BC HYDRO

GREEN & ALTERNATIVE ENERGY DIVISION

GREEN ENERGY STUDY FOR BRITISH COLUMBIA

PHASE 2: MAINLAND

Engineering

BC hydro

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EXECUTIVE SUMMARY

BC Hydro is exploring the potential for green energy—that is, energy generated from renewable resources through licensable and environmentally and socially responsible projects—to contribute to meeting future demand for electricity in British Columbia. The Green Energy Study for British Columbia is a pre-feasibility level assessment of the potential for developing green energy resources. Detailed green criteria can be accessed on BC Hydro's web site www.bchydro.com/greenipp.

Phase 1 of the study evaluated the resources on Vancouver Island. This report summarizes Phase 2 of the study, which considered the resources on the mainland of B.C. as well as tidal current energy around Vancouver Island. The study identifies opportunities in British Columbia for green energy and supports the body of information for existing initiatives under BC Hydro's Green and Alternative Energy Program. It is also a tool that can inform resource planning and the assessment of future generation options.

The study focused on resources that represent the best potential for utility development of green energy. Six separate reports were completed by consultants to investigate the following resources and their related technologies: biomass, geothermal, small hydro, tidal current, wind, and Building Integrated Photovoltaic (BIPV) solar and small-scale wind.

The main components of the study included: identification and evaluation of sites with the highest potential for development, an estimate of the levelized cost of energy, a review of the energy conversion technologies, and an assessment of the environmental and socio-economic impacts of development. The study provides potential capacity and energy production for development and is not an exhaustive inventory or an estimate of the total resource capability.

All the resources studied, with the exception of BIPV solar applications and small-scale wind, have the potential to contribute to the province's resource mix. From the projects identified, a potential nameplate capacity of about 5000 megawatts is estimated with a potential annual energy production of about 18 000 gigawatt hours. Production costs for the potential green energy range between four and 25 cents per kilowatt-hour. Since many of these resources are seen as near-commercial, the production costs are expected to decrease as the technologies develop, the resources are better understood and the processes for developing the resources are established. Other resource attributes and impacts, such as dispatchability and greenhouse gas reductions, are important for consideration of green energy in the resource mix. It must be emphasized that this is a pre-feasibility study, and further research may show that some of these potential projects will not be practical to develop, due to cost, location, dispatchability or other factors including, in some cases, the stage of development of the related technologies.

Green energy generation results in low or no emissions of greenhouse gases, sulphur oxides and local air pollutants. Since the sources are renewable, these projects do not deplete the Earth's resources. However, no energy resource is benign and the environmental aspects can vary from resource to resource.

All forms of generation—including green generation—have their benefits and their limitations. Understanding these issues sets the stage for planning and developing a sustainable resource mix.

BC Hydro actively supports the green and alternative energy sectors through three types of initiatives: commercial (acquiring green energy from IPPs or industrial customers with commercially competitive projects that also meet green criteria), near-commercial (enabling the development of green resources that are still not at the commercially competitive stage in B.C.) and retail (our Green Power Certificates product for businesses). Based on the results of this Green Energy Study for British Columbia—Phase 2: Mainland, there is promising potential for developing green energy in B.C.

1.0 INTRODUCTION

1.1 Background

This report presents the results of the pre-feasibility level studies for Phase 2 of the Green Energy Study for British Columbia. Phase 1 of the study evaluated the green energy resources on Vancouver Island and led to the announcement of a Green Energy Demonstration Project for Vancouver Island, involving wind, small/micro hydro and ocean wave energy resources. Electricity from the demonstration project is scheduled to enter BC Hydro's power grid in 2003/04.

Phase 2 of the study involved an assessment of green energy resources on the mainland of British Columbia, as well as tidal current energy around Vancouver Island.

BC Hydro is exploring the potential for green energy resources to help meet future demand for electricity in British Columbia. The results of this study can inform resource planning and the assessment of future generation options.

It should be emphasized that this study is at a "pre-feasibility" level, and uses available information and limited additional studies, modelling, and field investigations to assess the resource potential, capacity, energy, impacts, and cost estimates for potential green energy resources. Further study and investigation are needed before any of the identified potential resources are developed.

BC Hydro engaged the services of consultants to prepare separate studies on the different resources considered. The main components of the study included: identification and evaluation of sites with the highest potential for development, an estimate of the levelized cost of energy, a review of the energy conversion technologies, and an assessment of the environmental and socio-economic impacts of development. This report, prepared by BC Hydro and based on the consultants' reports, is a summary of the results.

1.2 Objective

The objective of the study is to investigate alternative energy resources that could potentially meet new electricity supply needs.

The study identifies opportunities in British Columbia for green energy and supports the body of information for existing initiatives under BC Hydro's Green and Alternative Energy Program. It is also a tool that can inform resource planning and the assessment of future generation options.

1.3 Scope/Methodology

In order to meet the objectives, the study focused on resources that represent the best potential for utility development of green energy. Six separate reports were completed by consultants to investigate the following resources and their related technologies: biomass, geothermal, small hydro, tidal current, wind, and Building Integrated Photovoltaic (BIPV) solar and small-scale wind.

The level of study for each resource depended on the level of current information on the resource, the potential of the resource to provide for electrical generation in British Columbia, and the stage of development of the energy conversion technology.

The study includes the following components:

- Identification of specific sites that have the most potential for development
- Estimates for capacity, production and generating characteristics such as capacity factor and predictability

- Estimates of production costs to yield a levelized cost in 2002 dollars
- General site transmission, distribution and interconnection requirements
- A review and evaluation of the technologies that are commercially available or in the R&D stage for use in the relevant applications
- Potential environmental and social impacts
- Characteristics/attributes for future resource decision-making
- Preliminary outline of actions required for development
- Constraints/limitations to development
- Recommendations of next steps in terms of process for development

The study focused on near-commercial green energy resources. Some resources and technologies that are commercial in other parts of the world may not be considered commercial in British Columbia because they have yet to be developed or do not compete economically with the relatively inexpensive and abundant conventional resources in the province, such as large hydro.

The study identifies opportunities in British Columbia for green energy. Further research may show that some of the specific sites or resources identified will not be practical to develop for a variety of reasons. Similarly, a significant number of other sites will likely be discovered or become feasible to develop as technologies evolve. Although it gives a good overview of what is known about the resources, the study is not an exhaustive inventory and cannot be relied on as sufficient information for any investment or development decision.

1.4 Availability of Reports

Separate reports were prepared by consultants for the six resources considered in this study. Along with this summary report, the tidal current, small hydro, and BIPV solar and small-scale wind reports are being made public, through posting on BC Hydro's web site. By providing the information in these three reports to all interested parties, including potential developers, BC Hydro's goal is to enable the advancement of these near-commercial technologies.

Site-specific information and certain other data obtained through the wind, geothermal and biomass studies are considered commercially sensitive to BC Hydro and, in the case of the biomass study, some of our partners or customers. For this reason, only commercially non-sensitive information is being publicly released for these three resources, through this summary report. This includes general information on resource potential and production costs.

2.0 GREEN ENERGY DEFINITION

Green energy is defined as energy generated from renewable resources through licensable and environmentally and socially responsible developments. Detailed green criteria can be accessed through BC Hydro's website www.bchydro.com/greenipp.

Green energy generation results in low or no emissions of greenhouse gases, sulphur oxides and local air pollutants. Since the sources are renewable, these projects do not deplete the Earth's resources. However, no energy resource is benign and the environmental aspects can vary from resource to resource.

The use of green energy does have some limitations. One of the biggest is that many of these resources are intermittent. Because these resources cannot be stored on a large scale, other conventional forms of supply (for example, large hydro and natural gas) are generally needed to meet peak customer demand. While B.C. has a wealth of potential green resources, much of this potential is located far from the electricity grid, making development prohibitively expensive. Some green energy technologies are still in the prototype testing stage and it will be some time before they are practical at a utility scale and economic feasibility can be proven.

All forms of generation—including green generation—have their benefits and their limitations. Understanding these issues sets the stage for planning and developing a sustainable resource mix.

3.0 PRODUCTION COST ESTIMATES

Cost estimates were completed for each of the resources studied. Consultants estimated the capital, operating and maintenance costs for the potential projects at the sites that they identified, as well as other costs and credits as they pertained to the specific cases. BC Hydro provided estimates for the transmission, distribution and interconnection costs for each resource[1].

3.1 General Cost Estimate

The costs calculated in this study are estimates, and are based on the pre-feasibility level studies. A common framework for estimating the cost for energy production for each resource was used, with the exception of small hydro[2]. The production costs calculated are unit energy costs, levelized in year 2002 Canadian dollars and represented in cents per kilowatt hour (¢/kWh). This is a useful value for comparing the cost-effectiveness of different resources. The costs capture production costs only. “Value” items, such as dispatchability or greenhouse gas (GHG) credits, are *not* included in the estimates.

[1] Individual transmission, distribution and interconnection cost estimates were not done for the Small Hydro study, due to the number of potential projects. These costs were estimated by Sigma Engineering and are detailed in their report.

[2] Due to the number of sites evaluated, Sigma Engineering used their own template for cost estimates. The approach is comparable to that used for the other resources.

3.2 Levelized Cost Framework

The following financial parameters were used in the cost estimates:

1. An inflation rate of 0% was assumed.
2. A nominal interest rate of 8% was assumed.
3. No taxes were included.
4. Interest during construction was included where the construction period was more than a year.
5. Net Present Value (NPV) was calculated for the costs over an estimated project life of 20 to 30 years (depending on the resource).

3.3 Transmission and Distribution Cost Estimates and Limitations

BC Hydro's Transmission and Distribution Planning groups provided cost estimates for the potential sites identified in the study. Estimates are preliminary, subject to site and project specifics and system conditions. No system impact studies were performed, nor are system reinforcement and network upgrade costs included. The costs of environmental impact assessment, public consultation and site approval for transmission and distribution components were also not included.

4.0 ENVIRONMENTAL AND SOCIAL IMPACTS

Environmental, social, and economic criteria were considered when quantifying resource potential and identifying specific projects based on available existing information. A potential project for any of these resources would need to be reviewed to determine whether it meets BC Hydro's Green Energy Criteria.

Wind, small hydro, solar, geothermal and tidal current resources have low or negligible greenhouse gas emissions. Biomass generation creates greenhouse gas and other air emissions, but is considered neutral provided the source of the biomass fuel is sustainable. All projects for these resources have the potential to create GHG credits and to be considered green energy projects under BC Hydro's definition.

The environmental analysis done for each resource was preliminary. The wind and geothermal studies considered the environmental impacts specific to potential project sites. The other resource studies considered the impacts in general terms assuming typical project development circumstances. Further screening and impact assessment would need to be conducted at the next stage in feasibility assessment of specific projects.

First Nations and other communities may be impacted by development of resources. Impacts may be positive, such as economic development and job creation. Potential conflicts may be greater for the land-based resources (wind, small hydro and geothermal) as well as for projects requiring new transmission lines. Consultation with communities and other stakeholders that would be impacted by a project would be a required regulatory step in the development process.

5.0 RESULTS

The results of the studies done for each of the potential green energy resources are briefly summarized below. These summaries describe the resources and their characteristics, the technologies for energy conversion, the impacts and attributes, and the estimated energy potential and costs. The nature and development stage of the resources are different and, therefore, the focus and format of the results vary somewhat. It should be noted that the final qualification of each resource as "green" would need to be determined on a project-specific basis. Further investigations, feasibility studies, and detailed design would be required for the specific resources and sites prior to development. A summary of the results of the study is provided in Table 1.

5.1 Biomass

Summary*: The biomass resources studied include wood residue, demolition and land clearing waste (DLC), landfill gas, and municipal solid waste (MSW). The largest opportunities for development are* *primarily for wood residue co-generation systems. The identified biomass projects have an energy potential of approximately 240 MW (1935 GWh per year) with capacity factors between 65% and 100%. The production costs range between four and 10 cents per kWh.*

Biomass is defined as organic material derived from plants. Biomass is produced through photosynthesis as plants convert the sun's energy into chemical energy. The chemical energy in biomass can be extracted through combustion to produce energy that can be used as heat or power.

The most abundant source of biomass fuel in British Columbia is wood residue, a by-product from sawmills and other forestry operations. Other major sources of biomass fuel include municipal solid waste, demolition and land clearing waste, and agricultural waste, most of which is now disposed of in landfills. Anaerobic decomposition of organic material in landfills produces another source of biomass fuel, landfill gas.

Sustainably managed biomass resources are considered green because they are renewable and do not contribute to global warming. Carbon dioxide generated from the combustion of biomass is consumed as plants re-grow, so that as long as the resource is sustainably managed (for example, through replanting), the net contribution of carbon dioxide to the atmosphere is zero. Using wood residue in energy projects can also reduce the amount incinerated in beehive burners, greatly reducing the particulate emissions associated with that biomass.

Because biomass projects are generally situated in developed and populated areas, they offer some advantages. They do not require long transmission line extensions, although the transmission or distribution may require system upgrades. As well, many biomass projects can contribute to economic development through employment and encouragement of industry.

The following summarizes the biomass resource potential identified in this study and the corresponding projects and technologies that would be considered for development. Actual potential, particularly for wood residue projects, can fluctuate depending on forestry operations, other demands for biomass, and policies for the related industries.

5.1.1 Wood Residue

In British Columbia over 600 MW of power is currently generated from biomass fuels. The majority of this generation is at pulp and paper mills on Vancouver Island and the coast.

Over 6.1 million Bone Dry Tonnes (BDt) of wood residue is generated annually by forest products operations on the mainland of British Columbia. About 4.9 million BDt or 80% of this volume is produced at sawmills, with the balance coming from chip plants, plywood mills, and other forest industry operations.

Some 4.5 million BDt or 74% of the total is consumed in pulp mill boilers, cogeneration plants, power plants, medium-density fibreboard plants, and other facilities. The balance of approximately 1.6 million BDt is incinerated in beehive burners, making no productive use of the resource and creating significant environmental and health problems.

The productive use of this wood residue as fuel for cogeneration and power plants would provide approximately 210 MW to 220 MW of power for sale to the grid. Several projects are currently being evaluated by power developers. The projects specified in the study represent a green energy potential of 180 MW capacity (1500 GWh per year) at a cost of four to nine cents per kWh.

Wood residue projects that result in the closure of beehive burners contribute to improved air quality and reduced health problems.

5.1.2 *Municipal Solid Waste (MSW)*

Over 4.2 million tonnes of municipal solid waste (MSW) is generated annually in British Columbia, of which 43% or 1.8 million tonnes is recycled. The balance of 2.4 million tonnes is disposed of primarily in landfills, with less than 10% being incinerated. The Lower Mainland region disposes of about 1.5 million tonnes, of which 1.2 million tonnes comes under the jurisdiction of the Greater Vancouver Regional District (GVRD). Some 250 000 tonnes of the GVRD total is incinerated in its Burnaby incinerator. The balance is sent to the Vancouver and Cache Creek landfills. A turbine generator now being installed at the Burnaby incinerator will generate some 22 MW of power for the grid. The 950 000 tonnes of MSW available in the GVRD jurisdiction could generate about 90 MW of power to the grid. The Kamloops/Okanagan area produces some 100 000 tonnes of MSW, which could generate about 9 MW of power.

Unlike Europe and other jurisdictions, landfilling continues to be the primary method for disposing of MSW in British Columbia, because of the relatively low cost. It is unlikely that there will be significant additional power generation from MSW in British Columbia in the near future. The projects specified in the study represent a potential of 25 MW capacity (200 GWh per year) at a cost of five to 10 cents per kWh. Because MSW is not considered a clean and renewable resource, it does not currently meet BC Hydro's Green Energy Criteria.

5.1.3 Landfill Gas (LFG)

Landfill gas (LFG) from landfill sites on the mainland of British Columbia has the potential to produce some 15 MW of power. An 8 MW system is now being developed at the Vancouver landfill. The balance could be from several smaller projects located at landfill sites located in the Interior; however, collection systems would have to be installed for potential power generation projects to be feasible. Generally LFG does not represent a significant source of power for the province. The projects specified in the study represent a green energy potential of 11 MW capacity (85 GWh per year) at a cost of four to five cents per kWh.

5.1.4 Demolition and Land Clearing (DLC)

An estimated 1.5 million tonnes of demolition and land clearing waste is available annually on the British Columbia mainland. The majority is delivered to landfills at a cost considerably lower than the tipping fee that would be required to cover the cost for transporting, sorting and processing the DLC so it would be suitable as a fuel. Unless disposal in landfills is restricted, it is considered unlikely that this biomass source will be a viable fuel in the foreseeable future.

5.1.5 New Technologies - Gasification

Most wood residue biomass projects use conventional combustion/steam cycle generation systems with or without co-generation of heat. This technology is the most feasible for large projects (over 10 MW). However, potential biomass projects that have a smaller fuel source often are not economically feasible using conventional technology.

New technologies have been developed for the gasification of biomass fuels. The major advantage is that a gas engine or gas turbine can be used in a combined cycle, which is 30% to 50% more efficient than conventional steam cycle technology. Also, since the gases produced by the gasifier systems contain fewer particulates, they can be used directly in existing boiler facilities to reduce fossil fuel usage and overall emissions. This also reduces the cost of emission control technology.

The main disadvantage of advanced gasification systems is that the initial capital costs can be significantly higher than for conventional systems.

British Columbia has numerous potential sites for small systems in the range of 1 MW to 5 MW. Such sites would primarily include sawmills and other forest operations that generate biomass fuel, but are located at a distance from larger projects, making the transportation costs prohibitive for a conventional biomass project. The gasification systems can also be automated, which can reduce the operating costs and improve the economics of smaller projects. The study identifies a capacity of 20 MW with energy production of 150 GWh per year at a cost of seven to 10 cents per kWh.

5.2 Geothermal

***Summary**: Geothermal energy has not yet been developed at a large scale in B.C., but there is ongoing exploration to prove the commercial viability of the resource. The identified geothermal projects have an energy potential of between 150 and 1070 MW (1200 to 9000 GWh per year) with a capacity factor of about 100%. The production costs range between five and nine cents per kWh.*

Geothermal energy may be exploited where heat concentrated near the earth's surface is recoverable in the form of natural hot water or steam. Superheated thermal water is recovered from geothermal reservoirs by drilling production wells. The resources considered for this study are high-temperature, liquid-dominated convection systems at 170°C to 260°C and moderate-temperature, liquid-dominated systems between 100°C and 170°C. Resources are most commonly associated with geologically young stratovolcanos or crustal rifts. Vapour-dominated systems are not known to occur in British Columbia.

For electric power production, geothermal reservoirs are tapped by drilling production wells, typically greater than 15 centimetres in diameter and up to 3000 metres in depth. Several wells spaced 200 to 500 metres apart, each having net capacities of 2 MW to 10 MW, are connected by steam lines to a central power plant. For high-temperature (above 180°C), fluid-dominated reservoirs, a portion of the reservoir fluid is flashed to saturated steam in a separator vessel at a reduced pressure, dried and passed through a conventional steam turbine. For moderate-temperature systems (120°C to 170°C), "binary" technology is used, where the geothermal fluid produced is put through a heat exchanger in which a secondary working fluid with a low boiling temperature—such as iso-butane, benzene or propane—is vaporized. Spent geothermal fluid is commonly re-injected.

Off-the-shelf geothermal power plants are available from a variety of large suppliers, such as Mitsubishi and General Electric, and specialty companies such as Ormat International Inc. and Geothermal Power Co., Inc. Common turbine sizes are 2 MW, 10 MW, 20 MW, 55 MW, and 100 MW installed separately, in pairs, or in other combinations. Existing geothermal operations (producing from fluid-dominated reservoirs) that supply electrical power in the western United States typically vary in size from 10 MW to 260 MW.

Sixteen prospective geothermal sites were identified in British Columbia for potential power production based on their geologic setting (volcanism, faults), evidence of repeated volcanism and the occurrence of hot springs and other geothermal manifestations.

Of the 16 identified geothermal sites, six sites offer the greatest potential for commercial development based on currently available data on their resource characteristics and their location relative to the power grid and market. The six sites are listed below in order of decreasing potential for development:

Site name (location)	Potential	Size (MW)
Meager Creek (Pemberton	Leased, possible commercial development	100-200
Pebble Creek (Pemberton)	Very good	200
Lakelse (Terrace)	Promising for binary plant	50
Mount Cayley (Squamish)	Promising, but severe terrain	100
Mount Edziza	Prospective, but little information available	200-500
Liilooet Fault Zone	Prospective, but little information available	20

The resource potential for these sites is between 150 MW (for two to three sites with greater probability for commercial development) and 1070 MW (higher end of total potential for the six sites). The capacity factor of geothermal resources is 100% and the availability of the plants is estimated at 95%. This yields an energy production potential of between 1200 GWh and 9000 GWh. The levelized cost of energy is between five and nine cents per kWh for a range of plant sizes between

10 MW and 55 MW[3]. Since capacity factor and resource availability are both high, geothermal plants are ideally suited to supply base power requirements.

Costly exploration and confirmation drilling is necessary at the outset of a project to determine production characteristics and the ultimate commercial production capacity of a resource. This represents high capital costs at a time when the commercial resource productivity is unconfirmed. Attractive project economics and incentives are necessary to overcome the early-stage resource risk.

Geothermal resources greater than 80°C are vested in the provincial government under the Geothermal Resources Act, revised by statute in 1996. Permits convertible to geothermal leases can be issued only by public tender. The requirement for competitive bids for permits creates a problem for exploration at this stage in the industry. More information is needed at virtually all of the prospective geothermal sites; however, private industry might not be willing to spend the money on grass-roots exploration with no assurance of the development rights. It is difficult to know with certainty how the industry will be governed in the future. Consequently, investment entails added risk.

Geothermal power is environmentally benign. A typical flash steam plant emits less than 250 kilograms (0.25 tonnes) of carbon dioxide per day per MW, compared with 5.5 tonnes per day for a coal plant and 3 tonnes per day for a methane gas plant. Binary plants are essentially free of emissions.

A number of impacts and benefits are associated with geothermal power development. These include environmental aspects, development

[3] These plant sizes were selected for the purpose of meaningful cost estimates. Some of the sites have the possibility of being developed in the order of hundreds of MW capacity, which would theoretically create economies of scale and lower the levelized cost.

challenges and social issues. As with any energy development project, these issues depend on the project and site characteristics.

5.3 Small Hydro

***Summary**: The hydro resources considered in this study are identified and evaluated as run-of-river projects up to 50 MW in size. The identified small hydro projects have an energy potential of about 2450 MW (10 700 GWh/year) with capacity factors between 25% and 70%. The production costs range between less than four and more than nine cents per kWh.*

The potential projects considered in this study are run-of-river hydro power facilities, which means that the streamflow passing through the powerhouse is essentially the flow that naturally occurs in the stream. This implies that there is no (or minimal) storage reservoir, and flows downstream of the powerhouse are virtually identical to pre-development flows.

The geography of British Columbia provides many opportunities for run-of-river small hydro development. Projects identified in the study range in size from 500 kW to 47 MW and are located in most regions of the province. Because of differing terrain, site layout, and hydrology, the projects also have a range of unit energy costs.

The identified run-of-river projects represent a potential total capacity of 2454 MW with the energy production of 10 712 GWh for 756 sites. The costs range from less than four cents per kWh to more than nine cents per kWh. About 40% of the project sites, comprising 67% of the total developable energy, have identified costs of less than seven cents per kWh. (This is indicative of the fact that larger projects are generally more economical than smaller ones.) These numbers are very crude estimates; more detailed studies would be required to define the costs for each project. This may increase the costs of some of the projects identified in this study and, in some cases, indicate that the projects are not economically feasible to develop. However, further investigation will likely identify additional small hydro sites not identified in this study.

The inventory of 756 sites is based on sizing each project to the mean annual flow and assumes operating on a run-of-river basis. However, this may not be the optimal configuration for some of these projects. The study treats each project separately and includes transmission costs to the nearest location on the BC Hydro grid.

Before considering development, each site would require detailed investigation of site layout, hydrology, and interconnection costs. This information can then be used to optimize layout and for project costing.

The relative density of projects in British Columbia, combined with the relative sparseness of transmission and distribution lines, makes it sensible to consider clustered projects that can share infrastructure. Roads, transmission lines, substations, penstocks, and even power stations can potentially be shared by more than one project.

Potential issues associated with small hydro power development include environmental aspects, development challenges and social issues. Since small hydro projects have well-established technologies and development processes, these issues are well understood and detailed in the Small Hydro report, available on BC Hydro's website.

5.4 Tidal Current

***Summary**: Tidal current energy is unique among the resources investigated in this study in that it has not yet been commercially developed anywhere in the world. This study is the first assessment of its kind done for tidal current energy in B.C. Several different technologies are being developed that could realize the potential of this resource.*

Because many of them are in the early stages of research and development, the energy production and cost estimate data are limited and have a high degree of uncertainty compared with those for the other resources. This study involved preliminary assessment of the resource and identification of potential sites. Case studies of two sites were done to produce a projection of what the resource may cost to develop. The identified tidal current projects have an energy potential of about 1500 MW (2700 GWh per year) with a capacity factor of about 20%. The production costs range between 11 and 25 cents per kWh.

Tidal current energy is derived from the flow of coastal ocean waters in response to the tides. Large tidal currents do not necessarily require a large tidal range. Two important factors that influence the magnitude of tidal currents are the phasing of the tides (location and timing of high and low tides) and the presence of narrow passages (concentration of tidal flow). The advantages of tidal current energy include the fact that it is regular, predictable and renewable.

In British Columbia, some of the highest-velocity tidal current flows occur through the passages between the Strait of Georgia and Johnstone Strait. The tidal range is moderate (5 metres), but the tides from the Pacific through Johnstone Strait are roughly 180 degrees out of phase with the tides entering the Strait of Georgia from the southern end of Vancouver Island.

In concept, tidal energy may be viewed as being extracted directly from the kinetic energy of a tidal stream, or as being extracted from the potential energy of impounded tidal water. In reality, the two are closely related, since the extraction of kinetic energy from a tidal stream increases the slope of the hydraulic grade line, yielding “partially impounded” water on alternating ends of the tidal channel.

The study reviewed several different tidal current technologies being developed. Each has a different configuration for extracting the power from tidal currents. In general, each technology has a component (a turbine or flow concentrator) that is installed in the tidal stream. The kinetic energy is transferred to a turbine, then converted to electricity by a generator.

The resource assessment identified 55 sites with current speeds over 2 metres per second (m/s), which would yield a gross annual energy potential in the order of 20 000 GWh. Selection of sites that are more feasible for development yielded 12 sites with a total energy production of 2700 GWh per year. It is expected that the number and capacity of potential tidal current sites could increase as the application of the technology to the resource is advanced.

Case studies of two sites were done to produce a projection of what the resource may cost to develop. As the technology is developed and the resource is better modelled, the costs are expected to decrease due to efficiencies and a larger amount of exploitable power. A large site in Discovery Passage (800 MW, 1400 GWh per year) yielded a cost of 11 cents per kWh. A smaller site at Race Passage (43 MW, 76 GWh per year) yielded a cost of 25 cents per kWh.

The environmental and socio-economic impacts of tidal current energy are dependent on location and specific physical site characteristics. Limiting these impacts would be a key consideration in siting, design and construction of each system. The effect of a tidal current development on the tidal regime is estimated to be low locally and negligible globally. Air quality impacts would also be negligible with low greenhouse gas emissions. The main impacts would be on fish and marine mammals and on navigation and fishing operations. These impacts would depend on the technology used and the site and development characteristics, and would require investigation on an individual basis.

The tidal current study explores the resource issues in detail and is available on BC Hydro's website.

5.5 Wind

***Summary**: Wind energy has not yet been developed at a large scale in B.C., and BC Hydro has focused much effort in the last few years on exploring and enabling this resource. The wind projects identified in this study have an energy potential of approximately 730 MW (1600 GWh/year) with capacity factors between 18% and 38%. The production costs range between six and 12 cents per kWh.*

Wind energy is considered a green energy resource because it is renewable and does not create greenhouse gas emissions linked to global warming, or other pollutants. Due to the intermittent nature of wind, wind energy is not a firm energy source, but can provide a good source of green energy as part of a resource mix. Wind turbines have been used in many parts of the world for utility-scale energy production. The technology has experienced great improvements in the last 20 years, with a resulting decrease in the cost of wind energy.

British Columbia has many windy locations; however, many of the best wind resources are in remote mountainous locations far from the transmission grid and difficult to access. In addition, turbines are best located on land with low or no vegetation. This combination of difficult terrain, along with the cold climatic conditions that are present in much of the province, presents some special challenges when developing wind energy and identifying potential sites. Nevertheless, wind energy has been developed in similar conditions in other parts of the world.

This study used a three-tiered process to identify potential wind farm locations, starting with spatial modelling conducted in a GIS (Geographic

Information System) platform, through to detailed investigation on small-scale maps, and finishing with site inspections. Three areas of the province appear to offer the best potential for wind development: the North-West Coast, the North-East and the South-Central Interior. At each stage of the process, the number of identified sites was reduced to concentrate the effort on sites that were the most economically viable and where construction and transmission connection were feasible. A detailed conceptual evaluation of the top 10 wind sites indicated a total potential installed capacity of 730 MW with the sites ranging from 24 to 133 MW of installed capacity. These 10 sites have a potential total energy production of 1600 GWh with production costs ranging from six to 12 cents per kWh. The study does not preclude other sites being identified in the province. The 10 sites are:

North-West Coast

- Mount Hays (Prince Rupert)
- Ridley Island (Prince Rupert)

North-East

- Mount Wartenbe (Chetwynd)
- Pingle Creek Ridge (Dawson Creek)
- Aasen (Dawson Creek)
- Bear Mountain (Dawson Creek)

South-Central Interior

- Sugar Loaf Mountain (Merritt)
- Ridge south of Ashcroft
- Ridge near Kingsvale
- Monte Ridge (Vernon)

One of the most important aspects in estimating the production costs of wind energy is to have a good estimate of the wind resource at a site. This generally requires monitoring the resource at the site for at least one year. For the Phase 2 study, measured data was not available for most of the sites, so the wind resource was estimated from the BC Wind

Resource, which shows the mean annual wind speed at a 1 km grid scale for all of B.C. The map was derived using a meso-scale wind model that takes the topography into account. Information on the BC Wind Resource Map and the details for purchasing the map can be found on: www.bchydro.com/greenpower.

Through its wind monitoring program, BC Hydro has installed a total of 20 wind monitoring stations across the province, of which four have been decommissioned. A typical installation includes a 50-metre mast with anemometers and wind vanes installed at 30-metre and 50-metre elevations. In some locations the monitoring equipment was installed on existing communications towers.

Wind development has a number of potential related environmental, cultural, and socio-economic issues. As part of the study, a simple screening methodology was used to identify such issues. The most common issues identified at the 10 sites were visual impacts from the development and potential impacts on birds. Generally it was concluded that these impacts could be avoided or mitigated by careful siting of the wind turbines. First Nations interests were also identified at some of the sites. None of the issues identified in the screening-level assessment have impacts significant enough to prohibit the development of a wind farm at any of the 10 sites.

Offshore wind development on Vancouver Island was also investigated as part of a separate study. The study covered only the northern end and west coast of Vancouver Island. Five potential sites were identified and two of the sites were recommended for further investigation. A 50 MW development at each of these two sites was estimated to have energy production costs of nine cents per kWh.

5.6 Building Integrated Photovoltaic (BIPV) Solar and Small-Scale Wind

***Summary**: Building Integrated Photovoltaic (BIPV) solar and small-scale wind were included in this study to provide a complete review of potential green energy resources. This part of the study focused on the opportunities from small-scale grid-tied applications. The identified solar BIPV potential is estimated at 11 MW (10 GWh per year) with capacity factors between 7% and 12%. The production costs range between 40 and 110 cents per kWh. The identified small-scale wind potential is estimated at 25 GWh per year with capacity factors between 10% and 30%. The production costs range between 20 and 35 cents per kWh. These resources have a high unit energy cost and do not represent a significant opportunity for development in B.C. The BIPV solar and small-scale wind study is available on BC Hydro's website.*

5.6.1 Solar

The solar energy resource in British Columbia varies widely between summer and winter. The fluctuation in seasonal weather patterns in British Columbia weather makes grid-tied solar electric systems more efficient than off-grid systems since battery storage is not required.

However, the low cost of utility electricity in British Columbia prevents grid-tied photovoltaic systems from being a viable economic choice unless other values can be obtained from the photovoltaic system. By using photovoltaic modules as building materials (Building Integrated Photovoltaics, or BIPV), this problem is partially addressed, reducing the overall cost of solar electricity and providing other benefits such as: acoustic insulation, thermal insulation, weather proofing, aesthetic building design, daylighting, shading and privacy. BIPV can be used in a building in many ways. BIPV roofing incorporates solar cells into conventional roofing products such as tiles or metal roofing.

Glass-based BIPV modules may be used in atria to replace overhead, semi-transparent glazing or in sunspaces, greenhouses and medium to large skylights. Curtain walls represent an even larger market for BIPV modules.

The total potential generating capacity from residential BIPV on detached or semi-detached homes in British Columbia is estimated at 280 MW. However, due to the unfavourable economics of using solar electricity in British Columbia, an assumed uptake of 2.5% of consumers with suitable sites leads to a potential generating capacity of 7 MW, which would produce approximately 7 GWh per year.

The maximum potential generating capacity from BIPV on commercial buildings in British Columbia is estimated at 160 MW. A conservative estimate of actual potential assumes an uptake of 2.5% and a system size of 2.5 kW, which leads to a potential generating capacity of 4 MW. This would produce approximately 2.6 GWh per year.

The cost of BIPV is very high when compared with most other renewable energy applications, at between 40 and 70 cents per kWh for commercial application to between 90 and 110 cents per kWh for residential applications. Because of the limited potential resource from BIPV and the high cost for electricity generation, BIPV is not feasible for production of green energy in British Columbia from a utility perspective. BIPV could be considered as an effective energy- and cost-saving measure for building owners.

5.6.2 Small-Scale Wind

This study also focused on small wind turbine installations, ranging in size from 1 kW to 50 kW. This type of wind turbine is considered suitable for residential, small business or farm applications.

Residential or small-scale wind power is much closer than photovoltaic power to being competitive with utility power in British Columbia, particularly if suitable windy locations are identified. It is difficult to predict the customer uptake of such systems. The potential for small-scale wind power production in British Columbia has been estimated at 25 GWh per year based on 10 kW installation at 1900 residential sites. The cost for small-scale wind application ranges between 20 and 35 cents per kWh.

6.0 CONCLUSIONS

Phase 2 of the Green Energy Study for British Columbia evaluated six green energy resources: biomass, geothermal, small hydro, tidal current, wind and BIPV solar. All of these resources, with the exception of BIPV solar and small-scale wind, have the potential to contribute to the utility resource mix. BC Hydro currently generates between 43 000 and 54 000 gigawatt hours of electricity annually. From the projects identified, a nameplate capacity of about 5000 megawatts is estimated with an annual energy production potential of about 18 000 gigawatt hours. The production costs for the potential green energy range between four and 25 cents per kilowatt hour. As many of these resources are seen as near-commercial, the production costs are expected to decrease as the technologies are developed, the resources are better understood and the processes for developing the resources are established. Other resource attributes and impacts, such as dispatchability and greenhouse gas reductions, are important for consideration of green energy in the resource mix. The results of the study are summarized in Table 1.

REFERENCES

The following reports were prepared by external consultants for BC Hydro Engineering for the purposes of this study.

1. Biomass: BC Green Energy Study - Phase 2 - Biomass, Stothert Engineering Ltd., 2002, P.301035
2. Geothermal: BC Green Energy Study - Phase 2 - Geothermal Potential, Fairbank Engineering Ltd., 2002.
3. Offshore Wind: Vancouver Island, Offshore Wind Farm Surveillance, Tech-wise A/S, 2002.
4. Small Hydro: British Columbia Green Energy Study Phase 2 – Small Hydro, Sigma Engineering Ltd., 2002, E6040.
5. BIPV Solar and Small-Scale Wind: BC Hydro Green Energy Study - Phase 2 - BIPV Solar and Small-Scale Wind, Eric Smiley, BCIT Technology Centre, 2002.
6. Tidal Current: BC Hydro, BC Green Energy Study - Phase 2 - Tidal Current Energy, Triton Consultants Ltd., 2002.
7. Wind: Wind Energy Resource Assessment - BC Green Energy Study - Phase 2 - Concept Study Report, Hydro Tasmania, 2002, No. 108034.

ADDITIONAL RESOURCE

Green Electricity Resources of British Columbia (map), BC Hydro and Canadian Cartographics Ltd., 2002. Available from Canadian Cartographics Ltd., www.canmap.com or 57B Clipper Street, Coquitlam, B.C. V3K 6X2.
ISBN 1-921259-28-X

TABLE

Table 1: BC Green Energy Study - Phase 2: Mainland - Summary Table

Notes and Assumptions

- This table provides a brief summary of information about the resources assessed in the Green Energy Study for British Columbia – Phase 2: Mainland.
- The estimates for energy potential, cost, and impacts are at a pre-feasibility level.
- The methodology for the estimates and the detailed assessments are provided in the study reports for each resource. They also contain more information on the resources including: characteristics, technology, and development methods.
- The points identified under Environmental, Social, and Development Factors for each resource are noted to bring the attention to possible concerns for each resource. All impacts and benefits are site specific and require assessment on a project basis.
- Environmental, social, and economic criteria were considered when quantifying energy potential and identifying specific projects based on available existing information. Projects would require review of compliance with BC Hydro's green criteria prior to development.
- The estimates of the energy potential are based on identified potential projects. These were selected based on economic, environmental, and social criteria and proximity to load centres and the power grid.
- Capacity factor: The ratio of the average annual power output to the rated power output of generating plants. Capacity factor refers to the resource capability to generate electricity. Intermittent resources dependent on weather and other conditions like wind and solar energy have lower capacity factors than resources with a constant or regular source, such as biomass and geothermal.
- Availability: Availability refers to the plant operation characteristics (including mechanical and electrical components). It is the fraction of time that all equipment is in operating condition and is usually estimated in per cent or number of hours operating in a year.

Environmental

- Wind, small hydro, solar, geothermal and tidal current energy have low or negligible greenhouse gas (GHG) emissions. Biomass has greenhouse gas emissions, but is considered neutral provided the source of the biomass fuel is sustainable.
- All projects for these resources have the potential to create GHG credits and to be considered green energy projects.
- The environmental analysis done for each resource was preliminary. The wind and geothermal studies considered the environmental impacts specific to potential project sites. The other resource studies considered the impacts in general terms using typical project development circumstances. Further screening and impact assessment would need to be conducted at the next stage in feasibility assessment of specific projects.

Social

- First Nations and non-First Nations communities may be impacted by development of resources. Impacts may be positive, such as economic development and job creation. Potential conflicts may be greater for the land-based resources (wind, small hydro, and geothermal) as well as for projects requiring new transmission lines.

Development

- Proximity to the power grid and requirements for interconnection are key components in the feasibility of projects. Other issues include but are not limited to: licensing, resource use planning, and stage of technology development.

Economic

- Production cost estimates were done for identified potential projects for each resource. The levelized cost of energy in year 2002 Canadian dollars was estimated (Net Present Value) in cents per kilowatt hour (¢/kWh). The costs shown here represent an average range of those results.

Table 1: Summary

Green Energy Resource	Technology	Energy Potential: Capacity (MW)	Energy Potential: Energy (GWh/yr.)	Estimated Unit Energy Cost (¢/kWh)	Capacity Factor	Availability	Potential In-service Time
Biomass	Conventional wood residue co-generation	180	1500	4 – 9	65% – 95%	91%	1 – 5 years
	Small-scale new technology (gasification)	20	150	7 – 10	95% – 100%		2 – 5 years
	Municipal solid waste	25	200	5 – 10	75% – 85%		1 – 5 years
	Landfill gas	11	85	4 – 5	95% – 100%		1 – 3 years
Geothermal	Single, double flash plants for high temperature resource (>180°C) and binary plants for moderate temperature (120°C – 170°C)	150-1070	1200-9000	5 – 9	100%	95%	2 – 5 years
Small Hydro	Run-of-river, sized to mean annual flow	447 497 639 270 <u>601</u>	2 112 2 284 2 698 1 162 <u>2 456</u>	< 4 4 – 5 5 – 7 7 – 9 > 9	Varies by location and season. Coastal origin or lake storage (60 – 70%). Pronounced spring runoff, dry summers and cold winters (25 – 40%)	91%	Project construction time: <1 MW: 1 yr. 1.1 – 10 MW: 2 yr. >10 MW: 3 yr.
	Totals	2 454	10 712				
Tidal Current	Assumed marine current turbine technology for estimates (but all technologies are in development stage)	1 500	2 700	11 – 25	20%	NA	5 – 10 years
Wind	Assumed 1.75 MW turbine (0.7 MW to 2 MW per turbine is possible)	550 180	1 300 300	6 – 9 9 – 12	18% – 38%	95%	2 – 3 years
BIPV Solar and small-scale wind	Building Integrated Photovoltaic (BIPV)	11	10	40 – 110	7% – 12%	95%	Installation of small-scale systems is dependent on building construction, but is generally short (weeks to months)
	Small-scale wind (1 kW – 50 kW turbines)	19	25	20 – 35	10% - 30%	91%	

See Notes and Assumptions

Table 1: Summary

Green Energy Resource	Environmental Factors	Social Factors	Development Factors	Assumptions/Comments
Biomass	• Greenhouse gas (GHG) neutral • Air pollutants: particulate, nitrogen oxides (NO_x), and carbon monoxide (CO). Emission control equipment and operation techniques are used to reduce emissions to required levels. Biomass energy plants that lead to the shutdown of beehive burners improve local air quality • Other environmental concerns include water use and sustainable practices for obtaining biomass fuel	• Local job creation • Economic development in communities • Concern with air pollution from combustion plants	• Customer-Based Generation program will enable many of the larger co-generation projects • Higher capital costs and longer payback periods prohibit development of smaller, more remote projects. Security of fuel supply	• Size and cost of biomass projects that will be developed depend on the availability of biomass fuel, which depends on many factors including those affecting the forest industry. Estimates are based on current biomass fuel estimates and cannot account for future mill closures, etc. • Municipal solid waste does not currently meet BC Hydro's Green Criteria • Gasification technologies are in use elsewhere in the world, but not in B.C. They have potential for smaller-scale applications where conventional systems are uneconomic
Geothermal	• Flash steam plants emit carbon dioxide (~250 kg/day/MW) • Sulfur dioxide and nitrous oxides emissions are a low percentage of that emitted by fossil fuel generation • Binary power plants do not emit geothermal gases into the atmosphere • Land use: 200-2000 hectares/ 100 MW plant. Land can be multi-purpose (e.g. agriculture)	• Noise and visual impacts of power plant • Competing uses for land: tourism, also high potential for new sites, access, opportunities • Investigation required to determine impacts on surface manifestations such as hot springs	• Commercial production has not been demonstrated at any identified resources in British Columbia • Feasibility stages of development have high costs and risks as exploratory drilling is required to confirm production capacity • Proven resources would have good expansion potential and provide dependable capacity	• Resource assessment was based on existing geologic information • Some temperature and other data are available from hot springs and drilling at some of the sites • Cost information is primarily from projects in the USA, where there has been significant development of geothermal resources • Resource potential (MW, GWh) is based on 6 identified sites with the greatest potential for commercial development. The range shows the limits of capacity for 2 sites (higher probability for commercial development) to 6 sites (higher end of total potential)
Small Hydro	• Fish and fish habitat • Linear element (penstock, T-line) disruption of migration corridor	• Minor land use issues • Water use issues– operating regimes	• Water licensing • Clustering of projects, sharing of infrastructure can improve the economics of hydro and other green projects	• Project size ranges from 500 kW to about 47 MW capacity • Approximately 40% of the project sites are developable at less than \$0.07 kWh; these comprise about 67% of the total developable energy • Larger projects are generally more economic • Sites were evaluated independently, not as clusters

See Notes and Assumptions

Table 1: Summary

Green Energy Resource	Environmental Factors	Social Factors	Development Factors	Assumptions/Comments
Tidal Current	• Environmental impacts are unquantified as there are no existing tidal current projects • Very small impact on global tidal balance, or climate change • Regional reduction in current velocities, tidal height and timing may have some biological and/or ecological impact • Direct impacts from construction, anchoring and operation on marine life and physical environment	• Marine traffic, navigational channels • Recreational and commercial fishing	• Tidal current power technology is unproven, though there are several different technologies in the development stage • Development of this resource would require significant further investigation, resource monitoring, and prototyping of technologies	• The cost estimates and other analyses are very rough at this stage based on the uncertainty in the technology, efficiency, deployment method, and size of installations
Wind	• Land use, impact on vegetation • Clearing of forested areas • Wildlife associated with habitat and migration paths, specifically birds • No absolute constraints to development at high potential sites	• Visual impacts • Recreation and tourism • Important landforms	• At least 1 year of monitoring is required for next phase of feasibility for project sites • Feasibility issues apart from wind resource and cost include: access, terrain stability, soil erosion, hydrologic impacts	• Wind farm sites range in size from 24 to 133 MW capacities • Site potential is based on limited modeled data (wind speed mapping and some monitoring data)
BIPV Solar and small-scale wind	• Toxic materials used in the manufacture of PV modules are the same as for micro-electronic devices • Recycling or reclamation mitigates the environmental impact of these materials	• Benefits to user of being socially responsible company or citizen • Economic development for manufacture and installation of systems	• For BIPV or small-scale wind to be developed in B.C., by residential and commercial customers, programs encouraging small-scale grid-tied renewables would be required, such as net metering	• The economics of BIPV depend on the avoided costs of traditional building materials • The technology is commercially available, and there are many provinces/states and utilities that have programs to promote their use

See Notes and Assumptions