actively involved with provinces, utilities, private industry, academic institutions and other organizations on key projects to reduce equipment and construction costs and increase turbine and site efficiencies, as well as to support technology demonstrations nationally and internationally. NRCan's Panel on Energy Research and Development (PERD) has been supporting the hydraulic machinery laboratory (LAMH) at Laval University over the last 10 years to become the only independent hydro turbine-testing laboratory in Canada. The laboratory fills an important gap in Canadian R&D capacity by enabling independent, credible testing of innovative turbine designs within North America. The federal government support of Laval University has been critical to the laboratory's early development and recent success.

Planned R&D work to be carried out and supported by the Hydraulic Energy Group of CanmetENERGY at NRCan over the next four years covers three main R&D themes:

Competitive low-head and water current systems
R&D under this theme involves the development of cost-effective and energy-efficient low-head and water current systems, and a large part of the R&D will be conducted with LAMH. R&D on the fish-friendly aspect of these systems will be carried out through joint projects under the eco-engineering theme. Codes and standards work will also serve as a precursor for codes and standards development for ocean energy-related technologies.

Eco-engineering
CanmetENERGY will be collaborating with the Department of Fisheries and Oceans (DFO) on turbine mortality and delayed downstream mortality studies to evaluate the biological effectiveness of the new fish-friendly turbine designs for use at low-head hydro plants. In addition, CanmetENERGY will continue to support R&D by DFO to improve modeling tools that prescribe environmentally acceptable flow regimes for developments affecting natural flow regimes.

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9 Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee. April 19, 2007, Ottawa.

10 National Hydropower Association 2007 *Hydropower's value recognized in $22 million appropriation in Energy and Water Development Bill.* Press Release, Washington, DC.

11 Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.

12 Ibid. 11

13 International Energy Agency (IEA). 2006. *Renewable Energy R&D Priorities – Insights from IEA Technology Programmes*. Organization for Economic Co-operation and Development (OECD).

14 European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering Work Group of the Thematic Network on Small Hydropower (TN-SHP).

Site assessment
Existing tools and data such as the Canadian Small Hydro Database and RETScreen® are well established and cover the data and pre-screening needed to move forward to pre-feasibility analysis. The focus of this theme will be completion and dissemination of tools already under development that complement existing tools and fill gaps.

These R&D themes were also identified by the IEA as high priority technology needs for small hydropower[15] and were reiterated at a recent Hydro Technical Advisory Committee 2007 meeting in April 2007.[16] NRCan's T&I expert group also rated low-head hydro as a high priority area. [17]

The international low-head hydro and low-impact hydro markets are still open, and Canada has an opportunity to lead cutting-edge R&D research and penetrate those markets. In addition, there are significant synergies between hydropower and ocean energy, and emerging technology innovations can be transferred and make a good proving ground. For example, the NRCan T&I project that created the water current turbine was first funded by the Technology Early Action Measures program for river current demonstrations in the amount of $1M, and it is now funded by Sustainable Technology Development Canada for marine current demonstrations in the amount of $2M.

This R&D work will also be supported by key infrastructure, stakeholder engagement, market analysis and communications products and activities such as the following:

Canadian consortium on hydraulic machines R&D - the consortium led by LAMH, will allow the small hydro subsector to share R&D results with large hydropower developers, enhance development of Canadian expertise in turbine design and independent testing to support the hydropower industry as a whole and enable LAMH to become a fully certified testing facility. Longer-term independence of LAMH through NSERC and industry funding is necessary in order to reduce the impact of federal funding decisions on the operation of the facility.

Expertise capacity - A succession plan is needed for the aging workforce, incorporating strategies such as on-the-job training and links to academic institutions as well as policy targets for developing resource potential and ensuring that the labour market meets expertise needs. The Human Resources and Social Development Canada (HRSDC) Electricity Sector Council has conducted preliminary scoping of expertise issues in the hydropower sector. The Council is now working with the Canadian Electricity Association (CEA) and other collaborators to plan for a detailed analysis and next steps. The Electricity Sector Council also has a renewable skills consultation table.
The Canadian Hydropower Association (CHA) has shown an interest in working with the government on this issue. CanmetENERGY plans to collaborate with the CHA on HRSDC initiatives for the hydropower sector.

Market analysis - CanmetENERGY is planning a study to assess the status of the small and low-head hydro technology market, the expected market penetration and costs for low-head hydro development, and the potential impact and strategies for low-head hydro development in Canada and abroad. Barriers to new technology market penetration and development of new low-head hydropower sites also need to be identified.

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[15] International Energy Agency (IEA). 2006. *Renewable Energy R&D Priorities – Insights from IEA Technology Programmes*. Organization for Economic Co-operation and Development (OECD).
[16] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee, April 19, 2007, Ottawa.
[17] Natural Resources Canada. 2004. T&I Distributed Energy Production Strategic Plan. Brandon, R.

1 Background

1.1 Definition

Small hydro developments are typically “run of river.” In other words, they involve plants that use the flow of the river in a manner that does not appreciably alter existing flows and water levels, unlike dams and reservoirs.[18] These types of developments can bring about environmental and socio-economic benefits through integrated design, multipurpose planning and community involvement. Low-impact hydropower facilities are those that are run-of-river or have been certified by the Environmental Choice Program as renewable low-impact electricity operations under EcoLogo[19] criteria. Low-impact hydropower can range across the entire scale of hydropower developments from small to large-scale plants.

In Canada, there are three recognized small hydro categories:

- Micro- hydro (less than 100 kW),
- Mini-hydro (100 kW –1 MW), and
- Small hydro (1 MW – 50 MW).

Internationally, the upper limit of small hydro varies from 2.5 to 25 MW, but 10 MW is becoming generally accepted.

There are also many undeveloped “low-head” sites in Canada (water level drop less then 15 m) that are run-of-river with potential capacities ranging up to 200 or 300 MW. Emerging technologies applicable to these medium-scale sites are also included in the scope of this R&D strategy.

There is growing interest in “water current”, “kinetic” or “instream” potential in Canada and around the world for power production using ‘zero head’ turbines (water level drop 1 m or less), which require no dams or barrages.

In Canada, many high-head small hydro sites near load centres have already been developed, and most of the remaining potential is located in remote areas. Impacts on aquatic ecosystems are not as significant with high-head sites because the large elevation drop rules out many of these sites for fish habitat. Few low-head sites in Canada have been developed since 1965, and there are many undeveloped sites both near load centres and in remote areas[20]. Water current potential in Canada and internationally is an emerging energy source.

1.2 Description

1.2.1 Small hydro

For a small hydro plant to operate, a sizable flow of water and a proper height of fall of water, called head, must be available without elaborate and expensive facilities. Small hydro plants can be developed at existing dams, and many plants have been constructed in connection with river and lake water-level control and irrigation schemes. When existing structures are used, only minor new civil engineering works are required, reducing the overall cost of site development.

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. The water flows via a channel or penstock to a waterwheel or turbine, where it strikes the bucket of the wheel, causing the shaft of the waterwheel or turbine to rotate. When generating electricity, the rotating shaft, connected to an alternator or generator, converts the motion of the shaft into electrical energy. This electrical energy may be used directly, stored in batteries, or inverted to produce utility-quality electricity.

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[18] Pollution Probe. 2003. *Primer on the Technologies of Renewable Energy*. With support from Industry Canada, Environment Canada, BIOCAP Canada, Ontario Waterpower Association and Investors Group.

[19] An official certification system 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 reusable or provides some other environmental benefit.

[20] Statistics Canada. 1986. Internal database of electric power generating stations.

In the more rugged regions of the country it is possible to develop relatively higher heads without elaborate or expensive civil engineering works so that relatively smaller flows are required to develop the desired power. In such cases, it may be possible to construct a relatively simple diversion structure and obtain the highest drop by diverting flows at the top of a waterfall or steeply falling watercourse.

The power available in a volume of water is a function of the quantity of water or mass (Q) and the height that it can fall (H). A simple way to estimate available power is to use o the following formula:

$$\text{Power } (W) = e.\, p.\, g.\, Q.\, H$$

Where,
- e is efficiency (about 0.8)
- p is the density of water (kg/m^3)
- g is the gravity constant (9.81 m/s^2)
- Q is flow (m^3/sec)
- H is head (m)

Thus, producing one kW at a site with a 10-m head requires ten times the water flow of a site with a 100-m head.

The capacity factor for run-of-river plants is a function of the available stream flow, subject to daily and seasonal fluctuations, and the efficiency of the plant. Thus, it is important to assess the resource availability for particular projects by using flow data at daily and seasonal time scales. On average, small hydro plants in Canada have annual capacity factors in the range of 40-80%.[21, 22]

Electro-mechanical equipment

The hydro turbine size depends largely on the flow of water it has to accommodate. Generating equipment for high-head, low-flow installations is typically less costly than for low-head, high-flow plants.

Hydraulic turbines transform the water's potential energy into mechanical rotational energy by means of one of two mechanisms:

1. Reaction turbines run full of water and, in effect, generate hydrodynamic "lift" forces to propel the runner blades. They include the Francis and Kaplan turbines. Francis turbines are generally used in a head range of 20 to 100 metres, while the Kaplan ones are used for low-heads in the range of 5-20m.
2. Impulse turbines are based on the principle that water pressure is converted into kinetic energy in the form of a high-speed jet that strikes buckets mounted on the periphery of the runner. The runner is designed to reverse the direction of the jet and thereby extract momentum from the water. The most common impulse-type turbine is the Pelton. These turbines are used in high heads (50 to several hundred metres) and "small" discharges.

Small hydro turbine efficiencies have increased over time and are also a function of size. Early turbines achieved efficiencies of 25%; now they approach 95%. Higher efficiencies (over 90%) are achieved with turbines producing several hundred kW or more, whereas the efficiency of a micro-hydro turbine of 10 kW is likely to be in the order of 65-80%. Small capacity low-head turbines (<50 MW) can reach efficiencies over 90%. However, overall costs are a concern, and from practical point of view, compromises sometimes need to be made between efficiency and costs.

Generators convert the mechanical energy into electrical power at high efficiencies of the order of 98-99%. They come in two generic types: synchronous and asynchronous. Synchronous generators typically have a higher efficiency but are more costly. Both of these types of generators are well known in industry and have been steadily improved upon. More recently, permanent magnet generators (PMGs) operating at very low speeds have been entering the market.

Civil works

Civil works components of a project are related much more closely to the local topography and the physical nature of a site, and site-specific costs can vary widely. The main civil works of a typical small hydro development are the diversion dam or weir, the

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[21] A BC Hydro summary of shortlisted hydro projects in 2006 gives capacity factors ranging from 41 to 73%, with an average capacity factor of 47%. Hydro Ottawa plants on the Ottawa River are operating at a capacity factor closer to 80%.

[22] For U.S. sites, typical net capacity factor of 52% was used in a cost estimates study: Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.

water passages and the powerhouse. The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet. The water then passes through the turbine, spinning it with enough force to create electricity in a generator. The water then flows back into the river via a tailrace.[23]

Project planning and development

The development of a small hydro project typically takes two to five years to complete, from conception to final commissioning. This time is required to undertake studies and design work, to receive the necessary approvals, and to construct the project.[24]

Planning small hydro projects requires technical feasibility and economic viability studies and is usually phased as follows:

- Reconnaissance surveys and hydraulic studies assessing multiple sites
- Pre-feasibility study
- Feasibility studies
- System planning, project engineering, and financing

The technical and financial viability of each potential project is very site-specific. Power output depends on the available water (flow) and head (drop in elevation). The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year. The economics of a site depends on the power (capacity) and the energy that a project can produce — whether or not the energy can be sold — and the price paid for the energy[25].

1.2.2 Water current

Water current turbines convert the kinetic energy of moving water at a velocity of 2 m/s or greater into mechanical power and only a very small head is needed (less then 1 m). Turbines are placed directly in the stream, as opposed to hydro schemes where costly civil works are required to divert the water for passage through the hydro turbines. There are also no dams or impoundments involved in water current developments.

Research in the 1980s revolved around the Darrieus vertical-axis hydro turbine funded by NRCan and the National Research Council — technology that was initially developed for wind energy generation. There is significant renewed interest in water current technology, and numerous second-generation turbines being developed and moving very quickly toward the first commercial application. Current Canadian R&D is focused on commercialization of the 5-25-kW Darrieus turbines, which have slowly rotating fish-friendly blades, and demonstrations are showing efficiencies up to 45%. Other R&D involves Canadian applicability of promising international turbine technologies with larger capacities, addressing operational concerns, especially in cold weather climates, as well as safety concerns.

1.3 Benefits and impacts

Energy generation through hydropower is clean and renewable and operating and maintenance costs are low, making it essentially inflation-proof. Hydroelectric stations have a long life, and many existing stations have been in operation for more than half a century and are still operating. Small hydro is especially attractive as an alternative to highly polluting and very costly diesel generation that currently provides electric energy in most remote communities across Canada.

For each MW of additional small hydro capacity installed, it is estimated that 5 kt/y of CO_2 could be displaced from equivalent fossil-fuelled generating plants. If the projected 2,000 MW of small hydro potential are realized, the additional investment required would be of the order of $2.2-$2.7 billion, while the potential CO_2 displaced would be in the order of 9 MT/y, or about 10% of the total CO_2 currently being emitted for electrical generation using fossil fuels. The IEA estimates that, globally, small hydro capacity could increase by as much as 1,000-2,000 MW/y over the next twenty years for a total additional capacity of 20,000-40,000 MW.[26, 27] The total CO_2 reduction would be in the range of 100-200 MT/y.

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[23] Natural Resources Canada. 2004. *Clean Energy Project Analysis: RETScreen® Engineering & Cases Textbook – Small Hydro Project Analysis Chapter*. In collaboration with NASA, UNEP and GEF.
[24] Ibid., 23.
[25] Ibid., 23.
[26] International Energy Agency (IEA). 2004. *Renewables for Power Generation – Status and Prospects*, Paris, France
[27] Navigant Consulting. 2003. *The Changing Face of Renewable Energy* – A Navigant Consulting Multi-Client Study.

Small hydro can have greater environmental and socio-economic benefits through environmental integration and proper multipurpose planning. Most of the negative environmental impacts of hydropower developments can be partially or entirely avoided by a good design and appropriate construction and operating practices. The most common concerns about small hydro projects are the impact of civil works construction on stream flow and aesthetics and prevention of fish movement towards their natural habitat. Fish injury and mortality from passage through turbines can be mitigated through the use of emerging hydropower turbine technology to minimize the adverse effects while preserving the ability to generate electricity. It is important to note that small hydro developments are site-specific, with each plant design having its own unique conditions and requiring appropriate environmental safeguards.

There is also a movement toward integrated design, where the environment is factored in and community involvement plays a key role. An example of the integrated design approach is a project in B.C., developed by Regional Power, Inc., which was awarded the United Nations Blue Planet Prize award. As part of the design framework, the powerhouse and intake were integrated into the landscape and the salmon run was successfully re-established through the creation of a separate spawning channel in partnership with the local Sechelt Indian Band and fisheries authorities.

Small-scale hydroelectric energy is an especially attractive alternative to traditional high-cost diesel generation that currently provides electric energy in most remote communities across Canada. In these communities, the value of power generated for consumption is generally significantly more than for systems that are connected to a central grid. Public electric utilities in Canada are required to provide electricity service to isolated communities. Utilities in several provinces are encouraging private development of abandoned power plants and at existing dams as well as new developments to replace diesel power in remote communities at a significant cost/benefit ratio.[28]

Compared with diesel generation, small-scale hydroelectric developments offer other interesting advantages:[29]

- They use a local resource and therefore produce electricity at a stable price that is not subject to the fluctuations of the international oil market;
- They provide more economic benefits to the region by way of construction employment and use of local services (10% to 25% of capital cost);
- They provide greater opportunities for local residents to learn and upgrade their construction skills;
- They provide an opportunity for wealth creation, especially for First Nations.

[28] Natural Resources Canada, 2006. “Small Hydro Technology Review.” Internal document. Prepared by the Renewable and Electrical Energy Division, NRCan.
[29] Ibid 28

2 Economics

2.1 Market

Renewable energy is now considered an integral part of a new electricity system management strategy designed to increase energy diversification, supply and security. It is recognized that renewable energy technologies are needed for electricity and natural gas load management and peak shaving, rising demand, price volatility, and reduction of GHG emissions. Another major driving force is the increasing cost of generation from fossil fuel-based energy sources, while the cost of hydropower production using emerging hydropower technologies is decreasing. There is also increasing public concern about climate change and air quality issues.

The recent calls for renewable energy RFPs, standard offer programs and net-metering in provinces across Canada have helped to strengthen interest in small hydropower development. In the last few years, Ontario and B.C. have taken the strongest steps to promote programs and incentives to encourage active participation by independent power producers (IPPs) in small hydropower investments. There has been positive policy shift to improving the approval process as well as improving relations with First Nations and including them as active project partners.

Ontario has set a target of 5% (1,350 megawatts) of all generating capacity from renewable sources by 2007, and 10% (2,700 megawatts) by 2010. It has also increased the net-metering eligible capacity from 50 kW to 500 kW. B.C. is introducing a similar standard offer program in 2007.

Nunavut has significant hydro potential that could be economical to develop as the cost of diesel generation increases. The Territory has initiated pre-feasibility studies of hydro potential around Iqaluit and is carrying out a feasibility study to develop hydropower that could significantly reduce dependency on diesel generation in Iqaluit. NWT is carrying out a study on its hydro strategy in order to meet its growing energy needs and reduce GHGs from its diesel generation.

With the new expanded markets opening up under these provincial/territorial programs as well as the advent of "green credits" and "carbon offsets," industry requires assistance mobilizing to meet increased demand and making operational changes to these new markets. In addition, climate change commitments have not yet been framed to help the small hydro subsector. While ad hoc provincial and voluntary industrial greenhouse gas programs were put in place, no concerted effort had been made federally to assign mitigation responsibilities. Doing so would quickly create a market base for the subsector, for example, by placing a value on green credits.[30]

The Canadian small hydro subsector includes more than 20 equipment manufacturers and about 70 engineering firms employing a total of approximately 2,000 people. It also contributes $150 million to the Canadian economy annually through local and overseas projects. Annual addition to generation capacity from small hydro represents an estimated 50-150 MW and $200 million in investments.[31] Canada is a recognized leader in several areas, including the following: low-cost application of control systems using microprocessors; upgrading refurbishment of existing hydro turbines; and development of innovative fish bypass systems. However, Canadian manufacturers of small hydro turbines have declined to the point where there are only a few left in Canada.

With respect to industry representation, there is no specific small hydro association in Canada. The Canadian Hydropower Association (CHA) represents both large and small hydro and ensures that hydropower is recognized, and supported in public policy, as clean, green and renewable both in Canada and on the international front. There are also a number of provincial independent power producer associations as well as provincial hydropower associations.

[30] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee meeting* of March 16, 2006, Ottawa.

[31] Natural Resources Canada, 2006. "Small Hydro Technology Review." Internal document. Prepared by the Renewable and Electrical Energy Division, NRCan.

Water current

Internationally there are over 20 players involved in R&D phase and offering competing designs for water current systems, a number of which are in the demonstration phase. It is expected that the number of successful players will be reduced to 2-5 by 2010, when the technologies are expected to be mature enough for market entry.[32]

2.1.1 Canadian market share

Statistics Canada surveys in 2005 show that the total small hydro capacity in Canada is approximately 3400 MW.[33] Most sites are located in Ontario, Quebec and British Columbia. New capacity is growing at a rate of 50-150 MW/y.[34] At the same time, many older sites have been decommissioned, resulting in a net increase of only a few MW per year.

Many older sites are low-head hydro facilities that were developed at the turn of the century since there were no other competing power sources. Statistics Canada data on low-head hydro capacity in Canada show that there was a total capacity of 1773 MW.[35] The majority of these sites have capacities of less than 50 MW, and 95% of them were built before 1965.

There are three generic markets for small hydro projects within Canada. They include (a) new installations, (b) restoration and refurbishing of existing facilities, and (c) addition of hydropower plants at dams built for flood control, irrigation and drinking water supply. Many of the projects that have been added to Canadian capacity in the last few years belong to the second category, while the additional potential would come under the first and third categories.

Ontario Power Generation has 67 hydroelectric stations throughout the province. About half of these are below 10 MW in capacity and they contribute about 6% of Ontario's power generation. Hydro-Quebec operates fewer smaller stations, relying instead on more large-scale hydroelectric plants. BC Hydro operates all the large hydro plants and a few of the smaller stations in the province. About 30 independent power producers operate the majority of the small hydro plants in B.C. Transalta Utilities operates virtually all the small-scale hydro plants in Alberta (Alberta Power has one small plant in Jasper), contributing about 5% of Alberta's total power generation. Nova Scotia operates about 40 small hydro plants supplying about 11% of provincial capacity. New Brunswick also operates about 40 small hydro plants, which contribute about 20% to provincial capacity.[36]

Table 1: Provincial market breakdown – Small hydro capacity

Province/ Territory	1999	2000	2001	2002	2003	2004	2005
	Capacity MW	Capacity MW	Capacity MW	Capacity MW	Capacity MW	Capacity MW	Capacity MW
AB	194	207	214	215	264	264	264
BC	622	622	623	565	597	703	794
MB	10	10	10	11	11	11	11
NB	90	90	90	90	84	83	85
NL	206	206	209	213	176	216	216
NS	169	169	169	169	174	174	174
NT	60	59	30	30	30	33	32
ON	1003	978	1006	1032	1023	1047	1056
QC	768	769	769	761	761	662	670
SK	25	25	23	23	23	23	23
YT	76	77	76	77	77	77	77
Total	**3224**	**3211**	**3221**	**3187**	**3219**	**3292**	**3401**

Source: Statistics Canada. 2004. Catalogue No. 57-206-XIB.

[32] Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.
[33] Statistics Canada 1996-2004. *Electric Power Generating Stations*. Catalogue 57-202-XIB.
[34] Ibid 33.
[35] Statistics Canada. 1986. Internal database of electric power generating stations.
[36] Statistics Canada. 2004. *Electric Power Generating Stations*. Catalogue 57-202-XIB.

2.1.2 World market share

World total installed capacity of small hydropower was estimated to be about 56,500 MW in 2003 and 61,000 MW in 2004, with a growth rate of 8%.[37] The growth rate for the last four years (2000-2004) has been very stable, averaging 7% per year. Most of the capacity installed has been in developing countries (39,000 MW), and China is the largest market with 34,000 MW. The principal barriers to more extensive worldwide exploitation of small hydro capacity are access to transmission systems and environmental and social concerns.[38]

2.2 Development potential

Overall hydropower potential in Canada is significant, amounting to 163,000 MW, a large portion of which is economically viable.[39] Most economical small hydro sites in Canada have already been developed, mainly near load centres. It is estimated that, with existing state-of-the-art technologies and under current socio-economic conditions, about 15% of the identified small hydro potential of 15,000 MW[40, 41] would be strong candidates for development. In addition, it is thought that another 10-15% of that potential could be available with improved technologies. It should be noted, however, that reducing capital costs by 10-15% would allow an additional 2,000 MW of small hydro potential to be exploited over the medium term, as there would be a higher rate of return.[42] Thus, the practical potential for additional capacity is between 2250 and 4500 MW.

Table 2: Provincial breakdown – Small hydro potential

Province/ Territory	Potential MW
AB	200
BC	3529
MB	309
NB	614
NL	1200
NS	164
NT	106
NU	129
ON	3699
PE	3
QC	4387
SK	575
YT	57
Total	14 970

Source: Canadian Hydropower Association. 2006. *Study of Hydropower Potential in Canada*. Prepared by EEM Inc.
Natural Resources Canada. 2005. *Small Hydro Atlas*. www.small-hydro.com.

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[37] REN21 Renewable Energy Policy Network. 2005. *Renewables 2005 Global Status Report*. Washington, DC: World Watch Institute. The document reports SHP based on individual country report. 50 MW is the upper limit in countries such as China and Canada and 10 MW in other countries.
[38] International Energy Agency (IEA). 2006. *Renewable Energy R&D Priorities – Insights from IEA Technology Programmes*. Organization for Economic Co-operation and Development (OECD).
[39] Canadian Hydropower Association. 2006. *Study of Hydropower Potential in Canada*. Prepared by EEM Inc.
[40] Ibid., 39.
[41] Natural Resources Canada. 2005. *Small Hydro Atlas*. www.small-hydro.com.
[42] The Conference Board of Canada. 2003. *Renewable Energy in Canada.*

There is also significant potential in Canada for low-head hydro, a portion of which could become economical with a reduction in equipment costs. A recent study of hydro potential in Ontario identified over 4000 MW of low-head hydro potential, including some sites with a potential exceeding 50 MW.[43] Outside Ontario, at least 2700 MW of low-head hydro potential have been identified in past studies, which only include sites up to 25 MW.[44] Low-head hydro potential mainly exists in sluice gates, irrigation canals, drinking water pressure release valves, municipal wastewater outfalls and numerous rivers. There are approximately 10,000 existing low-head dams and hydraulic structures for flood control and water supply/irrigation.[45] Significant opportunity exists by adding hydropower generation to these low dams and structures, and the environmental footprint would be minimal. The economically feasible potential is difficult to estimate due to the higher costs of the emerging technology.[46] Remote locations may be a potential near-term market, as the cost of generation in these communities is very high.[47]

The greatest potential for new hydropower is located in British Columbia, where it is estimated that just under half of the total potential could be developed for 7 cents/kWh. The cost for the remaining sites in Canada is higher and would vary from province to province.[48]

Table 3: Estimated deployment of small hydro in Canada by 2050

Year	Installed capacity (<50MW)
Now	3401
2015	4792
2025	6492
2050	7742
	Additional MW
2005 to 2015 180 MW/year	1620
2015 to 2025 170 MW/year	1700
2025 to 2050 50 MW/year	1250

Source: Natural Resources Canada, 2006. Based on aggregate information from communications with various public and private utilities and companies across Canada.

There is also potential for refurbishing many existing sites where maintenance and refurbishment are critical. Now, owing to rapid developments in computerized hydraulic design, it is possible not only to restore older plants but also to improve their performance. There are over 600 small and medium-sized hydropower plants with units installed before 1965[49] that have a refurbishment potential that would yield an estimated increase in total capacity of 1000 MW, assuming an increase in plant production of 15%. Internationally, the European Union has the oldest hydropower plants: almost 45% are over 60 years old and 68% over 40 years old.[50]

The WEC estimates that, under current policies, installed capacity of small hydro will increase to 55 GW by 2010, with the largest increase coming in China. Under the WEC's favourable case scenario, installed capacity will increase to about 75 GW by 2020. All regions of the world are experiencing significant increases in small hydro capacity, with China again showing the largest increase.[51] Statistics specific to low-head are not available.

[43] Hatch Acres. 2005. *Evaluation and Assessment of Ontario's Waterpower Potential*. Hatch Acres, Oakville. 55 pp.
[44] Natural Resources Canada. 2005. *Small Hydro Atlas*. www.small-hydro.com.
[45] Tung, Tony T.P., J. Huang, C. Handler, and G. Ranjitkar. 2007. Better Turbines for Small Hydro. *Hydro Review*, March 2007.
[46] A specific low-head technology and market assessment is needed.
[47] Natural Resources Canada. 2007. *Meeting Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting* of April 19, 2007, Ottawa.
[48] Natural Resources Canada, 2006. S*mall Hydro Technology Review*. Internal document. Prepared by the Renewable and Electrical Energy Division, NRCan.
[49] Statistics Canada. 2004. *Electric Power Generating Stations*. Catalogue 57-202-XI.B
[50] European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering Work Group of the Thematic Network on Small Hydropower (TN-SHP).
[51] World Energy Council, 2004.

Table 4: Estimated deployment of Small hydro by 2010, by region[52]

Region	Capacity (MW)	Production (GWh)
North America	5,500	25,000
Latin America	3,000	10,000
Western Europe	12,600	50,000
CEE and FSU	7,000	28,000
Middle East and Mediterranean	400	1,700
Africa	700	3,000
Pacific	750	3,000
Asia	25,000	100,000
Total	**54,950**	**220,700**

Water current

Water current potential in Canada is largely unknown. Only one Canadian study was conducted on the subject, in the 1980s. It attempted to quantify the potential and was limited to a few major rivers. It identifies those river reaches and tidal areas where "no-head" hydroelectric devices could be placed to extract available kinetic energy.[53]

2.3 Specific costs

In a deregulated electrical generation environment, hydropower offers the prospect of earning longer-term, sustainable returns. A comparison of the yield factors of various types of energy plants suggests that hydropower remains the most valuable form of energy since it provides the highest quantity of energy over its lifetime, as compared to the energy required for manufacture, operation and disposal, including secondary energy.[54] Small hydro also brings environmental benefits and, with indigenous technology, local economic benefits that are not accounted for and would be competitive if governments and utilities priced conventional power at its "true" cost.[55]

The typical investment cost ranges (in $Can) from $2,000 to $5,000[56] per installed kW, with an overall cost of energy of $0.04 to $0.10 per kWh.[57] Internationally, the small hydropower cost of energy is in the range of US$0.02/kWh to US$0.06/kWh; the lowest costs occur in good resource areas.[58]

The turbine itself accounts for 20% (for high head turbines) to 50% (for low-head turbines) of the total cost of a small hydro project (see Fig. 1). Once the high up-front capital costs associated with civil works and equipment are written off, it has very low operating and maintenance costs. Turbines and mechanical equipment typically have a life span of 25 years and can be refurbished; civil works components usually have a longer life span.

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52 World Energy Council, 2004
53 National Research Council. 1980. *Evaluation of the Kinetic Energy of Canadian Rivers and Estuaries.* Produced by the UMA Group for the National Research Council – Canadian Hydraulic Centre.
54 Natural Resources Canada, 2006. *Small Hydro Technology Review*. Internal document. Prepared by the Renewable and Electrical Energy Division, NRCan.
55 Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting.* March 16, 2006, Ottawa.
56 Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.
57 Natural Resources Canada. 2004. Deck on small hydro. Internal document. Prepared by the Renewable Energy Technology Group, NRCan.
58 International Energy Agency (IEA). 2006. *Renewable Energy R&D Priorities – Insights from IEA Technology Programmes*. Organization for Economic Co-operation and Development (OECD).

There is considerable variability in these costs as each project is site-specific. Development is challenged by natural factors such as river flow variation and the remote nature of many sites (requirement for long transmission lines, logistics of remote construction project, etc.). Using current technology, lower-head sites (less than 15-m head) have higher capital costs (Fig. 1). In addition, sites requiring long penstocks or canals, roads or bridges entail significantly higher capital costs.[59] Other factors include a lack of standard purchase contracts and requirements for interconnections with regional and provincial grids, resulting in high project preparation and design costs.[60] Regulatory burdens add significant costs as many small projects cannot support the comprehensive studies and assessments required of large hydro facilities.

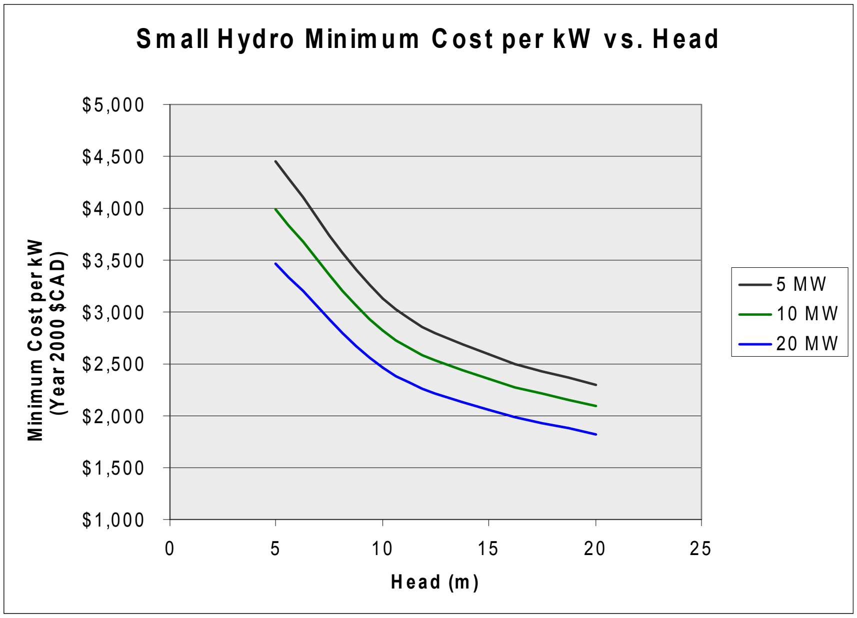

Figure 1

Generation economics for small hydro are attractive, especially for refurbished sites, and can be as low as 4 cents/kWh for the best sites. More complex sites can result in higher generation costs approaching 10 cents/kWh.

Operating costs vary with the particular project and range from 1.5 to 2 cents/kWh. With improvements in automation technologies, there is significant potential for bringing down operating costs.

A summary of the current range and nature of costs associated with small hydro is outlined in Table 4. It is important to remember that

- Generation costs for new plants decrease as installed capacity increases due to economies of scale. There are certain fixed costs associated with all projects that do not significantly change with the size of the project, thus contributing to an increase in the final cost per kilowatt for smaller plants.
- Low-head, high-flow projects are more costly than high-head, low-flow projects. The cost of generating equipment decreases rapidly with increasing head; equipment costs represent a higher percentage of total project cost for a low-head project. Little information on cost ranges exists for low-head hydro as it is an emerging technology.
- About 75% of project development costs are determined by location and site conditions; only about 25% of the costs are relatively fixed.
- Capital costs for projects in remote areas are usually high and can exceed $6000 per kW.

[59] David Suzuki Foundation. 2004. *Smart Generation – Powering Ontario with Renewable Energy*. Vancouver, Canada
[60] Ibid., 59.

Table 5: Distribution of costs in small hydro projects

	Capital Costs $/kW	Percentage to Total Costs	O&M Costs ¢/kWh	Total Generation Costs[61] (¢/kWh)
Civil Works	$900 - $2800	60-70%		
Engineering and Planning	$75 - 400	5-10%		
Generating Equipment	$375 - $1400	25-35%		
Total	**$1500 - $4000**		**1.5 - 2**	**4.3 - 9.5**

Current low-head hydro R&D is expected to produce technological advances that will bring costs down significantly, making many low-head hydro sites economically viable.

The future cost of small hydro plants will remain relatively stable. No new technology breakthroughs are expected, but technical improvements and improved building techniques may reduce costs by an additional 10-15%, likely doubling the potential small hydro capacity that is economically viable.[62]

Water current

Cost estimates for plants ranging from 0.5 to 20 MW are $3000-$10,000/kW for 2007. Costs are expected to decline to $1000-$4000/kW by 2015.[63] Note that O&M costs are difficult to estimate. Some industry representatives use the assumption that kinetic O&M costs are three times that of wind.[64]

[61] Assume 25 years life, 10% discount rate, and an overall efficiency of over 66%, operating for 6000 hrs/y.
[62] The Conference Board of Canada. 2003. *Renewable Energy in Canada*.
[63] Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.
[64] Ibid., 63.

3 Challenges and opportunities

Canada, with its manufacturers, construction companies and operators, is known internationally for its expertise and excellence in the hydroelectric energy field. However, unlike European countries, Canada does not possess a long tradition of R&D on hydraulic machines, and there are no well-established independent testing/research facilities in Canada for both the large and the small hydro industry. NRCan-PERD has been supporting the hydraulic machinery laboratory (LAMH) at Laval University over 10 years to become the only independent hydro turbine-testing laboratory in Canada. The laboratory fills an important gap in Canadian R&D capacity by enabling independent and credible testing of innovative turbine designs within North America. The federal government support of Laval has been critical to the Lab's early development and recent success. However, the hydropower industry in Canada still lacks an equivalent to the Atlantic and Western Wind Test facilities, and there is a general lack of testing, research and training infrastructure across the country.[65] In addition, many R&D projects and innovations have been launched at hydropower sites, and a forum is needed for sharing the resulting expertise.[66]

In Canada and internationally, the perception is that hydropower is a mature technology and has few R&D requirements. As a result, many governments, organizations and businesses have not kept up with new innovations or attracted or allocated new R&D funding. The situation is even more critical for the small and low-head hydro industry as it lacks the capacity to carry out its own in-house R&D, due to the predominantly small company sizes, tough competition and cost pressures. Market forces are such that the developers and independent power producers rely on partnerships with the federal government and academia to conduct R&D. Federal funding is available for emerging renewable energy technologies to assist industry, but there are difficulties accessing money from certain programs since some policy makers do not deem the technologies to be innovative. Similarly, there is a lack of municipal, provincial and utility resources to fill the R&D gap, partly because provincial utilities are procuring power from IPPs, leaving them or their suppliers to conduct R&D.[67] However, some provincial utilities are beginning to work with universities.[68]

The current lack of international R&D in hydropower gives Canada a window of opportunity to become an international leader in emerging hydropower technologies, specifically in the areas of low-head fish-friendly turbine development and other low-head technologies.

Legacy hydro (aging hydro plants) is prevalent, particularly in Eastern North America, where most systems are low-head. For example, Hydro-Québec's rehabilitation investments over the next 10 years will be at least 180M$/year for major generation equipment and 100M$/year for civil works and spillway equipment.[69] The IEA reports that, out of 1469 units (89% capacity of US hydro), 20% of generating units are older than 75 years and 60% are older than the original intended design life.[70] Not all of these are small hydro plants, but they do represent a significant market opportunity.

Another significant issue facing the hydropower industry is the aging workforce; it is estimated that there are only 10 years of expertise left in Canada. Already, there is a shortage of suitably qualified staff to design and operate hydro resources as a result of the lack of university or college courses on hydro. Industry has to rely on staff trained overseas, and this is a depleting resource.[71] Both government and industry need to take an interest and develop momentum to get emerging technologies into universities and encourage student uptake.

There are also many risks associated with small hydro development, with long lead times required for approvals, and schemes can become arbitrarily derailed by opposition during the public participation process. On average, at least 50 permits are required

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[65] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting*, March 16, 2006, Ottawa.
[66] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting. April 19, 2007, Ottawa.
[67] Clarke, Colin, Brookfield Power. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting. April 19, 2007, Ottawa.
[68] Ibid., 66.
[69] Ibid., 65.
[70] International Energy Agency. 2006. The IEA Hydropower Agreement and Insights from Technology Programmes. Presentation to the Hydraulic Energy Technical Advisory Committee, March 16, 2006.
[71] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting. April 19, 2007, Ottawa.

for small hydro developments, depending on the province/territory.[72] Current regulations focus on large-scale hydroelectric issues, imposing disproportionate demands on small developers, and there is a need for a more appropriate regulatory framework that focuses on small-hydro issues. In recent years, the provinces have begun to address some of these issues/barriers, using a more streamlined and sustainable watershed management approach. At the federal level, NRCan has committed to working with provinces on streamlining the waterpower development process.[73] Water current is facing similar issues in terms of licensing and permitting.[74]

On the technical front, the development of emerging hydropower technologies for small and low-head hydro and water current systems face specific challenges from large hydro technologies. Proper technologies involve more than simply downscaling of large hydro equipment and know-how; there are unique technical problems to be addressed in terms of first principles. Small-scale projects face higher generation costs as some of the fixed costs do not change with the scale of the project. Since most economical small hydro sites near load centres have already been developed, the challenge is to develop the many remaining sites that are currently uneconomical. Low-head hydro potential exists near load centres and in more remote areas but is not yet cost-competitive.

For low-head sites, equipment costs are a much larger portion of total project costs, since much larger equipment is required to accommodate larger water volume and slower turbine speeds. This results in an increase in the final cost per kilowatt, especially for smaller plants. The goal is to develop market-oriented technologies that will make low-head hydro a more viable and economically feasible option, allowing substantial exploitation of run-of river low-head hydro potential. R&D focus is needed on the design of highly efficient fish-friendly turbine systems which require less civil works.

R&D on the fish-friendly aspects of turbine development (particularly applicable to low-head and water current turbines) is vital for minimizing environmental impacts from hydropower development and meeting more stringent environmental requirements. R&D is also needed on the improvement of civil works to overcome high construction costs in northern climates, the design of portable micro-hydropower units for off-grid applications and remote communities, and the design of efficient water current turbine systems that will be especially applicable to ocean energy.

The development of improved infrastructure for decision making on natural flow regime alteration is also critical to ensuring sustainable development of hydroelectric resources from an environmental, economic and social acceptance perspective.[75] DFO has made progress has been made on the development of modeling frameworks for improved habitat hydraulic modeling tools as a means of prescribing environmentally acceptable flow regimes for developments that alter natural flow regimes (including hydropower developments). DFO and the Canadian Electricity Association (CEA) are working with the provinces on a consistent national framework for the management of natural flow regimes, but they have not yet come to an agreement. Completion of an Interpretation Bulletin on flow management by DFO-CEA will be an important first step in this regard.[76]

There is also a need to develop tools to help designers evaluate the impact of various options and determine optimum mitigation and compensation measures that would need to be taken to improve acceptability of small and low-head hydro from an environmental as well as economic standpoint.[77]

Analytical tools are also needed for site and resource assessment and environmental optimization and design at the feasibility study stage. Tools may be available, but they are often proprietary, or potential users lack the skills.[78]

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[72] Sjöman, P. 2006. Presentation at the *Micro-hydro Workshop*, Victoria, B.C., March 18, 2006.
[73] Hon. Gary Lunn, Minister of Natural Resources Canada 2006. Speech at the *Forum on Hydropower 2006*. Canadian Hydropower Association (CHA), October 26.
[74] Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.
[75] Department of Fisheries and Oceans (DFO). 2005. Report Submission to the Panel on Energy Research and Development (PERD), Natural Resources Canada.
[76] Department of Fisheries and Oceans (DFO). 2005. Report Submission to the Panel on Energy Research and Development (PERD), Natural Resources Canada.
[77] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting,* March 16, 2006, Ottawa.
[78] Ibid., 77.

Lastly, there is still an opportunity to bring down costs for small hydro an additional 10-15% through technology development, increasing the number of potential sites that are feasible for development. The efficiency of existing and planned small hydro systems can be upgraded through[79]

- improved maintenance, operating and management systems
- O&M decision-making tools by means of enhanced measurement and diagnostics
- new approaches to maintenance and repair
- improved hydraulic, electrical and mechanical equipment
- improved control, protection and surveillance systems

[79] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting,* March 16, 2006, Ottawa.

4 State of industry and R&D

The small hydro subsector is diverse and ill defined. It includes older, established and commercial technology that often must compete in the same financial and regulatory arenas as the technologies of the highly developed large-scale hydro sector.[80] The technologies involved in small hydro projects are both a by-product of the large hydro industry and the result of application of appropriate technology by small manufacturers, organizations and agencies. Perhaps the greatest difference in the technology status of large and small hydro is the large variability of designs, layouts, equipment types and material types used. It can be said that there is no "state of the art" but rather a huge body of knowledge and experience in designing and building projects to fit the site and resources of the developer.[81]

The hydropower industry has existed for over 100 years. Many older plants are smaller-scale, are running inefficiently, or have been shut down for economic or environmental reasons. Other small hydro plants were shut down as a result of the central grid expansion. There is an urgent need for simple, efficient, low-impact, low-cost technologies for both existing and new small and low-head hydro plants.

The small hydro subsector offers flexible, innovative approaches to hydraulic generation; however, utilities are often unable to relate to these innovations. Their mindsets (and RFPs) are structured around design and delivery concepts relating to large-scale hydro, an area in which SMEs cannot compete because of the overhead required.[82] Much of the hydropower research is financed with public funds in partnership with major equipment manufacturers. Research costs are high, many of the research funds target larger hydro, and small hydro R&D tends to be overlooked as the power generated is limited. In addition, there is a perception that large hydro concepts can be modified for small and low-head hydro application, but this is only true to some extent.

There are several codes and standards that cover hydropower installation, commissioning and operation. The most widely used and accepted international standards are those of the International Electro-mechanical Commission (IEC) and the Institute for Electrical and Electronics engineering (IEEE). Both are used by Canadian utilities and the Canadian hydropower industry. Standards are essential quality control tools to ensure that the supplier delivers the highest quality product as specified. They are used as technical guidelines for utilities as well as manufacturers who supply and install hydro turbines and other related equipment.

The IEC and IEEE standards cover design, manufacturing and rehabilitation, commissioning, testing and operation of hydraulic machines including turbines, storage pumps and pump-as-turbines and related equipment. Standards are continually updated and revised to reflect changes in technology and practice and to meet new regulation requirements. Specific technical committees are struck to develop or revise standards, and international experts engage in an extensive process of reviewing and working toward an agreement on them.

4.1 Electromechanical equipment, control and monitoring

Mechanical equipment accounts for a large portion of the total cost of small hydro, especially for low-head hydro projects. Major mechanical equipment suppliers for large hydro power plants can afford sufficient capital to develop efficient techniques and methods to stay competitive. Substantial funds are invested in research, testing, tools and methodologies; however, this is not made public. Their subsidiary companies specializing in small hydro can benefit from the knowledge and results, but SMEs in the small hydro subsector generally do not have access to such resources

Major mechanical equipment manufacturers have conducted R&D and developed a specific range of small and low-head hydro products by standardizing the design and manufacturing procedure:

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[80] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee meeting.* March 16, 2006, Ottawa.
[81] International Energy Agency Renewable Energy Working Party (REWP) and Renewable Energy and Hydrogen Implementing Agreements. 2005. Joint seminar discussion paper - *Catching Up: Priorities for Augmented Renewable Energy R&D*, March 3, 2005.
[82] Ibid., 81.

- VA Tech Hydro has developed modular designs that consist of building complete units by using mechanical assembly of standardized components. Some of its standardized turbines are outlined below:

    - Hydromatrix turbine - a low-cost solution for existing low-head dams (heads 3 m to 30 m) and weir structures built for irrigation or navigation purposes, with no need for additional civil works and with no adverse effect on the primary purpose of the structures. The compact turbine-generator module includes trash racks, draft tubes, electric switchgears and control systems;

    - StrafloMatrix turbine - uses an integrated turbine runner-generator rotor design, where the outer edge of the turbine blade supports the generator rotor. This configuration significantly reduces the physical dimensions required and is applicable where space is limited;

    - Ecobulb turbine - for head ranges from 2 to 15 m covering output power from 500 kW to 5 MW. Using a high number of poles, its permanent magnet-based generator makes it possible to eliminate the gearbox, reduce bulb size and simplify mechanical elements. http://www.andritz.com

- Alstom Power Hydro has used the modular standardization approach to develop turbines for a variety of configurations. A large number of the small hydro turbines developed by Alstom have been installed in the last ten years, including Francis turbines, Pelton turbines, and S-type and Pit Kaplan turbines. Alstom uses a standardized distributor design for Francis turbines and the drawings are simply parameterized to fit the runner size; for Pelton turbines, standardized designs for turbine and injector are developed with drawings parameterized to fit the runner size; for S-type and Pit Kaplan turbines, fully standardized runners and distributors common to all configurations are used. http://www.hydro.power.alstom.com/home/

Standardization is one of the two development directions that can be taken in order to achieve high performance, reliability, short delivery time and low investment cost. However, site conditions vary greatly and, in order for standardized equipment to fit the majority of sites, a broader range of mechanical equipment, especially turbines, must to be developed. The other direction is customized design according to site conditions, which requires special solutions and equipment. Small and low-head turbine designers and manufacturers urgently need support to increase R&D research capability.

With only limited applied R&D, a few Canadian small and low-head hydro mechanical equipment manufacturers, including Norcan Hydraulic Turbines Inc. and Canadian Hydro Components Ltd., have been able to provide high-quality and affordable turbine products and gain a significant market share. However, more R&D and support are essential for the Canadian small and low-head hydro manufacturers to develop a broader range of products and become more competitive internationally.

Electrical equipment, control and monitoring represent a relatively low percentage of the total project cost; however, they do play a major role in ensuring the long-term reliability of the power plant. Major multinational companies carry out R&D and manufacture electrical equipment for the hydropower market. Specifically in control and monitoring, smaller companies have been able to compete and provide equipment at competitive costs for small hydro projects. They include Powerbase Automation Systems, Rapid-eau Technologies, Mavel A.S., Cink, L&S Electric of Canada and HydroLink.

Water current[83]

Water current technologies are in a similar position to the one that wind technologies were in 10 years ago. R&D is needed to optimize trade-offs between aspects such blade size, low-speed generators, gearboxes, power converters and control. R&D is also needed to reduce the cost of deployment and installation (for foundations) as well as of environmental controls and mitigation.

4.1.1 Turbines[84]

The turbine accounts for 20% to 50% of the total cost of small and low-head projects respectively. Therefore reducing turbine design and manufacturing costs is the main economic objective in the market. This can be achieved by standardizing design and manufacturing procedures. However, in some cases, custom design according to specific site data is needed to secure higher efficiency and reliability expectations. Solutions for achieving optimized turbine efficiency, lower manufacturing costs and setting up various systematization procedures must also be validated through laboratory tests. This is only possible if supported by the public sector, performed by neutral organizations.

[83] Navigant Consulting. 2007. *Renewable Energy: Costs, Performance and Markets – An Outlook to 2015.* Prepared for CEA Technologies, June 22, 2007.

[84] Swiderski Engineering Inc. 2006. *Strategy for Research and Technological Development in Small Hydro Power-Mechanical Aspect of Small Water Turbines.* Prepared for Natural Resources Canada.

Turbine manufacturers have only limited resources and infrastructure to carry out R&D.
To remain competitive, small hydro turbine manufacturers typically sell equipment with a very low overhead cost, leaving little, if any, profit margin to invest in R&D or to acquire modern designs and manufacturing techniques. These manufacturers usually have small teams that lack infrastructure, facilities, funding, appropriate expertise and other resources to carry out R&D activities, and their applied R&D work is therefore limited to improving a handful of products.

There is a lack of external support from universities and research centres.
It is not common practice to cooperate with scientific centres during a normal site design process. Their expertise is usually called for only after a serious failure. The small hydro subsector is driven by notoriously low budgets and very tight schedules, which is a major obstacle in communicating and establishing working relationship with universities and research centres. The high costs of laboratory studies by such institutions are incompatible with the size and turnover of small hydro projects. Cooperation with large industrial groups and large hydro power plants capable of financing these activities is possible, but the R&D should be performed by neutral organizations.

Computational fluid dynamics (CFD) and structural/stress analysis are emerging technologies of benefit to the hydropower industry.
They are becoming more and more useful in large hydro for hydraulic and mechanical designs of new turbines as well as for checking existing turbine performance or turbine characteristics; CFD and structural/stress analysis tools are considered to be virtual laboratory environments, complementing turbine laboratory testing and at the same time reducing dependency on costly laboratory tests. A few consulting companies and engineering firms provide these services to small and low-head hydro turbine manufacturers, but generally at a cost that is prohibitive for small developers.

Technical issues

Mechanical design follows solutions from large hydro.
Small hydro mechanical designs follow solutions from the large hydro field. Solutions for large power plant designs are normally created with the help of scaled models and laboratory tests, and the newest techniques and research methods may be adapted partially by small hydro. While hydraulic designs implemented in large hydro projects are easily scalable to the small hydro range, mechanical designs are much more difficult for adapt by means of scaling. For small-hydro, it is often necessary to reduce the complexity of mechanical structures. In addition, the interactions between changed components make predictability of transmitted loads much more complex.

Conventional methods are still used but are constantly under development to simplify design.
Conventional methods have been used since the 1950s and are constantly being developed to simplify turbine designs. These methods, published in engineering textbooks and manuals, are based on many assumptions that to a large degree simplify mechanical models. They are used only for solvability reasons.

Sophisticated mechanical structure/vibration analyses are prohibitively expensive.
Generally higher natural frequencies of all components are encountered in small hydro due to increased relative rigidity, since essentially the same materials are used to build smaller-scale structures. In mechanical structures of small hydro-generating equipment, this is a mostly positive phenomenon. However, vibrations, which result from interferences of coherent vibrations, are practically non-predictable. Comprehensive vibration analysis must be conducted in situations where new materials are implemented, but the high costs do not allow small hydro to perform this kind of analysis.

Design safety factors are only very roughly estimated.
Design safety factors are often estimated very roughly as the loads are not well known and model tests, fluid and structural modeling are not commonly used for small hydro. In an effort to achieve the desired degree of simplicity in the mechanical models used, design practice safety factors are usually overestimated.

Research and development areas

On-site turbine performance
On-site performance testing is very costly: it can range from $20,000 to $100,000, which is beyond the reach of most small operators. There is currently no economical test methodology to verify installed unit performance characteristics for small power stations, especially low-head stations, or to ascertain wear and make adjustment-related performance determinations. CanmetENERGY is investigating the development of cost effective test equipment: the new test procedures would reduce set-up time, data analysis and reporting, bring the cost range down to $10,000-$20,000, and demonstrate to the hydroelectric power producers the benefits of investing in knowledge acquisition to operate efficiently, utilize the water resources efficiently and

improve power production from the same water resource amounts.[85] Flow measurement is one of the key parameters for accurate measurement of site performance, which the test system is expected to control within a 2% margin of error.

Medium- to-high-head turbine R&D
Both the large and the small hydro industries have developed significant expertise in design and manufacture of convectional turbines for the medium-to-high-head turbine range such as the Pelton, Francis, Kaplan and Propeller turbines. Numerous R&D activities have been carried out to improve their performance, power production and reliability, and to reduce the overall costs. CanmetENERGY and Laval University have jointly developed a medium-head axial flow turbine with a simple and reliable design that is very cost-effective. CanmetENERGY has also provided funding for Dependable Turbines Ltd. to develop a dual-vane Francis turbine that does not need the costly conventional flow regulation system.

Low-head turbine R&D
High R&D priority areas are hydraulic issues, environmental impacts and operational issues. CanmetENERGY is supporting the development of a low-head fish-friendly turbine that will use a large turbine runner to reduce expensive civil structures, thus lowering the required civil costs and overall project costs significantly. Fish-friendly features have also been incorporated into the design, as have variable-speed technologies, which allow turbine units to run more efficiently for a broader operation range of flow and heads than conventional turbines.

Water current turbine R&D
Various water current turbines such as the Darrieus ("egg-beater") turbine (tested by NRC and CanmetENERGY between 1982 and 1987), the horizontal-axis propeller turbine, the open-centre turbine and Gorlov's helical turbine have been investigated in the past. They avoid the cost of building dams, but many more turbines of these types are required at a facility than is the case with the conventional barrage method. Several companies are currently engaged in developing water current turbines to harness tidal current and river current energy in Europe, the U.S. and Canada. However, no commercial system is operating to date. CanmetENERGY is evaluating the most promising water current turbine technology for river current applications and is developing a smaller system for remote residential communities that are not connected to the local grid.

Other R&D
There are approximately 10,000 existing low-head dams and hydraulic structures for flood control and water supply/irrigation. Significant opportunity exists by adding hydro plants at these low dams and structures, and the environmental footprint would be minimal.[86] R&D is needed to develop innovative turbines that can be easily adapted to existing facilities/structures.

4.1.2 Electrical components

Electrical equipment and components represent a relatively low percentage of total project costs; however, they do play a major role in ensuring the long-term reliability of a power plant. Large multinational companies carry out R&D and manufacture electrical equipment for the hydropower market. However, in the field of control and monitoring, smaller companies have been able to compete and provide small hydro equipment at competitive costs, including Powerbase Automation Systems, Rapid-eau Technologies, Mavel A.S., Cink, L&S Electric of Canada and HydroLink.

Generator
Generators are a well-established technology with an excellent performance track record. They are the heart of any electrical power-generating plant. The cost of a generator is more or less inversely proportional to the speed: the lower the speed, the larger the frame size needs to be for equivalent power. In order to match the speed of the generator to the low speed of the turbine, speed increasers such as a belt or gearbox are normally required.

Low-head sites have very low turbine speeds, and there is growing interest in low-speed direct-drive generators that eliminate the need for gearboxes, resulting in lower costs, improved efficiency and greater reliability. The emerging designs are based on permanent magnet generators with a high number of poles that are able to operate at very low speeds and at variable speeds. The wind industry has been investing significantly in the development of low-speed generators, and the techniques and designs would be suitable for low-head plants as well.

There is also growing interest in the possibility of operating turbines at variable speeds, for changes in flow and head conditions. This option allows for a simpler turbine design and improved operating efficiency, thereby lowering initial project costs while also providing operational flexibility, especially for low-head sites. However, electrical power must be supplied at a constant voltage and frequency, so an electronic power converter to convert grid voltage and frequency from variable-speed generation would be required. Power converter technology developed for the wind industry is being investigated for adaptation to hydro

[85] Tung, Tony T.P., J. Huang, C. Handler, and G. Ranjitkar. 2007. Better Turbines for Small Hydro. *Hydro Review*, March 2007.
[86] Ibid., 84.

applications. However, the additional cost of power converters and losses within the converters need to be considered and evaluated.

Control and monitoring

The trend toward privatization and opening up of the electricity market has meant that greater demands are being placed on monitoring and control systems. Plants have become more complex with the need for greater reliability and fast response to changing conditions. The general engineering approach to control and monitoring of large hydro plants is not economical for small hydro control requirements. Simplicity of control, reliability and low cost are the main objectives. Control and monitoring requirements are based upon the complexity and size of the installation and must be met without compromising unit dependability, grid stability and personnel safety. Sophistication of controls will vary depending on the site.

Control logic systems designed for small-scale plants are provided by hardwired relay logic, programmable controllers, microcomputer-based systems, or a combination of these tools. The unit control system must be designed to provide start-up and shut-down sequencing under both normal and abnormal conditions. Under normal conditions, the unit is started and stopped in a manner that causes minimal disturbance to the system. The industry trend is toward water-to-wire, low-cost, modular approaches involving powerhouse automation systems unique to small hydro. Module-based standardized products have helped to lower costs and improve performance, thus enhancing remote control and automation of small hydro plants. Typical protection and control devices use generic programmable logic controllers (PLCs) or combine control components from several manufacturers. Both approaches require considerable system integration and generate hardware/software engineering costs; the cost of developing the software for a PLC-based system often exceeds the costs of the actual control unit.

Speed governors are used to regulate water flowing into the turbine: adjustments must be made continuously to meet the changes in power demand and water use regulation requirements for the plant. Traditional hydraulic-based governors are being replaced with compact digital governors that are less expensive and offer better response, stable control and additional protection features.

It is crucial to continue invest in R&D to develop standardised equipment to meet the growing requirement for a stable interconnected grid and to improve automation in small hydro plants.

4.1.3 Micro-hydro

The majority of micro-hydro systems are run-of-river with no need for a dam or reservoir as only a fraction of the available stream flow at a given time is normally diverted for power generation. Micro-hydropower development is a complex process and technical expertise is essential during the design and construction phases. The major barriers to uptake of this technology are the high up-front costs for civil works and equipment, the technical expertise requirement for design and construction, and the lengthy approval process.

Canada has established itself as a world leader in micro-hydro technologies and products. CanmetENERGY support for the development of micro-hydro standalone systems for control and load governing, low-cost induction generating systems and simpler turbines have resulted in sales of thousands of systems over the last 20 years, with 80% of the products being sold overseas. The niche market activities in Canada involve supplying electrical power to remote communities where grid extension is too costly or impractical and replacing diesel generation.

Small hydro and micro-hydro are attractive renewable energy sources for remote communities looking to reduce the high cost of energy production and to reduce GHG emissions. In some cases, however, these options are being overlooked, and there is a little support to encourage this sector. Further R&D and policy support is needed to refine and standardize these products so that they can be mass-produced and the amount of testing required for individual projects is reduced.

4.2 Civil works and engineering[87]

The civil works component usually accounts for a major portion of costs for both large and small hydropower projects. In general, there is no R&D on new civil works approaches geared toward small hydro plants because of the highly competitive nature of the construction industry and the resulting lack of available resources for R&D efforts. In addition, there are no construction companies providing civil engineering services specifically for small hydro plants.

[87] Ottawa Engineering Ltd., 2006. *Status of Small-hydro Civil Works Research and Development in Canada*. Prepared for Natural Resources Canada.

Innovation in the design and construction of small-hydro civil works occurs to a certain extent as part of the normal competitive project implementation process. In order to make small hydro projects feasible and/or win development contracts, consultants and contractors search for cost-reducing designs and construction methods and/or materials.

For larger plant designs, R&D is conducted on an individual plant basis. Calculations and tests for the main hydraulic structures are performed in laboratories, using scaled-down physical models of intake systems, weirs and dams. Most of these laboratories are located in universities; major utilities have their own R&D facilities, and there are some specialized laboratories that provide such services.

As the most feasible small-hydro sites become developed, pressure will increase to find lower-cost solutions for the required civil works structures for the remaining undeveloped sites. This will be particularly true for smaller projects where margins are especially tight, such as low-head, high-flow sites with potentially adverse hydraulic conditions. The development of standardized/systemized hydraulic structures would aid in reducing design and construction costs.

However, innovation without adequate R&D can lead to costly errors. Undersized structures can fail, and improperly designed hydraulic structures can significantly reduce energy production through unforeseen head losses and/or unsteady flow. Cost reduction drives ad hoc R&D in the course of project implementation, yet ongoing R&D is essential for improving the reliability of civil works.

There is a growing interest in developing hydro potential in Northern Canada because of global warming and the cost of fossil fuels. The cost of developing hydro is very high because the harsh, cold environment increases the cost of civil works and other related structures including the transmission/distribution network. A major challenge is to reduce costs of civil works through innovative design and construction methodology.

Over the last 20 years in the field of small-hydro engineering currently very little R&D is being done by private industry on small-hydro civil works.

4.2.1 Intake

Sediments and floating debris in water intakes are major problems in both larger and smaller plants. In order to reduce costs, a number of companies have developed intakes that are simpler and self-cleaning, such as the Coanda and Tyrol self-cleaning water intakes. A compressed air system has also been developed to keep trash and frazil ice away from trash racks; it has been installed at three small-hydro plants and is operating smoothly. Further R&D could be done to develop systems that lift trash and ice before they reach the racks, like the system described in Creager and Justin's *Hydroelectric Handbook* for large hydro.[88] For high head intakes, there is a need to develop more efficient desilters.[89]

4.2.2 Forebay

Irregular flow patterns in the forebay can dramatically impact the energy production of power plants with multiple units. R&D could involve CFD analysis of forebay and intake hydraulics of existing low-head sites, i.e., case studies to develop guidelines for appropriate designs to limit head losses. This approach could also be extended to other water passage structures (bends, elbows and tailrace).[90]

4.2.3 Low-head dams and weirs

A low dam or diversion weir of the simplest construction is normally used in the development of a small hydro project. Construction can be of concrete, wood, masonry or a combination of these materials. Considerable effort continues to be spent to lower the cost of dams and weirs for small hydro projects, as the cost of this item alone frequently renders a project not financially viable.[91]

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88 Ottawa Engineering Ltd., 2006. *Status of Small-hydro Civil Works Research and Development in Canada*. Prepared for Natural Resources Canada.

89 MHyLab (Switzerland). 2006. Presentation by Vincent Denis at *Research, Development and Innovation in Small Hydropower: Opportunities and Challenges*, Crieff, Scotland, June 2006.

90 Ibid., 88.

91 Natural Resources Canada. 2004. *Clean Energy Project Analysis: RETScreen® Engineering & Cases Textbook – Small Hydro Project analysis Chapter*. In collaboration with NASA, UNEP and GEF.

Development of small dams that could be constructed from local or easily transported materials would reduce costs for remote sites. R&D efforts could include identifying appropriate construction materials and techniques and developing guidelines for selecting and constructing small dams at remote locations.[92] There is also a need to find new maintenance, repair and overhaul methods for alternatives to conventional cofferdams. Head enhancement techniques for very low heads should be explored as well.[93]

R&D should also be conducted to gain a better understanding of the resistance to overtopping of timber crib dams and the manner of breaching in the event of timber crib dam failure. Currently, no method exists for determining the hydrodynamic force of water flowing across the crest of a timber crib structure. Typically, a timber crib spillway is assumed to be strong enough to resist a head of 1.0 m of overtopping flow. R&D efforts could include the following:[94]

- Research to determine forces associated with increasing flow capacity (raising head of overtopping flow) and development of guidelines for the design of the required crest planking to resist the forces – e.g., if there is a requirement to raise the head to 1.5 m to increase spillway flow capacity, how does one determine these forces and satisfy oneself that the crest planking is strong enough?
- Research into the effect of ice loads or boat impact (if structure is part of a dock) to determine how resistance/strength should be calculated and how much deformation can be tolerated before the structure fails.

4.2.3 Penstock

Penstock construction is dangerous, difficult and costly. Work on directionally drilled penstock tunnels has been successfully undertaken in Norway. If the process proves to be competitive, design and construction guidelines could be developed.[95]

Appropriate design of steel penstocks without anchor blocks for small hydro sites would also reduce construction costs. R&D is needed to understand stresses and make progress toward optimum penstock design. In addition, understanding the mechanical strength of field butt welds with some flaws may reduce the need for expensive X-ray testing of steel penstocks. R&D could involve destructive testing and analysis of a variety of steel welds of various qualities to assess the risks involved in avoiding X-ray testing of penstock welds.[96]

4.2.4 Powerhouse

There are significant civil costs associated with the forming of irregular shapes in powerhouses (they are often formed with very traditional methods). R&D on alternative concrete forming materials combined with CAD would reduce forming costs of some elements such as water passage intakes and transition files. R&D efforts could include investigating alternative materials for forming (plastic, etc.) and the integration of CAD data into onsite forming to reduce construction costs. There have been instances where contractors built formwork similar to the ribs/frames of a ship using full-scale CAD files to create the "frames."[97]

4.3 Eco-engineering and environmental integration

The most common environmental concerns with run-of-river developments are the impacts of river diversions and reduction in natural discharge on aquatic habitat, obstacles created by weir and intake structures that prevent fish movement towards their natural habitat, and fish injury and mortality caused by passage through turbine chambers. The major concerns for water current mainly revolve around the fact that the device itself is installed directly in the river; there are no river diversions in water current developments.

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92 Ottawa Engineering Ltd., 2006. Communication with Rapid-Eau Technologies Inc. *Status of Small-hydro Civil Works Research and Development in Canada*. Prepared for Natural Resources Canada.

93 Ibid., 89.

94 Ottawa Engineering Ltd., 2006. Communication with Philip Helwig, P. Eng., 2006. *Status of Small-hydro Civil Works Research and Development in Canada*. Prepared for Natural Resources Canada.

95 Norwegian Water Resources and Energy Directorate (NVE). 2006. Presentation by Erik Juliussen at *Research, Development and Innovation in Small Hydropower: Opportunities and Challenges,* Crieff, Scotland, June 2006.

96 Ottawa Engineering Ltd., 2006. Communication with PO Sjöman Hydrotech Consulting, 2006. *Status of Small-hydro Civil Works Research and Development in Canada*. Prepared for Natural Resources Canada.

97 Ottawa Engineering Ltd., 2006. Communication with IBI Group, 2006. *Status of Small-hydro Civil Works Research and Development in Canada*. Prepared for Natural Resources Canada.

The total life-cycle emissions for small hydro plants are an order of magnitude lower than the direct emissions of a new coal station with flue gas desulphurization.[98] There are only emissions involved with the manufacturing of the generation and transmission equipment and construction materials for civil works.[99]

There is a movement towards eco-engineering and integrated design where the environment and local community are involved in design. Rather than viewing the development as having a negative impact that must be mitigated, the environment plays a key role in the design process.[100] Social acceptance, while not a technical issue, has a significant impact on the development of a project if there is great opposition. Steps taken to include the community in project design and development have lasting benefits to both the owner and the local community.

The Sechelt Creek generating Station in B.C., owned by Regional Power Inc., won the UNESCO Blue Planet prize award for a number of eco-engineering design features and community involvement. A key component of the project was the incorporation of a salmon spawning channel through sediment removal and replacement with native gravels, and fed from clean, regulated tailrace water. As a result, the salmon run was successfully re-established through the creation of a separate spawning channel in partnership with the local Sechelt Indian Band and fisheries authorities.[101]

There are no suppliers providing small hydro plants with specific solutions to environmental problems. Several engineering companies have experience with large hydropower projects, but the technology and their expertise are not directly applicable to small hydro as the costs of such measures are too high for smaller developments.

4.3.1 Instream flow requirements

Residual flow, or instream flow, is a certain amount of flow that must be left in the river throughout the year for environmental reasons.[102] This is a significant issue for the hydropower industry and the current environmental legislation that determines the minimum average flow that must be flowing in the river at all times has made potential projects unattractive.[103] In addition, industry often bears the cost of funding impact studies.

Improved infrastructure for decision making on natural flow regime alteration is critical to ensuring sustainable development of our hydroelectric resources from an environmental, economic and social acceptance vantage point.[104] The industry needs a streamlined and uniform process for regulatory permitting, while ensuring that fish are protected. The *Fisheries Act* limits Department of Fisheries and Oceans to a certain extent. On the regulation side, DFO is currently working with the provinces and the CEA, and it anticipates a two-year horizon for change.[105]

A new paradigm of thinking for flow is needed and there is also a need to compare the overall picture of climate change impacts on fish and the need for clean energy with hydro development and its impacts on fish. A hydro-perspective evaluation of the numerous methodologies for in-stream flow requirements would also be valuable to the hydropower industry.[106]

NRCan-PERD is supporting DFO on R&D related to biological criteria and winter and ice conditions as well as the development of a national, comprehensive framework for assessment of flow-related alterations on fish and fish habitat. In addition, DFO's fish passage research has provided important biological guidance for improving fish passage technologies.

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[98] European Commission, DGXII, Science, Research and Development. 1995. JOULE Externalities of Energy Project, Vol. 2. *Coal and Lignite*, EUR 16522.
[99] International Energy Agency (IEA) - ETSU 1997. *Renewables in Power Generation: Towards a Better Environment*, AEAT-2211.
[100] European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering Work Group of the Thematic Network on Small Hydropower (TN-SHP).
[101] Regional Power Ltd. 2007 www.regionalpower.com.
[102] Natural Resources Canada. 2004. *Clean Energy Project Analysis: RETScreen® Engineering & Cases Textbook – Small Hydro Project Analysis Chapter*. In collaboration with NASA, UNEP and GEF.
[103] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting.* March 16, 2006, Ottawa.
[104] Department of Fisheries and Oceans (DFO). 2005. Report Submission to the Panel on Energy Research and Development (PERD), Natural Resources Canada.
[105] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting, April 19, 2007, Ottawa.
[106] Ibid., 103.

4.3.2 Water quality improvement and mitigation

Small hydro development can impact water quality in a number of areas. Aeration of water flowing through the turbine may increase oxygen content, improving water quality (e.g. with high-head cross-flow turbines). Retrofit of existing dams may reduce the level of dissolved gasses downstream that exert a negative impact on aquatic ecosystems. This can be mitigated by releasing some or all flow during summer low-flow periods.[107]

Nitrogen super-saturation can cause gas bubble disease in fish and can be an issue with high-head plants. It occurs when nitrogen is diffused into the diverted water from air bubbles in the high-pressure penstock and becomes super-saturated at the tailrace under normal atmospheric pressures. However, good design practices can minimize these impacts. [108]

Changes in the level of suspended solids in the river can affect siltation, erosion, visual aspects and aquatic ecosystems. Impoundments tend to accumulate sediments, while discharge water may contain little sediment. Even without impoundments, alteration of natural flow affects sediment erosion and deposition patterns, impacting aquatic ecosystems and particularly affecting spawning areas. Again, suitable design can minimize these impacts. [109]

Site operation involves use of lubricants and cleaning products that can pollute waters. Research on new materials and components to eliminate use of polluting lubricants and development of biodegradable lubricants is underway.

4.3.3 Fish migration

Despite the availability of spillways and by-pass systems at hydroelectric projects, many fish continue to pass through turbine chambers. Survival rates for fish passing through turbines depend largely on the hydropower plant as well as the characteristics of the fish species. A report from the U.S. Department of the Environment (DOE) states that "some small turbines designed for high-head installations probably cause complete mortality."[110] For turbines in larger water passages, survival rates are typically greater than 70%. In the U.S., R&D targets are to develop turbine passage at a 98% survival rates, a similar to other downstream passage routes.[111]

Canada and France are at the leading edge in R&D on fish-friendly turbine technology, which was originally pioneered in the U.S. CanmetENERGY is working with France on improving the overall survivability of fish passage through turbines while maintaining the ability to generate electricity.[112] CanmetENERGY is also supporting the development of the Darrieus vertical-axis water current hydro turbine, which is fish-friendly.

Natural pool passes are now becoming more prevalent in Europe and have been used in a number of projects in Canada. They are efficient in providing upstream and downstream migration and provide spawning grounds and habitat for young fish. [113]

4.3.4 Other civil works and site construction

The impacts from construction are similar to any civil works projects of this scale and typically last up to a year. Construction can also have the socio-economic benefit of increased employment when local industry and materials are used where possible. The benefit is often significant in remote communities. Low-head schemes typically require greater quantities of materials and construction materials than high-head schemes by an order of magnitude. Overall the impacts are short-term, and most ecosystems recover quickly. [114]

The main impacts of civil works and some mitigation practices are as follows:[115]

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[107] International Energy Agency (IEA) - ETSU 1997. *Renewables in Power Generation: Towards a Better Environment*, AEAT-2211.
[108] ORNL/RfF. 1994. *Estimating Externalities of Hydro Fuel Cycle*. US-EC Fuel Cycle Study, Oak Ridge National Laboratory, Tennessee, U.S.A. Report 6.
[109] Ibid., 107.
[110] U.S. Department of Energy. 2000. *Hydropower R&D: Recent Advances in Turbine Passage Technology*. Glenn F. Čada, Environmental Sciences Division, Oak Ridge National Laboratory Oak Ridge, Tennessee and Ben N. Rinehart Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho, DOE/ID-10753.
[111] Ibid., 110.
[112] Tung, Tony T.P., J. Huang, C. Handler, and G. Ranjitkar. 2007. Better Turbines for Small Hydro. *Hydro Review*, March 2007. .
[113] European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering Work Group of the Thematic Network on Small Hydropower (TN-SHP).
[114] International Energy Agency (IEA) - ETSU 1997. *Renewables in Power Generation: Towards a Better Environment*, AEAT-2211.
[115] Ibid 114.

- Some sites have small impoundment reservoirs (with less then 48 hours of storage) and may impact agriculture, local infrastructure and archaeological and cultural sites. They may also alter the local water table and ecosystem; however, non-sensitive species usually adjust within six months.
- Construction of low-head dams and weirs can be phased in so as to avoid the spawning season of fish.
- Pipe-laying activities can impact terrestrial ecosystems and should avoid sensitive areas.

Waterways of low-head sites are more challenging for environmentally friendly design due to their larger size and flow volumes. A few techniques that are being used, such as design of headrace and tailrace channels, serve ecological functions and bioengineering practices.[116]

Bioengineering is now more frequently used as an environmentally friendly mitigation procedure to address visual and mechanical effects of a site. This involves techniques such as naturalizing embankments and consolidating slopes. Little R&D has been done on the effectiveness and reliability of these techniques. In addition, cost reduction and assurance of reliability is needed in comparison to traditional methods in order to increase usage of such techniques.[117]

4.3.5 Aesthetic impacts and recreation

Small hydro plants can result in both advantages and disadvantages for recreational activities. Examples of disadvantages include aesthetic impacts on wilderness value, reduction in current affecting water sport, and noise levels affecting recreation and tourism (R&D in is in progress to develop low-noise gearboxes and generators). However, communities can also benefit from the new impoundment areas that can be used for various recreational activities. Low-head schemes incorporated into existing reservoirs have a minimal impact on both recreation and aesthetics.[118]

The major source of visual impacts is the associated buildings and structure of the plant and maintaining flow over waterfalls. Powerhouses and intakes can be designed to have minimal visual impact on the landscape.[119] For site refurbishments, the historical architecture of the existing plant can be incorporated into the new design and thus preserved. Equipment and structures such as penstocks and turbines can be buried or screened to minimize visual impact, and cosmetic engineering can be used to preserve or enhance the appearance of waterfalls.[120]

4.4 Plant rehabilitation and modernization

Aging plants can be rehabilitated by identifying improvement options that require minimum civil work and adapting new techniques for turbine/generator upgrading, such as using computational fluid dynamic (CFD) analysis on the turbine and intake casing, rewinding generators, modifying mechanical governor and using low-cost automation control systems.

Refurbishment and upgrading can improve power output 15-20% without the environmental impact of a new site development, increases efficiency and extends plant life 40-50 years. However, the required rehabilitation and upgrade can be substantial, sometimes requiring complete renewal and significant investment.[121]

There are no companies specializing specifically in small hydro refurbishments. Rather, there are a handful of small engineering companies with experience in plant rehabilitation and modernization.

For both large hydro and small hydro, refurbishment of plants involves replacement of electromechanical equipment with parts that are more efficient, with possible upgrades, thereby increasing energy output. Measures can also be taken to reduce downtime and extend the life of equipment, thus improving operational efficiency and reducing operating costs.[122]

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[116] European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering work Group of the Thematic Network on Small Hydropower (TN-SHP).
[117] Ibid., 116.
[118] International Energy Agency (IEA) - ETSU 1997. *Renewables in Power Generation: Towards a Better Environment*, AEAT-2211.
[119] Regional Power, 2007. www.regionalpower.com.
[120] Ibid., 118.
[121] Moretti, A. and R. Picci. 1993. Refurbishment of small hydroelectric plants while preserving natural and aesthetic values. Conference Proceedings: *Hydropower, Energy and the Environment*, Stockholm, Sweden, 1993. Vattenfall AB, Sweden.
[122] Nöjdh, R. and Krångede, AB. 1993. Experiences from restoration and upgrading of hydropower plants Conference Proceedings: *Hydropower, Energy and the Environment*, Stockholm, Sweden, 1993. Vattenfall AB, Sweden.

- Replacement parts with corrosive protection extend the life of parts in contact with water.
- Widening of cable passages reduces downtime in replacing cables and shortens the break in production.
- Placement of the turbine runner low enough to avoid cavitation is initially costly, but future upgrades are significantly more cost-effective
- Parts should be chosen that have a similar life span such that replacement can be done at the same time rather than on an ongoing basis.

Over the last 50 years, large engineering firms and electricity producers have developed new technologies to increase energy output from existing equipment and optimize construction methodologies for large hydropower sites. [123]

With support from NRCan, a number of demonstration projects have adapted these new technologies for small-scale projects over the past decade both in Canada and abroad:

- Use of computerized hydraulic design to enhance existing turbine designs and improve efficiency and energy output.
- Automation of old mechanical governors for monitoring and optimization of individual turbine production.
- Use of control and protection systems to allow for monitoring of stations on-site or remotely via computer.

Many managers of these older plants are confronted with a range of project and technology options for rehabilitating and upgrading the plant. Ensuring that such large investments are cost-effective requires a good understanding of the technologies and innovative approaches to refurbishment as well as the risks associated with these kinds of projects. A U.S. technical methodology and guidelines for refurbishment of small hydro plants are now available.

4.5 Project planning

At the national level, resource potential assessment is necessary to quantify the gross theoretical potential and technically feasible potential for policy and decision making. Once focus areas have been identified, a desktop reconnaissance study can be used to screen and identify potential sites for further investigation. When individual sites have been identified, site assessments and preliminary designs can be carried out at the pre-feasibility and feasibility stage, in each case with an increasing level of detail and cost.

Detailed investigations cannot normally be justified for smaller-scale hydro projects, and accessing remote locations is costly. Study costs are generally the same regardless of project size. For smaller projects they are typically greater than 15% of site development costs — a significant risk for small developers. Low-cost analytical tools need to be developed for technical, financial and environmental optimization and design. Tools may be available, but they are often proprietary or potential users lack the skills.[124]

4.5.1 Reconnaissance/pre-feasibility

A database of Canadian small hydro potential sites is hosted on the International Small Hydro Atlas website at www.small-hydro.com. The website is managed by CanmetENERGY as part of Canada's contribution to the IEA Small Hydro Annex II, of which Canada is a member. The potential site database and atlas contain reconnaissance-level type information suitable for input into tools such as RETScreen®. The website also contains information on assessment tools, financing, risk analysis, countries and contacts and organizations in the industry

The RETScreen® International Small Hydro Project analysis software is designed for the initial planning stage to assess potential small hydro projects. It is a desktop-type analysis tool used to evaluate energy production, life-cycle costs and greenhouse gas emissions (GHG) reduction for central-grid, isolated-grid and off-grid small hydro projects. It is intended for use by planners, decision makers and industry to implement small hydro projects and, with training available, it can build the capacity of users with little no expertise in small hydro. [125]

Specifically for micro-hydro, there is no single integrated software tool to design a micro-hydropower system from water to wire. Tools such as RETScreen® are not suitable for such small-scale projects. CanmetENERGY is supporting the development of a

[123] Gestion Conseil S.C.P. 2003. *Final Report for Rehabilitation and Modernization of Powerhouse No. 2 and No. 4 Victoria Island of Energy Ottawa Inc.* Under Climate Change Action Fund, Technology Early Action Measures (TEAM).
[124] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting.* March 16, 2006, Ottawa.
[125] Natural Resources Canada, 2007 RETScreen® website at www.RETScreen.net.

preliminary design software tool for developers with micro-hydropower potential (10-100-kW systems). The software will be made compatible with RETScreen® for financial and GHG analysis. It addresses the needs of many off-grid residents and communities that may be interested in developing micro-hydropower to offset costly diesel generation and provide power to the grid via a net-metering program.

In terms of preliminary resource assessment, existing tools and methods do not take advantage of Environment Canada's historical streamflow data now available online. CanmetENERGY, the National Research Council (NRC) and Environment Canada (EC) are collaborating on a proposal for a web-enabled digital atlas for small hydro and water current resource assessment. Building on the success of the national wind energy atlas, the intent is to provide first estimates of resource potential for a prospective small hydro site for input into NRCan's RETScreen® software. Maps of national and regional water current potential would be included, and there would be an update of the 1980 water current potential study.[126]

4.5.2 Feasibility assessment

There are currently no tools available for the second phase of site assessment – the detailed costing and preliminary optimization of a selected site. Simple costing programs have been developed by some large consultants, but not for feasibility level analysis, and they are unavailable to small engineering companies or developers. Feasibility-level costing usually requires several months of work by a number of engineers. This is costly, and as a result many developers exclude this stage and instead ask for combined design-build quotes from contractors. With minimal site information, most contractors are unwilling to provide bids, and sites remain undeveloped.[127] CanmetENERGY is supporting the development of HydroHELP, a modular design and costing tool for engineering consultants that covers the entire range of small hydroelectric turbines and project components.

A detailed hydrological assessment requires the expertise of specialized consultants or expert hydrologists. CanmetENERGY plans to promote and support the packaging of existing advanced hydrological software with physiographic and hydrometric data for Canada. The software is developed and maintained on a cost-recovery basis by the Canadian Hydraulic Centre of the National Research Council (NRC-CHC). This will provide specialized consultants and engineering firms with advanced tools for more precise estimates needed to design small hydro sites.

4.6 Integration with other renewables

Hybrid systems offer flexibility, efficiency and reliability and are an economically attractive energy option. Integration of renewables with hydropower is best suited for hydro schemes with storage capacity.[128] A wind–hydro system, for example, reduces intermittency issues with wind, has the potential to provide more consistent power, and is well suited for island energy needs where the wind resource potential is typically high. The combination of technologies often results in better utilization of available resources, i.e., through use of hydropower to firm and shape wind energy.[129]

R&D on coupling emerging hydro technologies, hydrogen production and storage presents another integration option. However, hydro/hydrogen integration is likely only economically feasible with large hydro plants.[130] SDTC is supporting a demonstration project of Renewable Microgrid Systems (RMS) in the remote community of Bella Coola, B.C., to allow for high penetration of renewable energy sources. A hydrogen energy storage system is proposed to be incorporated into the microgrid.[131]

The Wind Energy R&D group of CanmetENERGY is embarking on a wind-diesel-hydrogen storage project that will provide valuable insight into hybrid projects involving both wind and hydrogen. In addition, involvement of CanmetENERGY with other renewable IEA implementing agreements (IAs) such as the Wind-Hydro IA may allow for collaborative R&D ventures with other countries.

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[126] National Research Council. 1980. *Evaluation of the Kinetic Energy of Canadian Rivers and Estuaries*. Produced by the UMA Group for the National Research Council – Canadian Hydraulic Centre.
[127] James, L. Gordon. 2007. Final report for HydroHELP "Expert" Hydro Design Costing Tool. Submission to Natural Resources Canada.
[128] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting, April 19, 2007, Ottawa.
[129] International Energy Agency Renewable Energy Working Party (REWP) And Renewable Energy and Hydrogen Implementing Agreements. 2005. Joint seminar discussion paper - *Catching Up: Priorities for Augmented Renewable Energy R&D*, March 3, 2005.
[130] Ibid., 128.
[131] Sustainable Development Technology Canada (SDTC). 2006. GE Canada Project. http://www.sdtc.ca/en/results/portfolio/projects/GECanada.htm

5 Current Canadian R&D activities and international R&D involvement

The federal Hydraulic Energy Group (HEG) of CanmetENERGY at Natural Resources Canada is the only government R&D group in Canada dedicated specifically to the needs of small-scale emerging hydropower technologies. Individual utilities, utility consortia, utility interest groups and electricity associations all have hydropower R&D strategies and programs; however, they are dominated by the large hydro R&D agenda. Because small hydro lacks a national association to direct R&D, its specific needs are addressed and represented by the Hydraulic Energy Group of CanmetENERGY in national and international R&D arenas.

Prior to 1986, the Hydraulics laboratory of the National Research Council was involved mainly with water/tidal–current turbines testing in cooperation with Natural Resources Canada. In 1995, it became a standalone laboratory under the new name of "Canadian Hydraulics Centre (CHC)" within NRC, and all R&D related to hydro-turbine testing was conducted on a cost-recovery basis for outside clients or OGDs. The CHC now mainly provides coastal engineering/investigation services to Canadian and international clients. Individual CHC experts can provide contractual services to clients on water-current turbines and ocean energy (wave and tidal) resource assessment.

5.1 Federal R&D

Over the last 25 years, the federal government has been supporting small-scale hydro emerging technologies The Hydraulic Energy Group HEG supports efforts by Canadian industry to develop and commercialize advanced small and low-head hydro and water current technologies with industry by:

- identifying and accelerating strategic R&D
- engaging in demonstration and deployment
- fostering the commercialization of new technology
- identifying and developing opportunities for renewables integration
- developing infrastructure to support innovation such as standards and codes
- developing linkages between utilities, industry, and academia
- supporting the development of resource assessment data and tools
- supporting training and education
- disseminating results and findings
- supporting federal policy and programs such as ecoEnergy Renewables

HEG is actively involved with provinces, utilities, private industry, academic institutions and other organizations on key projects to reduce equipment and construction costs and increase turbine and site efficiencies as well as support technology demonstrations nationally and internationally. This facilitates the realization of the additional capacity available within Canada while at the same time helping the industry to strengthen its expertise in both products and services within Canada and abroad.

Numerous demonstration projects have been launched from 1980s to the present with the help of funding from federal-provincial joint programs. The total number of projects delivered across the country over this period is about 100. Most of these projects are still in operation. The projects were designed to demonstrate the development of environmentally sustainable projects, diesel fuel displacement in remote communities, and innovative technology applications. The demonstrations also increase public awareness of the important role that hydropower plays in Canada.

Over the past five years, funding for hydraulic energy research has been directed toward improvement of small and low-head turbines and related power plant equipment to increase efficiency, reduce costs and advance the ecological/environmental benefits of low-head hydro developments. Major achievements include the following:

- The digital governor developed by Powerbase Automation Systems Inc. with support from CanmetENERGY and successfully tested in 2003 has now been supplied to China (a number of units), Panama (two units) and the U.S. (one unit). Development of the excitation module was completed in June 2004; the module has been tested in the laboratory and is ready for field testing. These systems are fully compatible with other hydro control equipment in the powerhouse and are simple to install and maintain. They improve reliability by reducing downtime and reduce initial equipment costs.

- The CanmetENERGY-led CIDA project, "Transferring Canadian small hydro technologies to China for promoting environmentally sustainable development," was a CCCDF ($2M) small hydro project in China that was completed in 2007. It consisted of five sub-projects, including the Francis Turbine Design Enhancement, which used Canadian technology and was geared to the Chinese small hydro market. Chinese partners have been trained in the design process, demonstrating Canadian expertise to one of the largest international markets for small hydropower.

- CanmetENERGY -supported Rapid-Eau technologies Inc. in developing the low-head fish- friendly turbine technology. Model turbine testing at LAMH showed good performance, and the University of New Brunswick is now working on the generators and other electrical equipment such as power converters, which will allow variable-speed operation of the turbine-generator units. A 300-kW prototype turbine unit will be installed in 2007 at the Corkery Hydro Plant near North Bay, Ontario.

A key component of the Hydraulic Energy Group's activities is the Laval University hydraulic machinery laboratory (LAMH) in Quebec City. LAMH is the only independent hydro-turbine-testing laboratory in Canada and one of the top five laboratories in the world for measuring turbine efficiencies. LAMH was developed with the support of NRCan and Laval University. It validates new hydro-turbine designs with improved efficiency and provides educational facilities to train future engineers and researchers.

Major projects at LAMH:

Hydraulic losses: This generic research is needed to develop turbines with improved efficiency and reliability and to train future researchers. This is especially important for low-head systems as even small hydraulic losses impact flow rates through the turbine, significantly reducing power output.

Kaplan turbine generic tests to improving operating efficiency: A detailed study of Kaplan blades will provide invaluable data to improve design and efficiency. Kaplan turbines are widely used in low-head sites and have good efficiency at part-flow rates, resulting in increased power generation from existing and future low-head hydro plants.

5.2 Industry R&D

Canadian consortium on hydraulic machines R&D
Major large hydro turbine manufacturers have recognized the importance of, LAMH and have joined the recently initiated Canadian consortium on hydraulic machines R&D. The consortium is designed to facilitate joint R&D undertakings between industry, academia and government, closely aligned with the current federal S&T strategy for laboratories. This will allow LAMH to be fully certified, contribute to a better understanding and simulation of hydraulic turbines, and train researchers and engineers for the industry. This is key to maintaining and developing Canadian expertise in turbine design and independent testing to support the hydro industry. The consortium represents a significant step in reducing the laboratory's dependence on NRCan funding.

CEA Technologies Inc. (CEATI)
The CEATI program collaborates with the Canadian and international electrical industry and organizations to stay abreast of the latest developments and to address emerging technical issues.

CEATI's Hydraulic Plant Life Group (HPLIG) y focuses on large hydro R&D, but there are some key synergies for small and low-head hydro R&D. Specific projects include HPLIG involvement with development of the very low-head turbine (VLH) and the exit stay apparatus (ESA).

The Sustainable Options Interest Group (SOIG) is broader and covers distributed technologies such as wind, solar and small hydro and other distributed resources. Their focus is to develop, evaluate and demonstrate sustainable power generation technologies that will result in an increase in power supply capacity and a reduction in greenhouse gas emissions. Currently, there is a proposal for implementation of a prototype VLH fish-friendly turbine system at a site (<500 kW) with existing infrastructure in Canada.

Hydro-Québec
Hydro-Québec operates number of technical innovation research institutes that carry out projects in cooperation with universities, research centres and industry in support of its core business. Its main priorities are in generation, transmission and distribution.

The two major laboratories are Hydro-Québec's Research Institute (IRHQ) in Varennes and the Energy Technology Laboratory in Shawinigan. IndusTech is a wholly owned subsidiary of Hydro-Québec that works with the private sector on the industrial production and marketing of technologies resulting from Hydro-Québec's research activities.

BC Hydro
Powertech Labs Inc. (Powertech) is an R&D subsidiary of BC Hydro that provides consulting, testing, R&D and technology demonstration services to the electrical, gas and automobile industries. Powertech has multidisciplinary expertise and world-class laboratories relevant to development, demonstration, integration, monitoring and operation of alternative energy technologies, such as small hydro, wind power, ocean wave, tidal and marine current.

5.3 Canadian involvement in international R&D

While some countries have moved away from emerging hydro R&D, the European Union (EU) continues to perform R&D in small hydro, and there is renewed hope in the U.S. that their hydropower R&D program will be reinstated. [132] The EU has a keen interest in addressing aging hydro sites, particularly tapping into the large low-head potential of abandoned sites and water resource infrastructure. The goal is to make it even more economically viable to increase clean energy capacity and contribute to meeting Kyoto targets and well as providing new opportunities for export and technology transfer for EU manufacturers.[133] Canada has international partners in this endeavour, such as the new NRCan T&I-funded VLH fish-friendly turbine project, which is being carried out in collaboration with France and features both French and Canadian demonstrations.

International Energy Agency
Canada is a member of the International Energy Agency Small-Scale Hydro Annex (for sites less than 10 MW). The international R&D activities of Small Hydro Annex aim to reduce the cost of small turbines, hydraulic equipment, control systems, and professional services required for design and operation of small plants. Small Hydro Annex members include Japan, Norway, France and Canada. Associate members include China, Brazil, India and the European Small Hydro Association (ESHA).

Canada leads small hydro tasks on the following:

- Management of the IEA Small Hydro Website at www.small-hydro.com.
- An annual Joint Small and Medium Hydro Workshop with CanmetENERGY and the IEA Small Hydro Annex at the North America Hydrovision and Waterpower Biannual conferences.
- Summary of available international software for site assessment.

Canada also participates in the following tasks:

- Reporting on environmental policies and mitigation measures.
- Survey and case studies of innovative technologies and applications for small, mini- and micro- hydro.
- Case studies of successful rehabilitation/upgrading/modernization of existing small hydro plants.

[132] National Hydropower Association, 2007. *Hydropower's value recognized in $22 million appropriation in Energy and Water Development Bill.* Press Release, Washington, DC.
[133] European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering work Group of the Thematic Network on Small Hydropower (TN-SHP).

6 Emerging hydropower technologies (EHT) R&D strategy

R&D support is essential for Canadian manufacturers of emerging hydropower technologies in small and low-head hydro and water current. Manufacturers have little capital for R&D to develop a broader range of standardized products and make them more competitive internationally. This is in contrast to the IEA OECD report that identified manufacturers as the "best entity to initiate or sponsor" in the development of equipment and improvement for small hydro.[134] Public R&D programs support manufacturers by making results available, giving them the ability to "systematically develop an optimized laboratory design."[135]

Standardization of equipment also aids developers who have limited resources for laboratory studies at universities and research centers for custom design. In addition, simpler turbine designs reduce the costs of turbine manufacturing, installation and maintenance. Other equipment must be custom-designed for individual sites, and Canadian designers and manufacturers require support to increase their R&D research capabilities.

Legacy hydro has been identified as a significant market opportunity in North America.[136] Aging plants can be rehabilitated by identifying improvement options that require minimal civil work and adapting new techniques for turbine/generator upgrading such as the use of CFD analysis. The feasibility of this approach has been demonstrated through a number of CanmetENERGY projects. However, the cost of resources such as CFD analysis is still prohibitive for small utilities and private plant owners and few companies provide these services.

Standardized computer approaches to hydrology, technical optimization, financial and risk assessment and environmental impacts have been identified as priority needs for the EHT industry.[137]

Involvement in developing and maintenance of codes and standards related to R&D themes is important for representing Canadian interests and ensuring that Canada maintains its worldwide leadership role. IEC and IEEE standards cover hydraulic energy designs, manufacturing and rehabilitation, commissioning, testing and operation of electromechanical equipment such as turbines, speed governing systems, generators, transformers and control systems.

Based on the priority needs, R&D work carried out and supported by the Hydraulic Energy Group at CanmetENERGY is proposed under three main R&D themes. Over the next four years, this R&D work will also be supported by strategic planning that will cover infrastructure, stakeholder engagement, market analysis and communications products (see Section 7).

6.1 Theme One: Competitive Low-Head and Water Current Systems

R&D under this theme involves the development of cost-effective and energy-efficient low-head and water current systems, and a large part of the R&D will be conducted with LAMH. R&D on the fish-friendly aspect of these systems is carried out through joint projects under the environmental engineering theme. The IEA has also identified fish-friendly turbines, low-head technologies, in-stream flow technologies and additional generation capacity for existing structures as high priority R&D areas.[138]

At present, there are no codes and standards that regulate the testing requirements for low-head hydro. Low-head hydro turbine laboratory tests and on-site flow and performance measurements will assist in developing codes and standards to guarantee that

[134] International Energy Agency (IEA). 2006. *Renewable Energy R&D Priorities – Insights from IEA technology Programmes*. Organization for Economic Co-operation and Development (OECD).
[135] European Directorate for Transport and Energy and Swiss Federal Office for Science and Education. 2004. *European Strategy Document for Research, Technology Development and Demonstration in Small Hydropower*. Prepared by the Engineering work Group of the Thematic Network on Small Hydropower (TN-SHP).
[136] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting.* March 16, 2006, Ottawa.
[137] Ibid., 136.
[138] International Energy Agency (IEA). 2006. *Renewable Energy R&D Priorities – Insights from IEA Technology Programmes*. Organization for Economic Co-operation and Development (OECD).

the turbine's design, manufacturing and performance meet the technical specifications. At the same time, these tests and measurements will pave the way for the development of codes and standards on ocean energy technologies.

Existing and proposed projects

Low-head fish-friendly systems (head 1-3 m)
CanmetENERGY is carrying out a project for the development of a low-head fish-friendly turbine using a large turbine runner to eliminate expensive civil structures and significantly reduce overall project costs. The design involves less civil work with simple mechanics and is designed for retrofit in an existing canal. The turbine technology was checked with computational fluid dynamics (CFD) to integrate the fish-friendly features in the design, and model testing at LAMH showed good performance.

A demonstration project is in progress in France, and demonstration is being planned in Canada. Successful implementation in Canada is essential for its commercialization in North America. The Canadian demonstration allows evaluation of the turbine under cold climate conditions and will include the prototype turbine, permanent magnet variable-speed generator and power converter. Incorporation of the variable-speed generator (VSG) technology extends the operating range of the turbine, while maintaining maximum structural simplicity.

Water current systems (head < 1 m)
CanmetENERGY is involved in evaluating the most promising water current turbine technology for river current applications as well as developing a smaller system for remote residential communities that are not connected to the local grid. Currently, CanmetENERGY is supporting development of 5-kW- and 25-kW-capacity modular Darrieus vertical-axis hydro turbines. The turbine utilizes water velocities from 1 to 4 m/s, with efficiencies up to 45%, and the slowly rotating turbine blades are fish-friendly. The first demonstration of a 5-kW installation at the BonnyBrook Wastewater Treatment Plant, Calgary had 300 hours of successful operation in 2006. By the end of 2008 there will be a total of 250 kW of demonstration installations across B.C., the Yukon, Ontario and Alberta. Another project involves Canadian testing of a U.S. company's 60-kW turbine for commercial use (launch in summer of 2007). The project is led by the University of Manitoba in cooperation with CanmetENERGY and a number of utility partners including Manitoba Hydro.

On-site turbine performance evaluation
CanmetENERGY is investigating the development of cost-effective test equipment and procedures that would reduce set-up time, data analysis and reporting in the cost range of $10,000-$20,000. This will provide operators with a basis for daily operating decisions, allowing them to choose the best operating mode. It will also demonstrate to the hydroelectric power producers the benefits of investing in tools and information for operating efficiently, maximizing use of allotted water resources and improving power production.[139]

6.2 Theme Two: Eco-Engineering

R&D under this theme will focus on two major environmental concerns with run-of-river developments: impact of river diversions and reduction in natural discharge affecting aquatic habitat and fish injury and mortality rates from passage through turbine chambers.

Existing and proposed projects

Instream Flow Requirements
NRCan-PERD supports R&D carried out by the Department of Fisheries and Oceans to improve modeling tools prescribing environmentally acceptable flow regimes for developments that will alter natural flow regimes. DFO and the Canadian Electricity Association (CEA) are exploring opportunities for developing a comprehensive framework for assessment of flow-related alterations on fish and fish habitat that will provide government, industry, and the Canadian public with a consistent, clear, yet flexible approach to the management of natural flow regimes throughout Canada. Biological effects monitoring and adaptive management are also important tools for management of river flow regimes.[140]

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[139] Tung, Tony T.P., J. Huang, C. Handler, and G. Ranjitkar. 2007. Better Turbines for Small Hydro. *Hydro Review*, March 2007.
[140] Department of Fisheries and Oceans (DFO). 2005. Report Submission to the Panel on Energy Research and Development (PERD), Natural Resources Canada.

Fish-friendly turbines
CanmetENERGY and its industrial and university partners in Canada and France are developing a simple, non-regulated vortex propeller turbine system coupled with a variable-speed generator to operate at the optimum rotational speed with varying flow rates. Extensive CFD flow simulation and laboratory testing will be used in the design process. It is expected that this fish-friendly turbine will reduce fish mortality to less than 5%. In addition, the turbine will have the ability to operate at variable speeds over a wide operating range of high or low flows at high efficiency and a high turndown ratio, therefore increasing overall power generation.[141] CanmetENERGY will be collaborating with DFO on turbine mortality and delayed downstream mortality studies to evaluate the biological effectiveness of the new designs for use at low-head hydro plants.

6.3 Theme Three: Site Assessment

Existing tools and data such as the Canadian Small Hydro Database and RETScreen® are well established and cover the data and pre-screening needed to move forward to prefeasibility analysis. The main focus of this theme will be completion and dissemination of tools already under development.

Existing and proposed projects

HydroHELP design-cost tool
CanmetENERGY is supporting the development of a feasibility-level, comprehensive, preliminary design and costing tool covering the entire range of hydroelectric turbines and project components. The tool has four modules under development and testing: turbine selection and three modules for Francis, Impulse and Kaplan turbine projects. A small hydro version (under 50 MW) will be available, along with a professional version that can be used for both large and small hydro.

Micro-hydropower design tool
CanmetENERGY is supporting the development of a tool with a technical section for designing and specifying micro-hydropower equipment and sizing of civil works, including costs for systems up to 100 kW. Data from this tool could be exported to other tools, such as RETScreen®, for financial and GHG analysis.

Canadian Small Hydro Database
The records in the Canadian Database (located on the IEA Small Hydro website at www.small-hydro.com) are a compilation of various reports and studies from different regions across Canada, some dating back more than 40 years. The potential sites are geographically referenced for display and query with other relevant map data such as transmission lines, roads, parks, etc. Updated datasets are now available from many provinces and territories such as Ontario, B.C., Yukon and Nunavut, and CanmetENERGY plans to update the database and ensure that the database fields are compatible with tools such as RETScreen®.

Resource assessment
CanmetENERGY, the National Research Council and Environment Canada are collaborating in a proposal for the development of a national atlas providing pre-processed watershed delineations and site-specific historical hydrographs for preliminary small hydro resource assessment. The proposal also involves an update of the 1980 study entitled *Evaluation of the Kinetic Energy of Canadian Rivers and Estuaries*[142] for national and regional assessment of water current potential and to aid in identifying areas for further investigation. This includes an investigation of the possible predictive methodologies for water currents and their relative accuracy to improve upon methods used in the 1980 study. Any resulting maps would be displayed in the atlas. Packaging of NRC's existing advanced hydrological toolkit within a GIS-enabled modeling environment is also proposed and would provide engineering firms and research scientists with advanced tools for more precise estimates needed to design small hydro sites.

[141] Tung, Tony T.P., J. Huang, C. Handler, and G. Ranjitkar. 2007. Better Turbines for Small Hydro. Hydro Review, March 2007.
[142] National Research Council. 1980. *Evaluation of the Kinetic Energy of Canadian Rivers and Estuaries*. Produced by the UMA Group for the National Research Council – Canadian Hydraulic Centre.

6.4 Other R&D

Civil works - Civil works as such are not proposed as a major R&D theme. However, two approaches are proposed for CanmetENERGY to become involved in addressing civil works R&D needs:

- Development of design guidelines based on R&D for specific components. Collaboration with the IEA Small Hydro Annex II could lead to a sharing of available resources and results. Particular interest has been expressed in undertaking R&D on timber crib dams.
- Collaboration with university civil engineering departments on the latest R&D in civil works and specifically on cold climate applications.

7 Strategic Planning

The Hydraulic Energy Group Technical Advisory Committee (TAC) annual meeting will be used for the strategic planning and direction of the Hydraulic Energy Group's R&D activities at CanmetENERGY. The TAC is composed of 12-14 members from across Canada representing the EHT industry, academia, associations, and other federal government departments.

7.1 Infrastructure support

Research and training infrastructure in Canada for hydraulic turbines is still lacking. Universities and government laboratories are in well-established position to carry out the R&D activities needed to resolve the technical issues and lack of capacity in the small hydro subsector and the hydropower industry in general. Cooperation and communication between industry and these laboratories needs to be enhanced to turn the leading R&D technology and know-how into products and practical solutions. Research centres can play a key role in developing standardized turbines applicable to a wider site range, helping to find more innovative, reliable and cost-effective solutions for customized designs, and fostering greater use of cutting-edge technologies to analyze and test equipment.

The lack of training and education capacity and the low number of new professional engineers entering the hydropower field are concerns both in Canada and internationally.[143, 144] A succession plan is needed for the aging workforce, incorporating strategies such as on-the-job training and links to academic institutions as well as policy targets for developing resource potential and ensuring that the labour market meets expertise needs.[145]

7.1.1 R&D facilities

Laval University hydraulic machinery laboratory (LAMH)

Continued short-term support from CanmetENERGY allows LAMH to build upon past R&D and continue to conduct fundamental R&D activities in hydraulic machines, improving the knowledge base within the hydraulic energy sector. LAMH provides the hydropower industry with an independent testing facility, facilitates the education and training of highly qualified hydraulic engineers and researchers, and assists the industry in commercializing their products. A significant part of the recent support from CanmetENERGY has been for the implementation of the universal turbine-testing rig at LAMH.

Canadian consortium on hydraulic machines R&D

Through this neutral organization, the small hydro subsector will be able to share the R&D results with large industrial groups and large hydropower developers that have a greater capacity to finance R&D activities. It will also enhance development of Canadian expertise in turbine design and independent testing, supporting the hydropower industry as a whole. It will also enable LAMH to become a fully certified testing facility and decrease the dependence of LAMH on federal funding. Longer-term independence of the laboratory through better access to NSERC and industry funding is necessary in order to reduce the impact of federal funding decisions on the operation of the laboratory.

In 2007 NSERC granted the co-funding for this important venture. Public and private partners have agreed on a three-year period for promoting new turbine designs. GE Hydro, Hydro-Québec, Alstom Hydro and CanmetENERGY have committed to make financial contributions. Proposed R&D for unsteady flow experiments on the low-head axial turbine will improve basic understanding of flow in these turbines, in order to design more reliable and efficient turbines.

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[143] Natural Resources Canada. 2006. *Final Report on the Hydraulic Energy Group Ad-Hoc Technical Advisory Committee Meeting.* March 16, 2006, Ottawa.

[144] International Energy Agency Renewable Energy Working Party (REWP) and Renewable Energy and Hydrogen Implementing Agreements. 2005. Joint seminar discussion paper - *Catching Up: Priorities for Augmented Renewable Energy R&D*, March 3, 2005.

[145] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting. April 19, 2007, Ottawa.

7.1.1 Expertise capacity

A succession plan is needed for the aging workforce, incorporating strategies such as on-the-job training and links to academic institutions as well as policy targets for developing resource potential and ensuring that the labour market meets expertise needs. The Human Resources and Social Development Canada (HRSDC) Electricity Sector Council has conducted preliminary scoping of expertise issues in the hydropower sector. The Council is now working with the Canadian Electricity Association (CEA) and other collaborators to plan for a detailed analysis and next steps. The Electricity Sector Council also has a renewable skills consultation table. The Canadian Hydropower Association (CHA) has shown an interest in working with the government on this issue. CanmetENERGY plans to collaborate with the CHA on HRSDC initiatives for the hydropower sector.

Through the IEA Small Hydro Annex II, Canada along with other member countries could also collaborate on this issue through various targeted tasks. One option under consideration is to use small hydro sites as a training ground for all types of hydro through a scholarship program, ultimately providing better access to trained engineers for small, medium and large hydro sites. The HydroHELP Design software has been suggested as a useful tool for teaching students or for providing continuing education through workshops, where individuals would cover the cost of training and the tool would become self sustainable.[146] There is also the possibility of using NSERC funds for training in collaboration with academia, industry and government. An international survey of training, workshops and other approaches to developing expertise in hydropower is proposed as a first step.

7.2 Stakeholder engagement

Canadian small hydro subsector
CanmetENERGY has a good working relationship with Canadian industry, supporting and collaborating on numerous projects with industry partners through the Hydraulic Energy Group TAC and active membership in CEATI-HPLIG.

International small hydro subsector
Canada initiated the IEA Small Hydro Annex II in 1995 and has been its most active member since inception. CanmetENERGY was also instrumental in the four-year CIDA–China project for transfer of Canadian technologies as well as projects with Canadian industry in Nepal, India and Poland. CanmetENERGY is currently exploring the potential for international technology transfer to Uganda and Kenya.

Academic institutions
Laval University's Mechanical Engineering Department has greatly benefited from CanmetENERGY support of their hydraulic machinery laboratory for over the last 10 years. There has been extensive collaboration on many R&D projects, and a number of graduate students have been able to conduct R&D as well. Collaboration with the University of New Brunswick on the development of generators and inverters is ongoing, generally leveraged with work in wind energy R&D. The University of Manitoba is leading a water current turbine demonstration project in cooperation with CanmetENERGY and a number of utility partners including Manitoba Hydro. Engagement with civil engineering departments to bring leading-edge civil works R&D to the EHT sector is needed.

National and provincial/territorial associations
The Canadian Hydropower Association (CHA) and the Canadian Electricity Association (CEA) rely on CanmetENERGY as a key knowledge base for small hydro resource potential, leading-edge emerging hydropower technologies R&D and technical information for small and low-head hydro and water current. Ties have been renewed with the Ontario Waterpower Association, and there are plans to forge links with other provincial/territorial associations as well. All of these associations in turn provide CanmetENERGY with important national and regional perspectives.

Non-governmental organizations
Pollution Probe has consulted CanmetENERGY on numerous publications over the last few years. There are plans to engage with other key NGOs such as the Suzuki Foundation and the Pembina Institute.

Provincial/territorial governments
CanmetENERGY has been collaborating with the Ontario Ministry of Natural Resources for many years on resource potential and site assessment. There are also links with the Yukon government, and CanmetENERGY staff recently visited Nunavut, where the territorial government is very interested in working with CanmetENERGY.

[146] Natural Resources Canada. 2007. Minutes of the Hydraulic Energy Group Technical Advisory Committee Meeting. April 19, 2007, Ottawa.

Other government departments
Through the Panel on Energy R&D (PERD), CanmetENERGY meets with Industry Canada, the Department of Fisheries and Oceans, Environment Canada and NRC's Canadian Hydraulic Centre (NRC-CHC). Some of these departments have also been directly involved with CanmetENERGY on a number of R&D projects.

Internal NRCan
Internal linkages with CETC-Varennes need to be strengthened to collaborate on common areas of focus. Relations with NRCan's renewable energy policy group also need to be strengthened for better leveraging and cooperation on the data and information needs of both groups. CanmetENERGY currently uses a number of available digital map resources from Geomatics Canada for site assessment.

7.3 Market studies

The existing market data available on small hydro and market assessment is based on the 1990 EMR report entitled "Small Hydro Technology and Market Assessment". As such, there is a critical need to provide updated information to the hydropower industry.

CanmetENERGY is planning a study to assess the status of the small and low-head hydro technology market, expected market penetration and costs for low-head hydro development, the potential impact and strategies for low-head hydro development in Canada and abroad. Barriers to new technology market penetration and development of new low-head hydropower sites also need to be identified.

This information is necessary to assist provincial and federal policy makers and R&D managers in planning the level and direction of support programs, development strategies and R&D activities. Stakeholders also require market information to better formulate business plans.

7.4 Communications

Statistics
CanmetENERGY is often approached for up-to-date information on resource potential and statistics on growth rates of the small and low-head hydro and water current sectors. The requests come from internal NRCan policy groups, NRCan management and external organizations such as the IEA, NGOs and other government departments, including Industry Canada. The CHA recently conducted a study on hydropower potential in Canada, providing valuable aggregate statistics on sites between 25 and 50 MW that are not currently in the Canadian Small Hydro Database. Updating of the Database to include sites up to 50 MW will also provide an up-to-date information source and will be carried out in cooperation with the provinces/territories and their databases. There are plans to work more closely with Statistics Canada in obtaining information from their existing database more easily and to produce value-added aggregate statistics on existing sites and growth/decline in the EHT sector.

Journal publications
A number of EHT R&D journal articles from the CanmetENERGY staff are published every year in prominent industry journals such as *Hydro Review* magazine.

Websites
The IEA Small Hydro Annex II plans to move the International Small Hydro website at www.small-hydro.com, to the Annex II Secretariat. Canada will contribute to Canadian content on the website but will no longer be managing the website itself.

There are also plans to update the hydropower information on the CanmetENERGY Canadian Renewable Energy Network (CANREN) website at www.canren.gc.ca.

Workshops
The joint Annual CanmetENERGY/IEA Small and Medium Hydro Workshop held alternately at Hydrovision and Waterpower conferences has been very successful, usually attracting about 75 participants from North America. This has given Canadian industry a unique opportunity to showcase its expertise and hydro products to a very large market and bring together EHT investors, developers and owners for an invaluable networking experience.

Communications products
Audience-targeted communications products need to be enhanced. Recently, CanmetENERGY has disseminated very few products such as brochures, fact sheets and individual project summary sheets to industry stakeholders and the general public. Three fact sheets are planned for the next year on the low-head fish-friendly turbine, the water current turbine and instream flow R&D.

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