Section 5
BC Transmission Inquiry

Comments on Resource Options to BC Hydro

by: ESVI, OEIA, ITO and ROMS BC

By: Ludo Bertsch, Horizon Technologies Inc.
(250) 592-1488; ludob@horizontec.com
Date: Aug 14, 2009
For: ESVI, OEIA, ITO and ROMS BC

On July 23, 2009, BC Hydro held a Resource Options workshop for the Long Term Electricity Transmission Inquiry. Participants were given the opportunity to provide written comments by August 14, 2009 for BC Hydro's consideration in its September 18 filings.

The following document contains the written comments on behalf of Energy Solutions for Vancouver Island Society (ESVI), Okanagan Environmental Industry Alliance (OEIA), IslandTransformations.Org (ITO) and Rental Owners and Managers Society of BC (ROMS BC).

Yours truly,
Ludo Bertsch, P. Eng
Horizon Technologies Inc.
bcuc@horizontec.com
(250) 592-1488

Representing: ESVI, OEIA, ITO & ROMS BC

1.0 Scenario evidence

We also hereby submit the attached ESVI, OEIA, ITO & ROMS BC to BCTC "Comments on Scenarios" for Transmission Inquiry[1] for BC Hydro to consider.

2.0 Solar:

2.1 Solar in US and BC

2.1.1 Solar - US and BC Solar Radiation

There is a tendency for one to consider that the hot Arizona desert has plenty of solar potential for solar renewable energy, and to assume that BC would have significantly less. This reaction is understandable with maps such as those shown below from the National Renewable Energy Laboratory[2,3]:

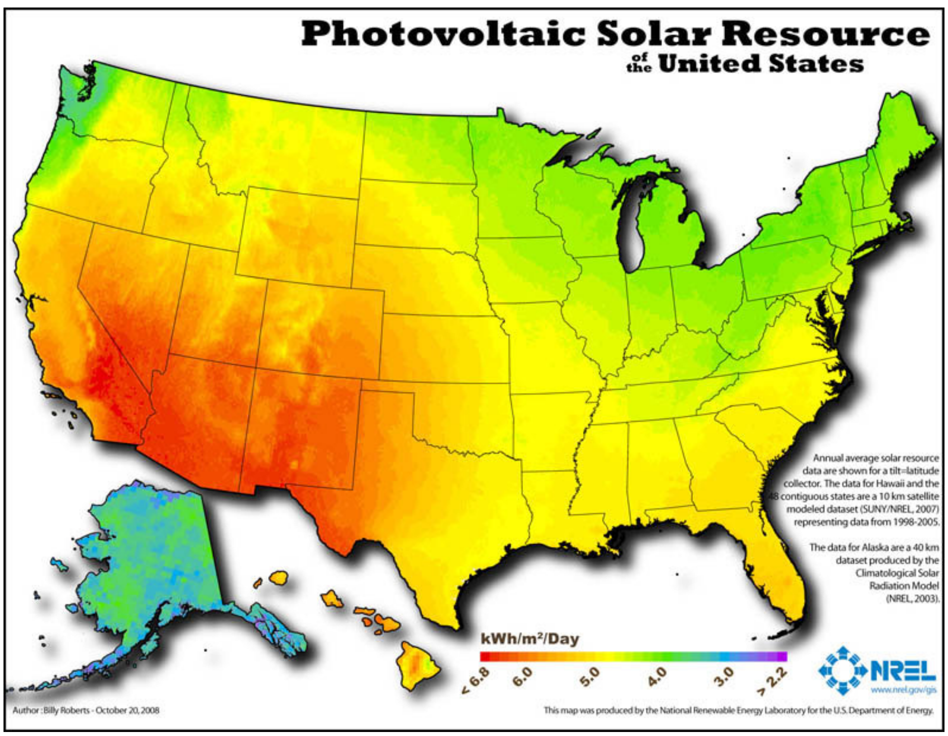

Figure 1 *– Solar insolation shaded map of US*

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[1] Accompanied ESVI, OEIA, ITO & ROMS BC "Comments on Scenarios to BCTC" for Transmission Inquiry, Aug 12, 2009

[2] Appendix A, (Figure 1), National Renewable Energy Laboratory, Solar insolation shaded annual map of US

[3] Appendix B, (Figure 2), National Renewable Energy Laboratory, Solar insolation lumped annual map of US

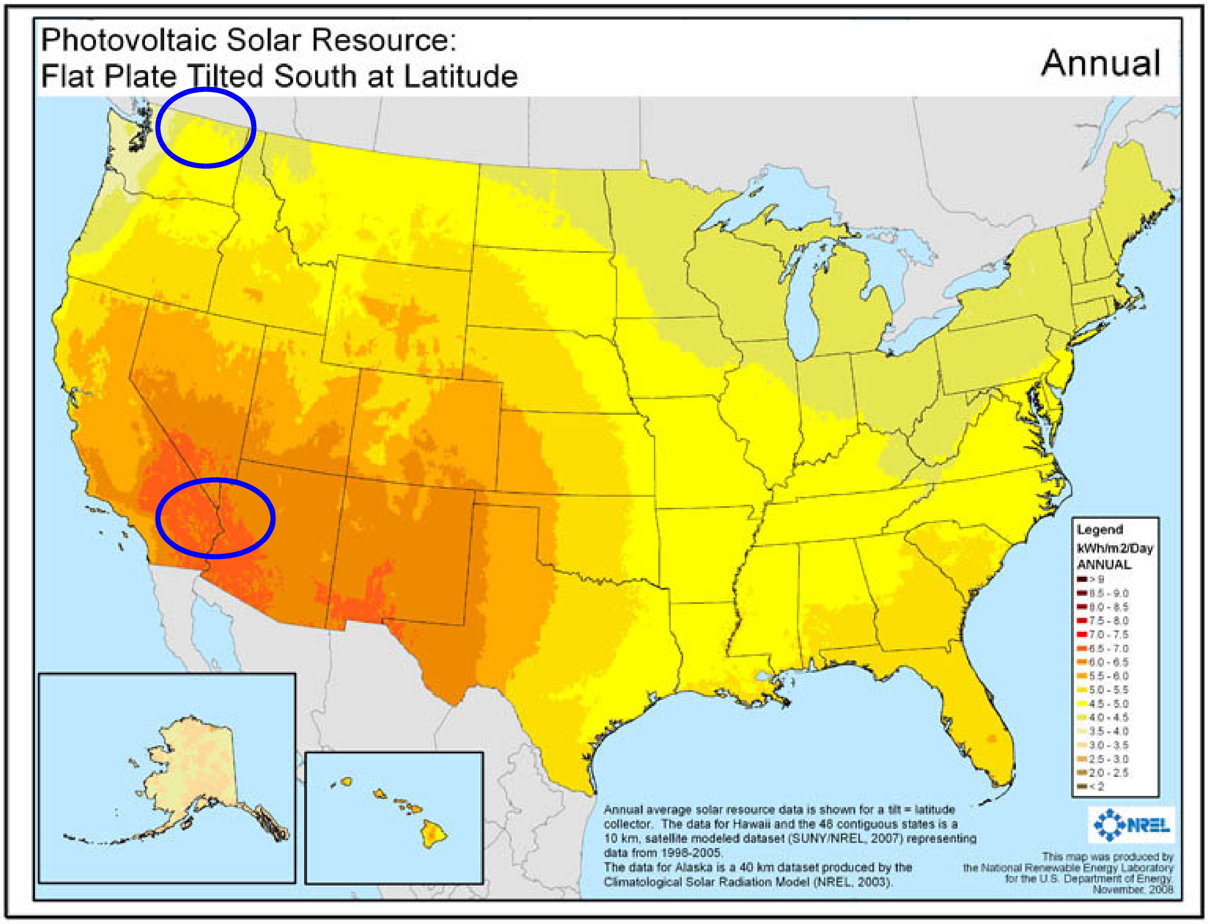

Figure 2 *– Solar insolation lumped map of US*

The maps show the annual levels of solar radiation (called, insolation) for areas through the United States.

The deserts of Arizona and Nevada are well known for their focus on significant solar projects. As seen in Figure 2 above, the areas around Arizona and Nevada show high levels of solar insolation with red shading, and northern Washington (bordering on BC) with lower levels with light brown/yellow shading. This seems to support the theory of a significant lack of solar potential in BC.

To gauge the actual difference between the two areas over the year, one approach would be to compare the actual solar insolation values for Phoenix, Arizona[4] and Kelowna, BC[5]. The overall solar radiation based on an average for the year[6], for Phoenix is 6.5 kWh/m^2 while Kelowna is 4.1 kWh/m^2 –

[4] Appendix C, National Renewable Energy Laboratory, Renewable Resource Data Center, Phoenix Solar Radiation tables

[5] Appendix D, National Resources Canada, Photovoltaic Potential and Solar Resources for Kelowna

[6] assuming the solar panels are tilted south at an angle equal to the latitude

Kelowna has 63%[7] annual solar radiation as Phoenix. Even this difference is not as significant as the maps tend to indicate.

These values are calculated for a fixed angle solar panel tilted south at an angle equal to the latitude. By adjusting the angle, one can improve the performance over the year, or season. Typical adjustments include +15% and –15% from the latitude angle, horizontal, vertical and tracking (a mechanism to adjust the angle to always face directly to the sun).

If one were to optimize during the year without tracking (choosing the best between latitude, latitude -15%, latitude +15%, horizontal, vertical) the value for Kelowna increases slightly to 4.2 kWh/m^2 by using latitude -15% tilt, while Phoenix's remains at 6.5 kWh/m^2 at latitude tilt. This results in Kelowna being at a slightly improved value of 65%[8] solar insolation of Phoenix.

If one were to consider tracking systems, Kelowna's solar insolation is 5.9 kWh/m^2 while Phoenix's value is 8.9 kWh/m^2 . This results in a slight improvement to 66%[9].

Values in kWh/m^2 unless otherwise noted	**Kelowna**	**Phoenix**	**Kelowna/ Phoenix**
Annual – latitude tilt	4.1	6.5	**63%**
Annual – optimize tilt	4.2	6.5	**65%**
Annual – tracking	5.9	8.9	**66%**

Table 1 *– Annual Average Daily Solar Insolation*

Victoria has a similar annual solar insolation of 4.0 kWh/m^2 [10] compared to Kelowna's value of 4.1 kWh/m^2 [11]. The first map in Appendix F[12] of solar insolation in south BC (and reproduced below) shows that the annual solar radiation levels throughout southern BC are similar, although there are noticeably higher levels in the southern Interior regions.

[7] 4.1/6.5 = 63%
[8] 4.2/6.5 = 65%
[9] 5.9/8.9 = 66%
[10] Appendix E, National Resources Canada, Photovoltaic Potential and Solar Resources for Victoria, Annual Average at latitude tilt
[11] Appendix D, National Resources Canada, Photovoltaic Potential and Solar Resources for Kelowna, Annual Average at latitude tilt
[12] Appendix F, National Resources Canada, PV Potential and Insolation, Annual South BC, Page 1

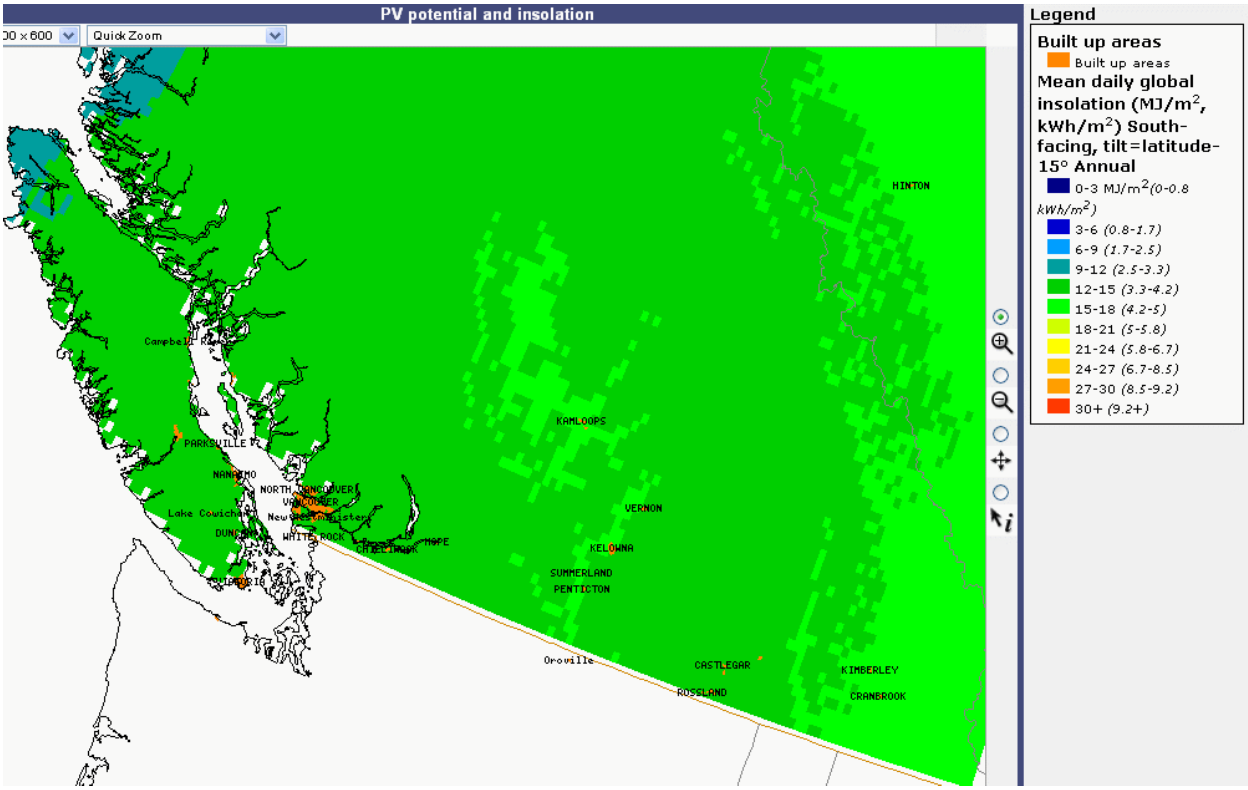

Figure 3 *– Annual South BC Solar Insolation*

The calculations and above maps are based on an annual basis.

The maps below (and the rest of the maps in Appendix F - pages 2 to 13), show the average solar insolation based on a monthly basis.

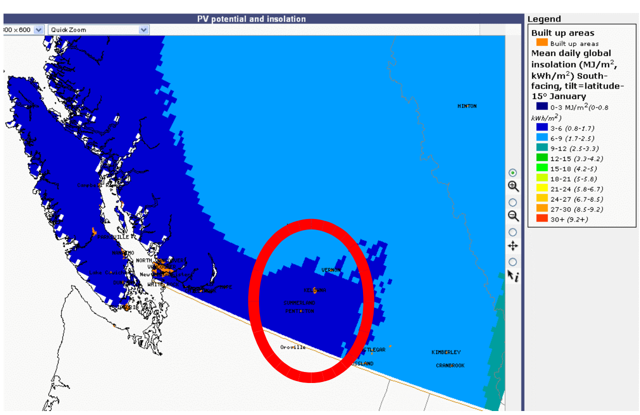

Figure 4 *– January South BC Solar Insolation*

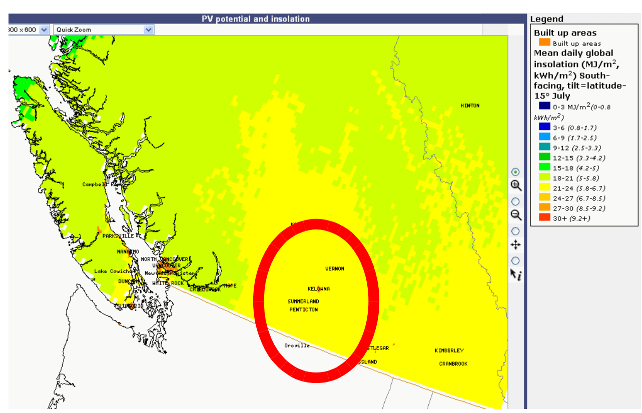

Figure 5 *July South BC Solar Insolation*

Looking at the maps above for January[13], the Southern Interior's (inside red marked zone) solar radiation levels are lower (darker blue) than areas to the

[13] Appendix F, National Resources Canada, PV Potential and Insolation, January - South BC, Page 2

east and north (lighter blue). On the other hand, the map for July[14] shows that the solar insolation levels are higher (yellow) in the Southern Interior than other areas in light green.

It is noted that the workshop presentation by BC Hydro on July 23, 2009 only provided an annual solar insolation map of BC[15]. We suggest that monthly solar insolation maps such as those as provided in Appendix F of this document should also be considered in evaluating the appropriateness and potential of the resource – see the following sections of this document (sections 2.1.2 and 2.1.3).

2.1.2 Solar - FortisBC 2009 Resource Plan

In the BCUC Scoping Document it is stated: "*FortisBC noted the importance of considering its recently filed 2009 Resource Plan and the* ***Panel concurs that FortisBC's 2009 Resource Plan will provide valuable information to the Inquiry**.*"[16]

From the FortisBC Resource Plan: "*FortisBC is a capacity constrained utility.*"[17]

"*Specific to the 'Canada' sub-region summer capacity is expected to be sufficient until 2015, at which time current and currently planned resources will no longer provide sufficient capacity. The shortfall at that time is projected to be about 336 MW.*"[18] The summer deficiency is shown in a graphical form in the Resource Plan[19].

As noted in FortisBC's Resource Plan, the WECC *2008 Power Supply Assessment* notes in reference to Capacity Constraints: "*'Surplus generation in the Pacific Northwest zone was often stranded due to transmission limitations... However, neither the summer nor the winter analysis for the Northwest sub-region captures the limitations on the ability of the hydro system to sustain output levels beyond a single hour. Because of this limitation, the reported surpluses, both for Northwest sub-region's load and for potential export to other sub-regions of the West, may be unrealistically high.*"[20]

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[14] Appendix F, National Resources Canada, PV Potential and Insolation, July - South BC, Page 8
[15] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "Solar Potential", Page 27
[16] Exhibit A-18, Appendix A, Page 6 of 13
[17] FortisBC 2009 Resource Plan, May 29, 2009, Page 3, Line 21
[18] FortisBC 2009 Resource Plan, May 29, 2009, Page 4, Lines 10 to 12
[19] FortisBC 2009 Resource Plan, May 29, 2009, Page 48, Graph 1
[20] FortisBC 2009 Resource Plan, May 29, 2009, Page 49, Lines 9 to 13

FortisBC continues: "*FortisBC acknowledges that the market environment has changed substantially since the publication of the 2008 WECC PSA . Specifically, FortisBC understands that the short term forecast gap between regional loads and resources has been reduced. The May 2009 forecast of the Energy Information Administration (US Department of Energy) notes that although energy consumption is expected to be reduced in 2009, it is expected to return to a more normal growth rate in 2010. Given that the planning period of this 2009 Resource Plan is twenty years, and that it contemplates new resources that require extended implementation timeframes, FortisBC believes it is still prudent to continue to use WECC's long term assessment of the wholesale electricity market.*"[21]

In summary: "*On this basis, over the longer term, an overall tight supply is forecast in the WECC region*."[22]

There are indicators of challenges for the summer load for FortisBC: "*FortisBC's system set a new summer peak requirement record of 569 MW in July 2007.*"[23]

Within the "*Market Shortages*"[24] section of the resource plan, one event was highlighted: *"For example, in July 2006 FortisBC experienced load 20% higher than the previous year's average July load, and 8% higher than on the previous year's hottest summer day, resulting in the need to make an unanticipated wholesale market purchase of 1,680 MWh at an average price of $225 per MW.*"[25]

In summary of the *"Market Shortages*" section, FortisBC notes: "*Consequently, FortisBC concludes that it is no longer reasonable to expect supply from the wholesale electricity market to be available, at a stable price, and on a reliable basis.*"[26]

Within the "*Price Risk*"[27] section FortisBC explains about the volatile market: "*This volatility potential is exacerbated by . . . FortisBC's summer peak is growing, and has exceeded existing capacity. During the summer months, markets in the southern states (California for example) are also peaking, and market costs are typically driven up at this time.*"[28]

"*The potential combined impact is that at some point the Company will be*

[21] FortisBC 2009 Resource Plan, May 29, 2009, Page 49, Lines 14 to 21
[22] FortisBC 2009 Resource Plan, May 29, 2009, Page 49, Lines 21 to 22
[23] FortisBC 2009 Resource Plan, May 29, 2009, Page 28, Line 9 to 10
[24] FortisBC 2009 Resource Plan, May 29, 2009, Page 63, Section 4.1.1.2
[25] FortisBC 2009 Resource Plan, May 29, 2009, Page 63, Line 9 to Page 64, Line 2
[26] FortisBC 2009 Resource Plan, May 29, 2009, Page 64, Lines 15 to 16
[27] FortisBC 2009 Resource Plan, May 29, 2009, Page 69, Section 4.4.1.2
[28] FortisBC 2009 Resource Plan, May 29, 2009, Page 69, Lines 21 to 27

paying well above FortisBC's current cost structure."[29]

In forecasting the demand, FortisBC notes: "*The summer season peak is the peak experienced in either July or August."*[30]

The increasing summer gap is illustrated in a graphical form in the Resource Plan[31] and is shown below. The FortisBC demand for years 2009 to 2028 are shown against the available resources:

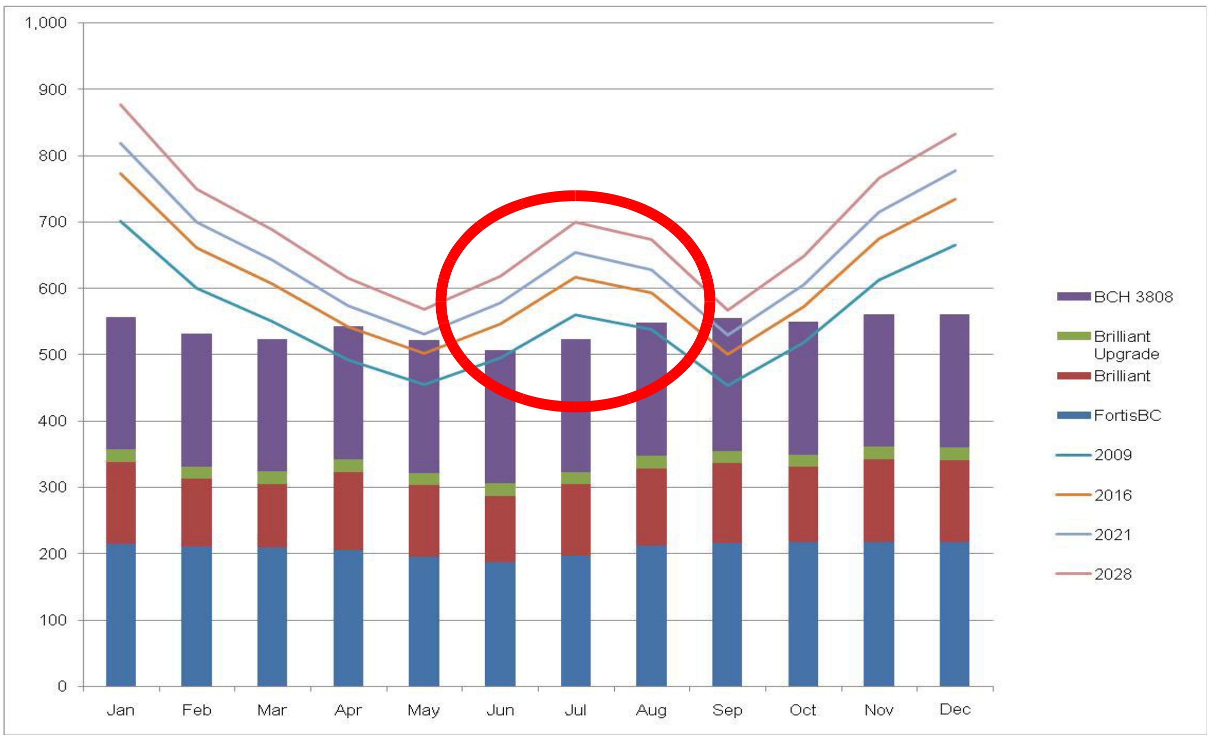

Figure 6 *- FortisBC Monthly Peak Capacity: Current & Forecast*

From the above graph, it can be easily seen that up to 2009 the summer shortage as marked by the red oval - June to August - for FortisBC has not been significant; e.g. the 2009 demand can essentially be supplied by the available resources. However, that situation changes dramatically by 2028 where the demand outstrips the resources for all summer months.

[29] FortisBC 2009 Resource Plan, May 29, 2009, Page 70, Lines 1 to 2
[30] FortisBC 2009 Resource Plan, May 29, 2009, Page 76, Lines 17
[31] FortisBC 2009 Resource Plan, May 29, 2009, Page 81, Figure 5.3.2

2.1.3 Solar - FortisBC/Southern Interior Summer Analysis

In the BCUC Scoping Document, the Inquiry Panel notes: "*ESVI also suggested that 'the regional aspect for wind be expanded to include the regional considerations for solar' . The Panel understands the examples in the Staff Paper to be illustrative and that the cost estimates for various generation resources (especially developing technologies, including both wind and solar) will have regional considerations.* ***Thus the Panel agrees with ESVI that regional considerations for solar are within scope.*****"**[32]

In looking at the summer challenges in the southern interior, a possible resource is solar (both thermal and photovoltaic). The advantages of a solar resource is that the main driving force behind the increased demand on a day by day basis is directly related to the resource during the summer season. It is a type of feedback loop, where the increased summer demand is typically caused by an increase in air conditioning requirements, which is accompanied by an increase in the solar resource.

In addition, should even sunnier weather be experienced by climate change impacts (as discussed in ESVI, OEIA, ITO & ROMS BC Scenario Comment submission[33]), this will also be typically accompanied by an increase in the availability of the solar resource.

The solar insolation for Kelowna is an average daily of 6.17 kWh/m^2 [34], while the average daily for Phoenix is at 7.7 kWh/m^2 [35].for FortisBC's predicted summer shortfall - the months of June, July and August[36]. This makes Kelowna a value of 80%[37] of Arizona's solar insolation for the summer.

The performance for Kelowna increases further by looking at on the months in which the peak summer demand occurs, July and August[38]. Kelowna's daily average is 6.15 kWh/m^2 [39] while Phoenix's daily average is 7.4 kWh/m^2 [40]. This means, during the months in FortisBC's summer peak occurs, Kelowna's

[32] Exhibit A-18, Appendix A, Page 5 of 13
[33] Accompanied ESVI, OEIA, ITO & ROMS BC "Comments on Scenarios to BCTC" for Transmission Inquiry, Aug 12, 2009, Section 4.1, "*Climate Change Impacts*"
[34] Appendix D, National Resources Canada, Photovoltaic Potential and Solar Resources for Kelowna; using values maximized for summer: (6.3+6.6+5.6)/3=6.17 for horizontal (not considering tracking)
[35] Appendix C, National Renewable Energy Laboratory, Phoenix Solar Radiation tables; using values maximized for summer: (8.4+7.6+7.1)/3=7.7 for horizontal (no considering tracking)
[36] See Section 2.1.2 "*Solar – FortisBC 2009 Resource Plan*" within this document
[37] 6.17/7.7 = 80% (this is for horizontal). The value for latitude–15% (next maximum value, not considering tracking) is the same: (6.0+6.3+6.0)/(8.1+7.5+7.3) = 80%.
[38] FortisBC 2009 Resource Plan, May 29, 2009, Page 76, Line 17
[39] Appendix D, National Resources Canada, Photovoltaic Potential and Solar Resources for Kelowna; using values maximized for July and August: (6.3+6.0)/2=6.15 for latitude–15% (not considering tracking)
[40] Appendix C, National Renewable Energy Laboratory, Phoenix Solar Radiation tables; using values maximized for July and August: (7.5 + 7.3)/2=7.4 for latitude-15% (not considering tracking)

solar insolation levels are at 83%[41] of those in Phoenix, Arizona.

With consideration to tracking, Kelowna rises to 9.03 kWh/m^2 [42] during the summer, and 9.05 kWh/m^2 [43] in July and August, while Phoenix rises to 10.5 kWh/m^2 during the summer and 9.95 kWh/m^2 in July and August. Correspondingly, Kelowna's solar insolation with tracking is at 91% of Phoenix, Arizona.

Values in kWh/m^2 unless otherwise noted	**Kelowna**	**Phoenix**	**Kelowna/ Phoenix**
Summer – optimize tilt	6.17	7.7	**80%**
July/Aug – optimize tilt	6.15	7.4	**83%**
Summer – tracking	9.03	10.5	**86%**
July/Aug – tracking	9.05	9.95	**91%**

Table 2 *– Seasonal Average Daily Solar Insolation*

2.2 Solar – Conclusion

In conclusion, we suggest the evidence provided within this document[44] shows that calculations and discussions for Solar technology as a resource for the prime areas in the US (e.g. Arizona) are nearly equally applicable for the southern Interior of BC for the summer peak times and should not be discounted out-of-hand.

Further discussion and technology background for Solar Technology including future price estimates are described in Section 6 and its subsections of the ESVI, OEIA, ITO & ROMS BC "*Comments of Scenarios*" submission[45] and we suggest BC Hydro should use that information for its Resource Options work and analysis. Similarly other sections of that submission, namely regarding Feed-In Tariffs and Distributed Generation[46] are also relevant and again we suggest BC Hydro should use that information for its Resource Options work and analysis.

It is noted that Solar is not listed in the Summary within the Cluster section[47] and

[41] 6.15/7.4 = 83% (this is for latitude-15%)
[42] Appendix D, National Resources Canada, Photovoltaic Potential and Solar Resources for Kelowna; using values for the summer: (9.0+9.5+8.6)/3=9.03
[43] Appendix D, National Resources Canada, Photovoltaic Potential and Solar Resources for Kelowna; using values for July and August: (9.5+8.6)/2=9.05
[44] Section 2 "*Solar*" and its subsections of this document,
[45] Accompanied ESVI, OEIA, ITO & ROMS BC "*Comments on Scenarios to BCTC*" for Transmission Inquiry, Aug 12, 2009, Section 6 "*Solar*" and its subsections
[46] such as Accompanied ESVI, OEIA, ITO & ROMS BC "*Comments on Scenarios to BCTC*" for Transmission Inquiry, Aug 12, 2009, Section 5 "*Feed-In Tariffs and "Distributed Generation*" and its subsections
[47] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Transmission Region Summary After Exclusion (Draft)*", Page 40 & 41

suggest that it be included. If no specific projects can be identified, it is suggested that estimates be included, along with assumptions.

3.0 <u>Ocean:</u>

3.1 Ocean - Discussion

The ESVI, OEIA, ITO & ROMS BC "*Comments of Scenarios*" submission submitted to BCTC on August 12 contained a section called "Ocean"[48]. That section described the Ocean Technology, referenced numerous tables and other information and we suggest the entire section (including all referenced footnotes) should be used by BC Hydro in their Resource Options work and analysis.

For convenience, we have attached an Appendix G, which is a compilation of CHC's report material referenced in the "Comments of Scenario submission"[49]. It appears that pages 31 and 95 have been used in the workshop presentation in slide 28[50].

There are also additional relevant reference material throughout in the "*Inventory of Canada's Marine Renewable Energy Resources*" report produced by Canadian Hydraulics Centre (CHC) of Natural Resources Canada - find attached Appendix H, which is a compilation of those pages[51].

A feasibility study, called "*Tidal Power Generation for a Remote, Off-Grid Community on the British Columbia Coast*"[52] written by Bob Davidson was done for the British Columbia Ministry of Energy, Mines and Petroleum Resources. In conclusion it states:

> "*At this point in time, tidal power technology is not far enough advanced for it to be feasible for installation at Stuart Island to replace the existing diesel generators. However, it won't be long until commercial size devices have been built and tested. There are a handful of Canadian manufacturers of tidal turbines that have working small scale devices that will soon be scaled up for use in commercial applications. The world leaders in the field are in the UK, but Canadian developers are not far behind.*"[53]

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[48] Accompanied ESVI, OEIA, ITO & ROMS BC "*Comments on Scenarios to BCTC*" for Transmission Inquiry, Aug 12, 2009, Section 7 and subsections, "*Ocean*"

[49] Appendix G, Canada Hydraulics Centre of Natural Resources Canada: pages that were referenced in ESVI, OEIA, ITO & ROMS BC "Comments of Scenario", August 12, 2009

[50] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Wave & Tidal energy Potential*", Page 28

[51] Appendix H, Canada Hydraulics Centre of Natural Resources Canada: relevant extra pages for this Resource Options

[52] Appendix I, British Columbia Ministry of Energy, Mines and Petroleum Resources, "*Tidal Power Generation for a Remote, Off-Grid Community on the British Columbia Coast*"

[53] Appendix I, British Columbia Ministry of Energy, Mines and Petroleum Resources, "*Tidal Power Generation for a Remote, Off-Grid Community on the British Columbia Coast*", Page 80

One of drawings in the report show the potential tidal resource sites along the mid Vancouver Island coast[54] - it is reproduced below.

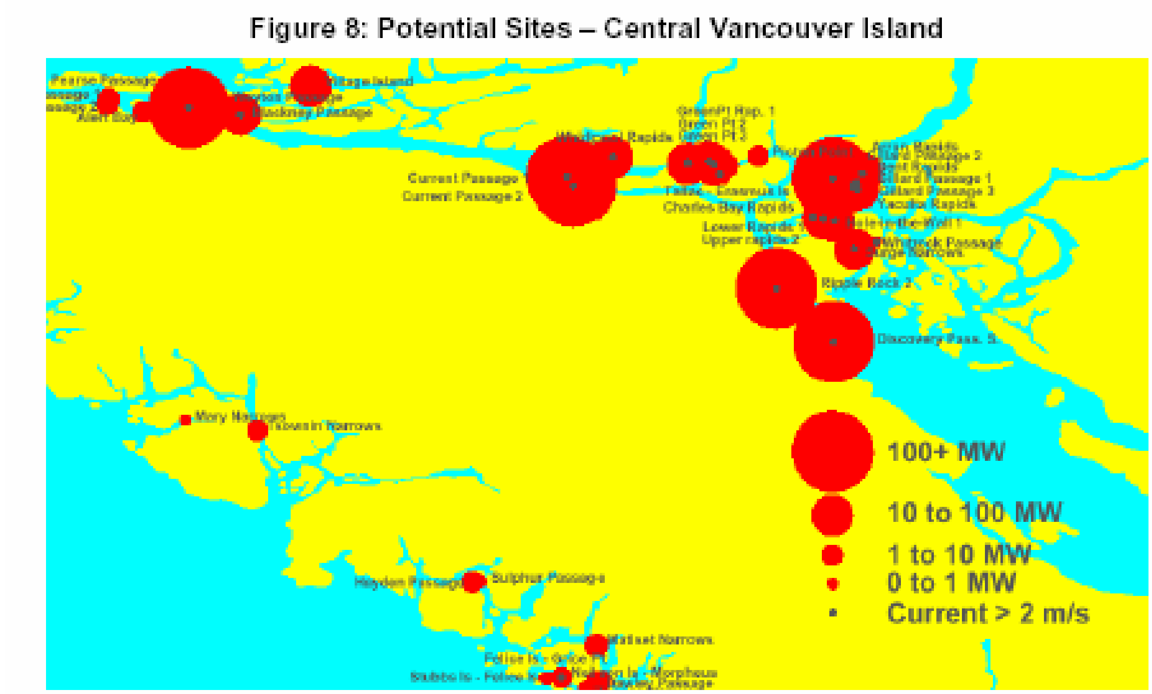

Figure 7 *- Tidal Resources along the Mid Vancouver Island coast*[55]

Another report examines the tidal current assessment potential in the Johnstone Strait region[56] and is included in Appendix J of this document.

> "*The maximum extractable power in northwestern Johnstone Strait is found to be 1335 MW, which agrees well with the theoretical estimate of 1320 MW. In Discovery Passage and Cordero Channel, the maximum extractable power is modelled to be 401 and 277 MW, respectively, due to the flow being partly diverted into the other channel.*"[57]

A table is produced showing the power estimates for various channels[58].

[54] Appendix I, British Columbia Ministry of Energy, Mines and Petroleum Resources, "*Tidal Power Generation for a Remote, Off-Grid Community on the British Columbia Coast",* Page 45

[55] Appendix I, British Columbia Ministry of Energy, Mines and Petroleum Resources, "*Tidal Power Generation for a Remote, Off-Grid Community on the British Columbia Coast",* Page 45

[56] Appendix J, G Sutherland, M.Foreman, and C Garrett, from UVic and Institute of Ocean Sciences, "*Tidal current energy assessment for Johnstone Strait, Vancouver Island"*

[57] Appendix J, G Sutherland, M.Foreman, and C Garrett, from UVic and Institute of Ocean Sciences, "*Tidal current energy assessment for Johnstone Strait, Vancouver Island"*, Page 147

[58] Appendix J, G Sutherland, M.Foreman, and C Garrett, from UVic and Institute of Ocean Sciences, "*Tidal current energy assessment for Johnstone Strait, Vancouver Island"*, Page 154

3.2 Ocean – Conclusion

We suggest that BC Hydro check that the workshop slides #28 & #29[59] has incorporated the reference materials presented in the two ESVI, OEIA, ITO & ROMS BC documents[60]. It is also suggested that BC Hydro take these reference materials into account in its further analysis.

4.0 <u>Distributed Generation:</u>

4.1 Distributed Generation - Discussion

The ESVI, OEIA, ITO & ROMS BC "*Comments of Scenarios*" submission submitted to BCTC on August 12 contained a section called "*Feed-In Tariffs and Distributed Generation*"[61]. That section discussed relevant topics, studies and reports regarding Feed-In Tariffs and Distributed Generation and we suggest the entire section (including all referenced footnotes) should be used by BC Hydro in their Resource Options work and analysis.

Amory Lovins, of Rocky Mountain Institute, and others wrote a best seller book called "*Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size*"[62].

> "*It finds that properly considering the economic benefits of "distributed" (decentralized) electrical resources typically raises their value by a large factor, often approximately tenfold, by improving system planning, utility construction and operation (especially of the grid), and service quality, and by avoiding societal costs.*"[63]

The book describes 207 benefits of distributed resources[64].

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[59] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Wave & Tidal energy Potential*", Slides 28 & 29

[60] This document and the accompanied ESVI, OEIA, ITO & ROMS BC "*Comments on Scenarios to BCTC*" for Transmission Inquiry document

[61] Accompanied ESVI, OEIA, ITO & ROMS BC "*Comments on Scenarios to BCTC*" for Transmission Inquiry, Aug 12, 2009, Section 5 and subsections, "*Feed-In Tariffs and Distributed Generation*"

[62] Appendix K, Amory Lovins, Rocky Mountain Institute, Excerpts from "*Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size", 2003*

[63] Appendix K, Amory Lovins, Rocky Mountain Institute, Excerpts from "*Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size", 2003,* Executive Summary, Page 1

[64] Appendix K, Amory Lovins, Rocky Mountain Institute, Excerpts from "*Small is Profitable: The Hidden Economic Benefits of Making Electrical Resources the Right Size", 2003, "207 Benefits of Distributed Resources"*

The Canadian Renewable Energy Alliance estimates in its Canadian Distributed Generation report that: "*as of 2005, fully 25% of new electricity generation installed came from distributed resources, compared to only 13% in 2002*"[65].

> "*Historically, energy policy in Canada has emphasized large centralized electricity generation and long-distance, high-voltage transmission from centralized sources such as large-scale hydro, coal, natural gas and nuclear power plants. Canada's aging centralized energy infrastructure is becoming more problematic as demand for clean, reliable and affordable electricity generation grows. North America's centralized grid system, stressed to its limits, has become vulnerable, increasingly brittle, and inefficient. Over-reliance on large, polluting and expensive generation and transmission is no longer an option that Canadians will endorse. More and more frequently, centralized generation is being supplemented or replaced by distributed generation (DG), a new way of thinking about electricity generation, transmission and distribution. The market share of renewable DG continues to grow, and shows no signs of slowing.*"[66]

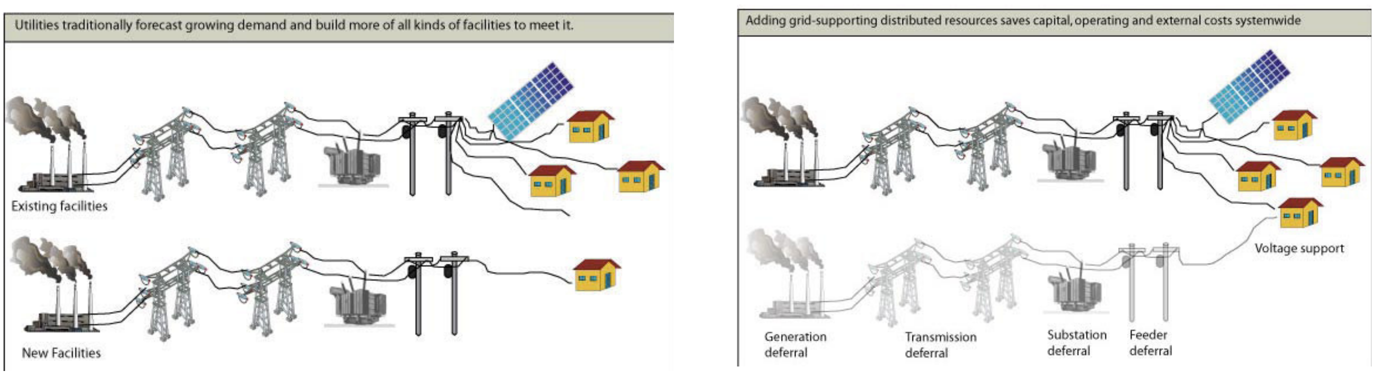

Figure 8 *– From a traditional utility to Distributed Resources*[67]

It is noted that while the other resource options have "*potential*" maps[68] for BC, Distributed Generation did not and we suggest that such maps be included – in addition to the text description was included[69]. If sufficient information for such a map is not possible, it is suggested that estimated generation should be used to develop the map, and we suggest the assumptions be included.

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[65] Appendix L, Canadian Renewable Energy Alliance, "*Distributed Generation in Canada -Maximizing the benefits of renewable resources*", 2006, Page 2

[66] Appendix L, Canadian Renewable Energy Alliance, "*Distributed Generation in Canada -Maximizing the benefits of renewable resources*", 2006, Page 2

[67] Appendix L, Canadian Renewable Energy Alliance, "*Distributed Generation in Canada -Maximizing the benefits of renewable resources*", 2006, Page 5 & 6

[68] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Transmission Region Summary After Exclusion (Draft)*", Slides 18 to 29

[69] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Distributed Generation*", Slide 30

It is also noted that Distributed Generation is not listed in the Summary within the Cluster section[70] of the workshop presentation and we suggest that Distributed Generation be included. If no specific projects can be identified, it is suggested that estimates be included, along with assumptions.

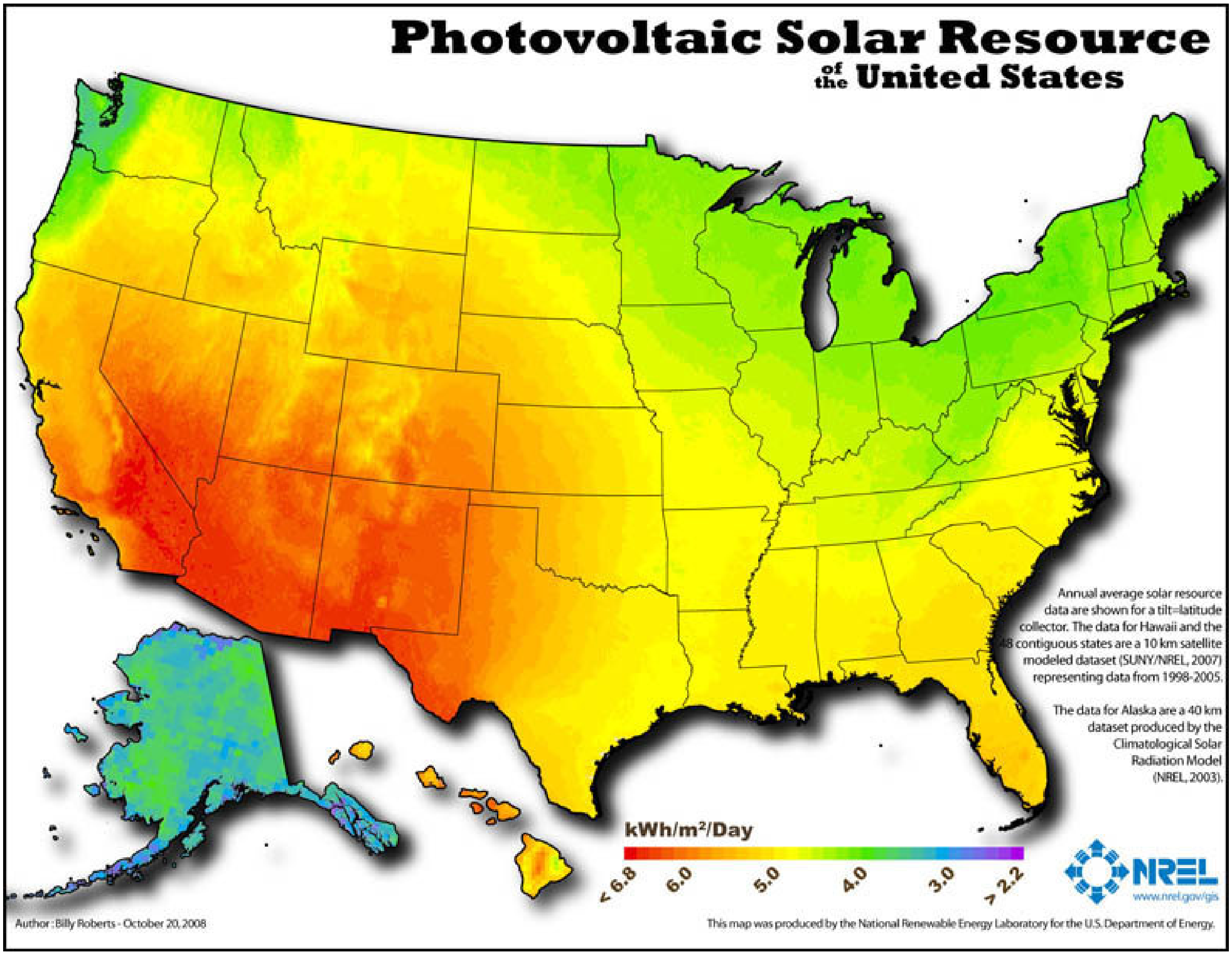
BC Hydro provides an estimate of 5100 GWh of potential due to Distributed Generation[71] – it is suggested that the assumptions and calculations used to calculate this number to be included; it is also suggested that this number be broken down to the regional level.

4.2 Distributed Generation – Conclusion

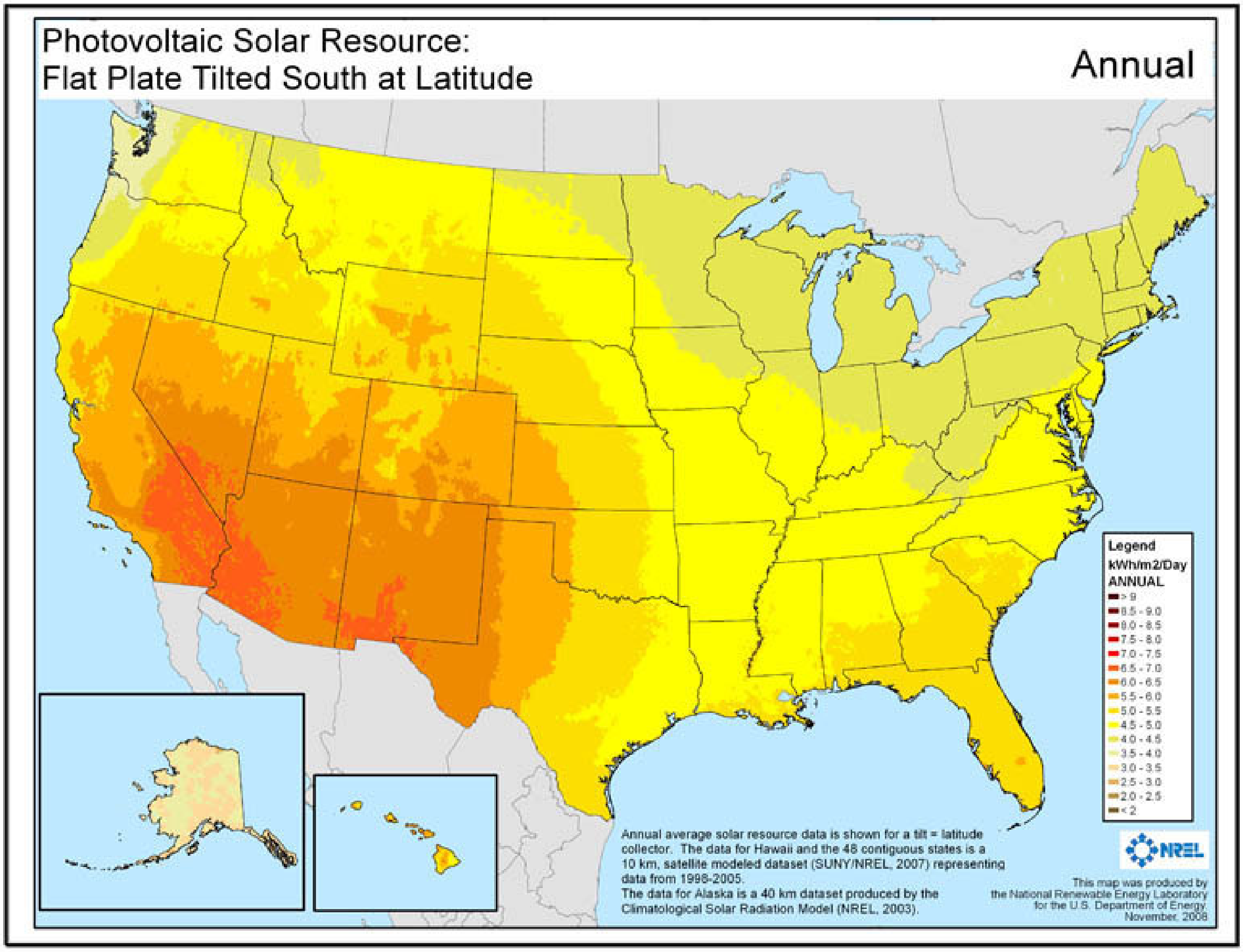
Based upon the direction of the industry and other information provided in the two ESVI, OEIA, ITO & ROMS BC documents[72] we suggest that BC Hydro fully develop the Distributed Generation resource as part of its Resource Options work, and consider appropriate pricing techniques to account for all the benefits of Distributed Generation.

[70] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Transmission Region Summary After Exclusion (Draft)*", Pages 40 & 41
[71] BC Hydro, Long Term Electricity Transmission Inquiry, Resource Options Workshop, "*Distributed Generation*", Page 30
[72] This document and the accompanied ESVI, OEIA, ITO & ROMS BC "*Comments on Scenarios to BCTC*" for Transmission Inquiry document

APPENDICES


Photovoltaic Solar Resource
of the United States
Annual average solar resource data are shown for a tilt=latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.
The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).
kWh/m²/Day
< 6.8
6.0
5.0
4.0
3.0
> 2.2
NREL
www.nrel.gov/gis
Author: Billy Roberts - October 20, 2008
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

Appendix A


Photovoltaic Solar Resource:
Flat Plate Tilted South at Latitude
Annual
Legend
kWh/m2/Day
ANNUAL
> 9
8.5 - 9.0
8.0 - 8.5
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
3.0 - 3.5
2.5 - 3.0
2.0 - 2.5
< 2
NREL
Annual average solar resource data is shown for a tilt = latitude collector. The data for Hawaii and the 48 contiguous states is a 10 km, satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.
The data for Alaska is a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).
This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. November, 2008

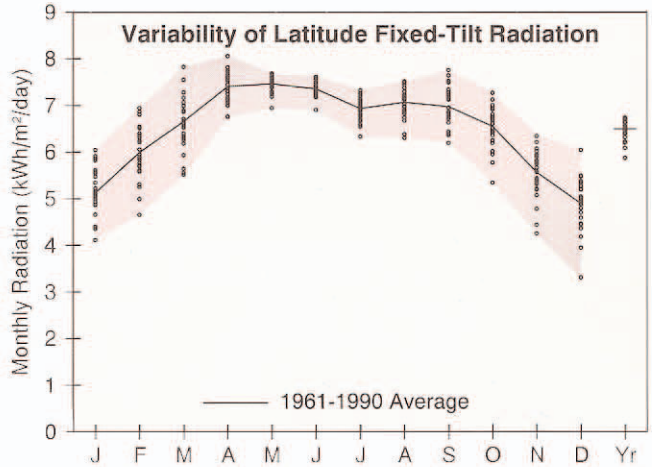
Appendix B

Phoenix, AZ

WBAN NO. 23183

LATITUDE: 33.43° N
LONGITUDE: 112.02° W
ELEVATION: 339 meters
MEAN PRESSURE: 974 millibars

STATION TYPE: Primary



Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.2	4.3	5.5	7.1	8.0	8.4	7.6	7.1	6.1	4.9	3.6	3.0	5.7
	Min/Max	2.8/3.7	3.5/4.8	4.7/6.4	6.4/7.8	7.5/8.3	7.8/8.7	6.9/8.1	6.3/7.5	5.4/6.7	4.2/5.3	3.0/4.0	2.2/3.5	5.3/5.9
Latitude -15	Average	4.4	5.4	6.4	7.5	8.0	8.1	7.5	7.3	6.8	6.0	4.9	4.2	6.4
	Min/Max	3.6/5.1	4.3/6.2	5.3/7.4	6.8/8.2	7.4/8.2	7.6/8.4	6.8/8.0	6.5/7.8	6.1/7.6	5.0/6.6	3.8/5.5	2.9/5.1	5.8/6.6
Latitude	Average	5.1	6.0	6.7	7.4	7.5	7.3	6.9	7.1	7.0	6.5	5.6	4.9	6.5
	Min/Max	4.1/6.0	4.7/6.9	5.5/7.8	6.8/8.1	6.9/7.7	6.9/7.6	6.3/7.3	6.3/7.5	6.2/7.8	5.3/7.3	4.3/6.3	3.3/6.0	5.9/6.7
Latitude +15	Average	5.5	6.2	6.6	6.9	6.6	6.3	6.0	6.4	6.7	6.7	5.9	5.3	6.3
	Min/Max	4.4/6.6	4.8/7.3	5.4/7.8	6.2/7.5	6.1/6.8	5.9/6.5	5.5/6.3	5.7/6.8	5.9/7.5	5.4/7.4	4.4/6.8	3.5/6.7	5.6/6.5
90	Average	4.9	5.0	4.5	3.7	2.7	2.3	2.4	3.1	4.2	5.1	5.1	4.8	4.0
	Min/Max	3.8/5.9	3.8/5.9	3.7/5.3	3.3/3.9	2.6/2.8	2.1/2.4	2.2/2.5	2.8/3.3	3.7/4.6	4.1/5.7	3.7/6.0	3.1/6.2	3.5/4.2

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	4.7	6.2	7.8	9.9	11.0	11.4	10.0	9.6	8.6	7.1	5.3	4.4	8.0
	Min/Max	3.8/5.6	4.6/7.3	6.2/9.5	8.9/11.4	9.9/11.8	10.3/12.2	8.8/11.1	8.0/10.5	7.4/9.9	5.6/8.1	4.0/6.2	2.9/5.5	7.1/8.4
Latitude -15	Average	5.6	7.1	8.5	10.3	11.1	11.3	10.0	9.8	9.2	8.0	6.3	5.3	8.5
	Min/Max	4.4/6.7	5.2/8.3	6.7/10.3	9.2/11.9	9.9/11.8	10.2/12.1	8.8/11.1	8.2/10.8	7.9/10.5	6.2/9.1	4.6/7.3	3.4/6.7	7.6/8.9
Latitude	Average	6.2	7.5	8.7	10.3	10.7	10.8	9.6	9.6	9.3	8.4	6.8	5.8	8.6
	Min/Max	4.8/7.4	5.5/8.9	6.8/10.6	9.1/11.8	9.6/11.5	9.8/11.6	8.4/10.7	8.1/10.6	8.0/10.7	6.5/9.5	4.9/8.0	3.8/7.4	7.6/9.0
Latitude +15	Average	6.5	7.7	8.6	9.9	10.1	10.1	9.0	9.2	9.1	8.5	7.1	6.2	8.5
	Min/Max	5.0/7.8	5.6/9.1	6.8/10.5	8.8/11.4	9.1/10.8	9.1/10.8	7.9/10.0	7.7/10.1	7.8/10.5	6.6/9.7	5.1/8.3	4.0/7.9	7.5/8.9

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	6.6	7.7	8.7	10.4	11.2	11.6	10.1	9.8	9.3	8.5	7.1	6.3	8.9
	Min/Max	5.1/7.9	5.6/9.1	6.9/10.6	9.2/11.9	10.1/12.0	10.5/12.4	8.9/11.3	8.3/10.9	8.0/10.7	6.6/9.7	5.1/8.4	4.0/8.1	7.9/9.4

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	4.2	4.6	4.8	5.7	6.4	6.8	5.6	5.3	5.2	5.0	4.5	4.1	5.2
	Min/Max	3.0/5.4	3.0/5.9	3.4/6.3	4.8/7.1	5.2/7.1	6.0/7.5	4.5/6.7	4.4/6.3	4.1/6.3	3.5/6.0	2.6/5.8	2.5/5.8	4.5/5.6
1-Axis, N-S Horiz Axis	Average	3.4	4.6	5.8	7.6	8.5	8.9	7.2	7.0	6.5	5.4	4.0	3.2	6.0
	Min/Max	2.4/4.5	2.8/5.9	4.0/7.7	6.5/9.8	7.0/9.7	7.9/10.0	5.7/8.8	5.6/8.4	5.1/8.1	3.6/6.6	2.2/5.1	1.8/4.5	5.2/6.5
1-Axis, N-S Tilt=Latitude	Average	4.7	5.7	6.5	7.8	8.2	8.3	6.8	7.0	7.1	6.5	5.2	4.5	6.5
	Min/Max	3.3/6.1	3.6/7.3	4.5/8.6	6.6/10.1	6.7/9.4	7.3/9.3	5.4/8.3	5.6/8.4	5.5/8.7	4.4/7.8	3.0/6.7	2.6/6.3	5.6/7.1
2-Axis	Average	5.0	5.8	6.5	8.0	8.7	9.1	7.3	7.2	7.1	6.5	5.5	4.8	6.8
	Min/Max	3.5/6.5	3.7/7.5	4.5/8.6	6.7/10.3	7.1/9.9	8.0/10.1	5.8/9.0	5.7/8.6	5.5/8.7	4.4/7.9	3.1/7.1	2.8/6.8	5.8/7.4

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	12.0	14.3	16.8	21.1	26.0	31.2	34.2	33.1	29.8	23.6	16.6	12.3	22.6
Daily Minimum Temp	5.1	7.1	9.3	12.9	17.7	22.7	27.2	26.2	22.7	16.0	9.4	5.4	15.2
Daily Maximum Temp	18.8	21.5	24.2	29.2	34.2	39.7	41.1	39.8	36.8	31.2	23.8	19.0	29.9
Record Minimum Temp	-8.3	-5.6	-3.9	0.0	4.4	10.0	16.1	15.6	8.3	1.1	-3.9	-5.6	-8.3
Record Maximum Temp	31.1	33.3	37.8	40.6	45.0	50.0	47.8	46.7	47.8	41.7	33.9	31.1	50.0
HDD, Base 18.3°C	201	126	101	42	4	0	0	0	0	9	74	192	750
CDD, Base 18.3°C	4	12	53	123	242	387	491	457	343	173	23	4	2312
Relative Humidity (%)	51	44	39	28	22	19	32	36	36	37	44	52	37
Wind Speed (m/s)	2.5	2.8	3.2	3.4	3.4	3.2	3.4	3.2	3.0	2.8	2.6	2.5	3.0

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3 characters minimum

Search

Municipality by province

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Photovoltaic potential and solar resource maps of Canada

Photovoltaic (PV) potential (kWh/kW) and mean daily global insolation (MJ/m^2 and kWh/m^2) data are presented below for the selected municipality. Data is presented for each month and on a yearly basis for 6 different PV array orientations.

Kelowna, British Columbia/Colombie-Britannique
Geographic location -> -119.45E,49.88N

PV potential (kWh/kW)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°
January	42	42	44	38
February	58	63	64	58
March	85	105	102	102
April	78	115	105	119
May	73	122	107	132
June	68	122	104	134
July	75	134	115	146
August	83	131	118	138
September	91	120	114	119
October	81	93	93	87
November	49	50	52	45
December	36	35	38	32
Annual	819	1133	1056	1151

Mean daily global insolation (MJ/m^2)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°	Two-axis sun-tracking	Horizontal (tilt=0°)
January	6.6	6.5	6.9	5.9	7.7	3.9
February	10.0	10.8	10.9	10.0	12.8	7.2
March	13.2	16.3	15.8	15.8	20.8	12.3
April	12.5	18.4	16.9	19.1	26.1	17.2
May	11.3	18.9	16.6	20.4	28.9	20.9
June	10.8	19.6	16.7	21.5	32.3	22.7
July	11.6	20.7	17.8	22.6	34.1	23.8
August	12.9	20.4	18.2	21.4	30.8	20.0
September	14.5	19.2	18.3	19.1	26.1	14.2
October	12.5	14.3	14.4	13.5	18.0	8.6
November	7.9	8.0	8.4	7.3	9.6	4.2
December	5.6	5.5	5.8	4.9	6.4	2.9
Annual	10.8	14.9	13.9	15.1	21.2	13.2

Mean daily global insolation (kWh/m^2)

Appendix D

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°	Two-axis sun-tracking	Horizontal (tilt=0°)
January	1.8	1.8	1.9	1.6	2.1	1.1
February	2.8	3.0	3.0	2.8	3.6	2.0
March	3.7	4.5	4.4	4.4	5.8	3.4
April	3.5	5.1	4.7	5.3	7.3	4.8
May	3.1	5.3	4.6	5.7	8.0	5.8
June	3.0	5.4	4.6	6.0	9.0	6.3
July	3.2	5.8	4.9	6.3	9.5	6.6
August	3.6	5.7	5.1	6.0	8.6	5.6
September	4.0	5.3	5.1	5.3	7.3	4.0
October	3.5	4.0	4.0	3.8	5.0	2.4
November	2.2	2.2	2.3	2.0	2.7	1.2
December	1.6	1.5	1.6	1.4	1.8	0.8
Annual	3.0	4.1	3.9	4.2	5.9	3.7

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Appendix D

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PV municipal rankings and hotspots

Municipality Search

3 characters minimum

Search

Municipality by province

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Photovoltaic potential and solar resource maps of Canada

Photovoltaic (PV) potential (kWh/kW) and mean daily global insolation (MJ/m^2 and kWh/m^2) data are presented below for the selected municipality. Data is presented for each month and on a yearly basis for 6 different PV array orientations.

Victoria, British Columbia/Colombie-Britannique
Geographic location -> -123.37E,48.43N

PV potential (kWh/kW)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°
January	43	43	45	38
February	52	57	58	53
March	74	95	91	92
April	71	108	98	112
May	67	118	103	127
June	63	118	101	131
July	70	130	112	142
August	78	128	115	135
September	91	123	117	121
October	76	88	88	82
November	45	47	48	42
December	40	39	41	34
Annual	771	1091	1017	1110

Mean daily global insolation (MJ/m^2)

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°	Two-axis sun-tracking	Horizontal (tilt=0°)
January	6.6	6.7	7.0	6.0	7.8	3.4
February	8.9	9.7	9.9	9.1	11.7	6.5
March	11.5	14.7	14.2	14.3	18.9	11.3
April	11.4	17.2	15.7	17.9	24.3	16.3
May	10.4	18.3	15.9	19.7	28.3	20.5
June	10.1	19.0	16.2	20.9	31.2	21.9
July	10.9	20.1	17.4	22.0	33.0	23.2
August	12.1	19.8	17.8	20.9	30.2	19.8
September	14.6	19.6	18.7	19.4	26.9	14.6
October	11.8	13.6	13.6	12.8	16.9	8.3
November	7.2	7.5	7.8	6.8	8.8	3.9
December	6.1	6.0	6.4	5.3	7.1	2.7
Annual	10.1	14.4	13.4	14.6	20.5	12.7

Mean daily global insolation (kWh/m^2)

	South-facing	South		South-facing	Two-axis	

Appendix E

	South-facing vertical (tilt=90°)	South-facing, tilt=latitude	South-facing, tilt=latitude+15°	South-facing, tilt=latitude-15°	Two-axis sun-tracking	Horizontal (tilt=0°)
January	1.8	1.9	2.0	1.7	2.2	0.9
February	2.5	2.7	2.8	2.5	3.3	1.8
March	3.2	4.1	3.9	4.0	5.3	3.1
April	3.2	4.8	4.4	5.0	6.8	4.5
May	2.9	5.1	4.4	5.5	7.9	5.7
June	2.8	5.3	4.5	5.8	8.7	6.1
July	3.0	5.6	4.8	6.1	9.2	6.5
August	3.4	5.5	4.9	5.8	8.4	5.5
September	4.1	5.5	5.2	5.4	7.5	4.1
October	3.3	3.8	3.8	3.6	4.7	2.3
November	2.0	2.1	2.2	1.9	2.4	1.1
December	1.7	1.7	1.8	1.5	2.0	0.7
Annual	2.8	4.0	3.7	4.1	5.7	3.5

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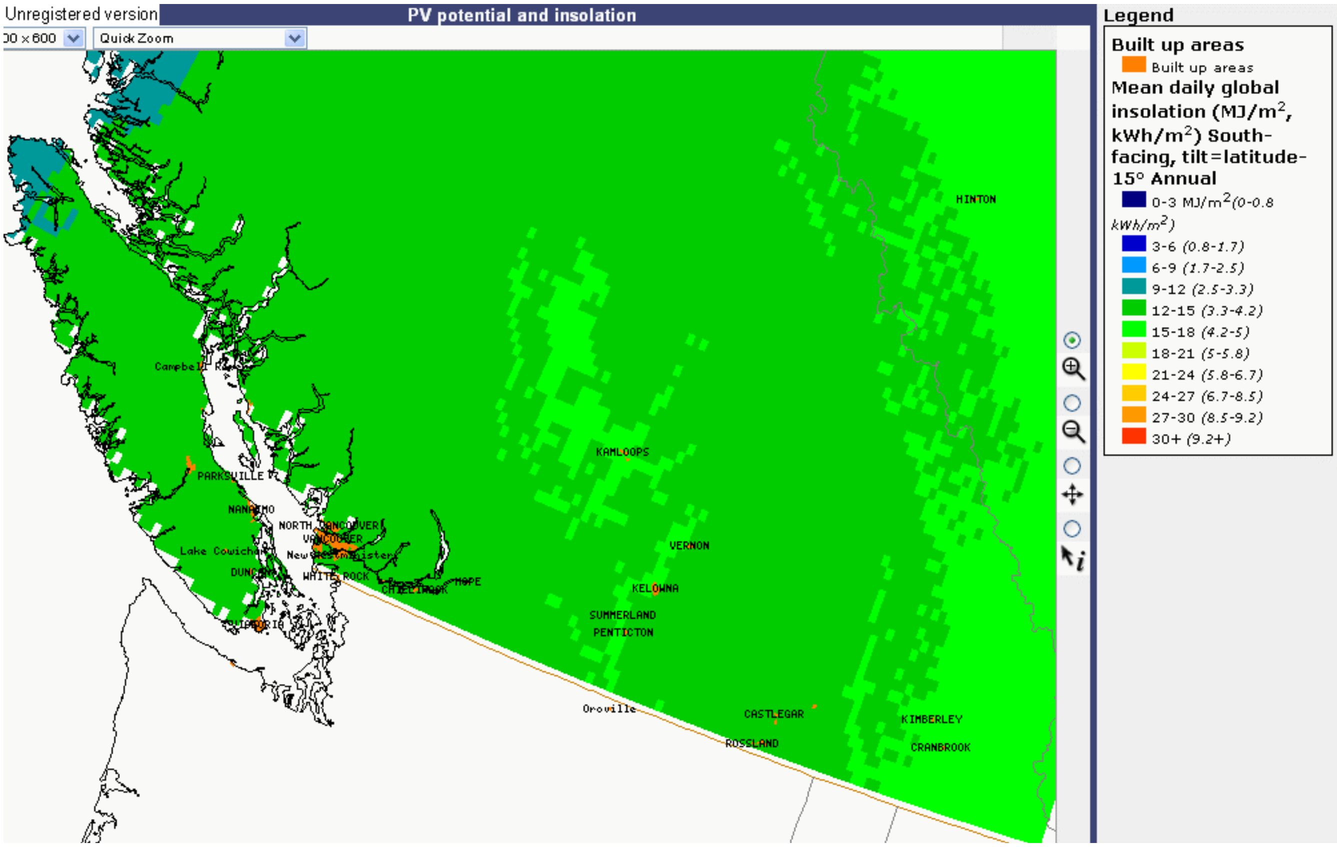
Unregistered version
PV potential and insolation
Quick Zoom
Legend
Built up areas
Built up areas
Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° Annual
0-3 MJ/m2(0-0.8 kWh/m2)
3-6 (0.8-1.7)
6-9 (1.7-2.5)
9-12 (2.5-3.3)
12-15 (3.3-4.2)
15-18 (4.2-5)
18-21 (5-5.8)
21-24 (5.8-6.7)
24-27 (6.7-8.5)
27-30 (8.5-9.2)
30+ (9.2+)
HINTON
KAMLOOPS
VERNON
KELOWNA
SUMMERLAND
PENTICTON
HOPE
WHITE ROCK
NORTH VANCOUVER
NANAIMO
PARKSVILLE
Lake Cowichan
Oroville
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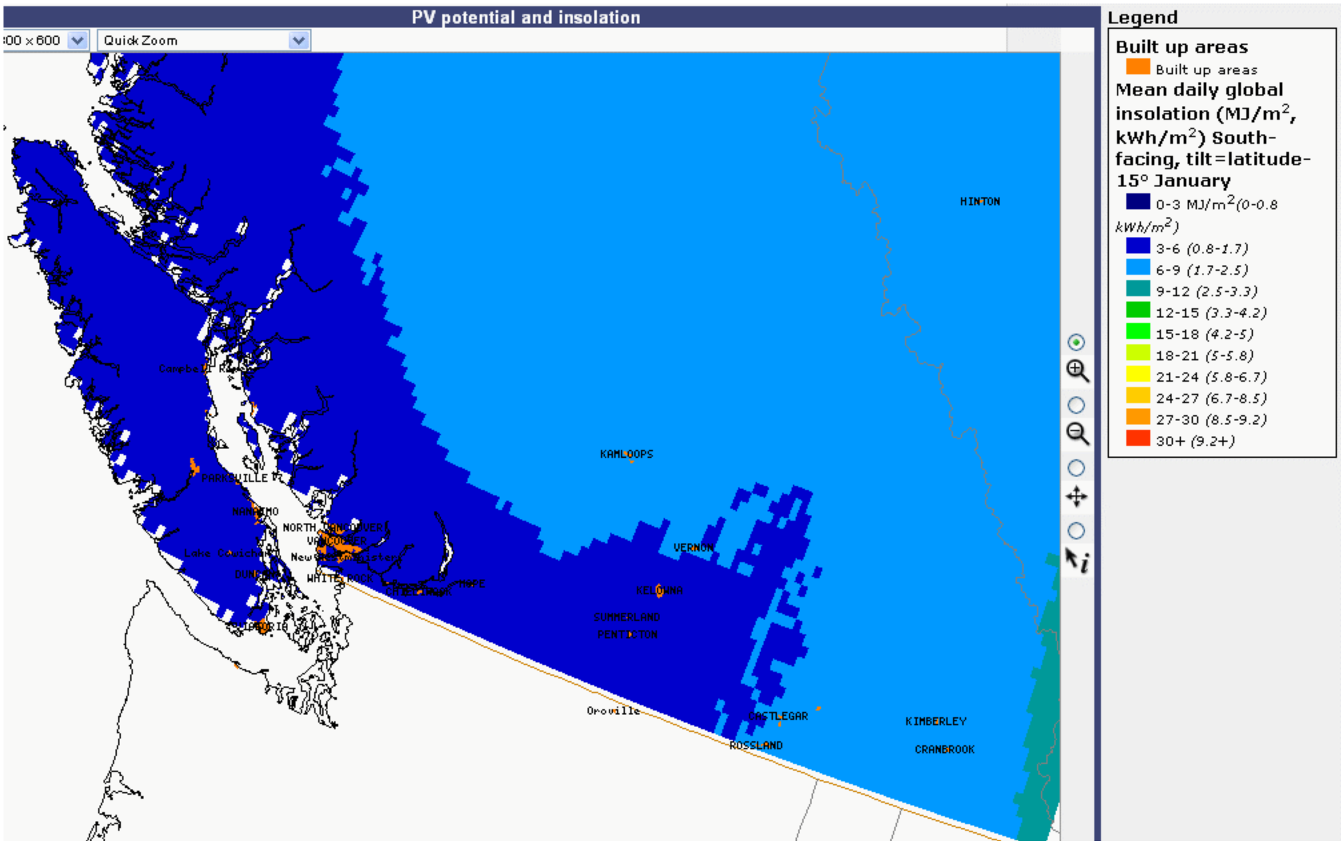
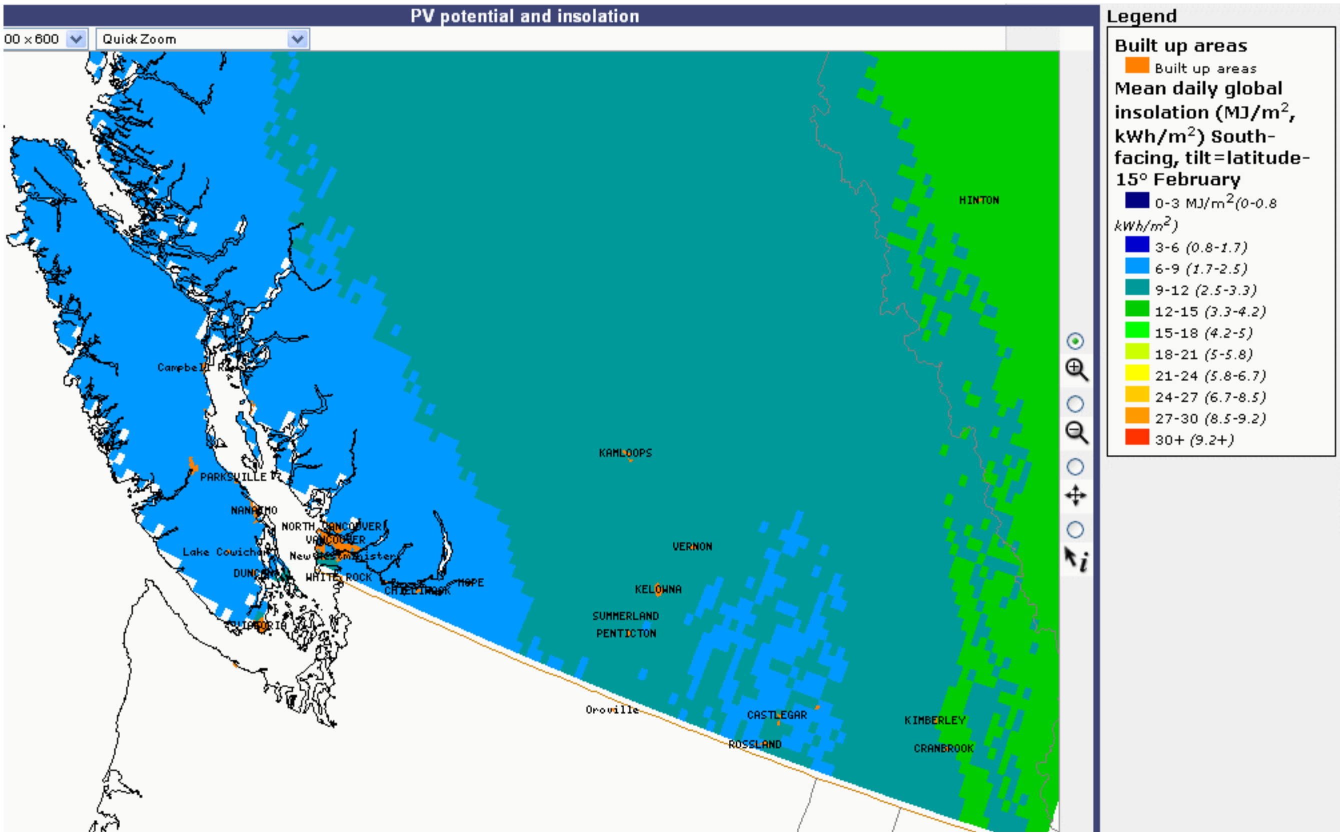


PV potential and insolation
Quick Zoom
HINTON
KAMLOOPS
VERNON
KELOWNA
SUMMERLAND
PENTICTON
NANAIMO
PARKSVILLE
NORTH VANCOUVER
WHITE ROCK
Oroville
CASTLEGAR
ROSSLAND
KIMBERLEY
CRANBROOK
Legend
Built up areas
Built up areas
Mean daily global insolation (MJ/m², kWh/m²) South-facing, tilt=latitude-15° January
0-3 MJ/m² (0-0.8 kWh/m²)
3-6 (0.8-1.7)
6-9 (1.7-2.5)
9-12 (2.5-3.3)
12-15 (3.3-4.2)
15-18 (4.2-5)
18-21 (5-5.8)
21-24 (5.8-6.7)
24-27 (6.7-8.5)
27-30 (8.5-9.2)
30+ (9.2+)


PV potential and insolation
Quick Zoom
Legend
Built up areas
Built up areas
Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° February
0-3 MJ/m2 (0-0.8 kWh/m2)
3-6 (0.8-1.7)
6-9 (1.7-2.5)
9-12 (2.5-3.3)
12-15 (3.3-4.2)
15-18 (4.2-5)
18-21 (5-5.8)
21-24 (5.8-6.7)
24-27 (6.7-8.5)
27-30 (8.5-9.2)
30+ (9.2+)
HINTON
KAMLOOPS
VERNON
KELOWNA
SUMMERLAND
PENTICTON
HOPE
WHITE ROCK
NANAIMO
Lake Cowichan
Oroville
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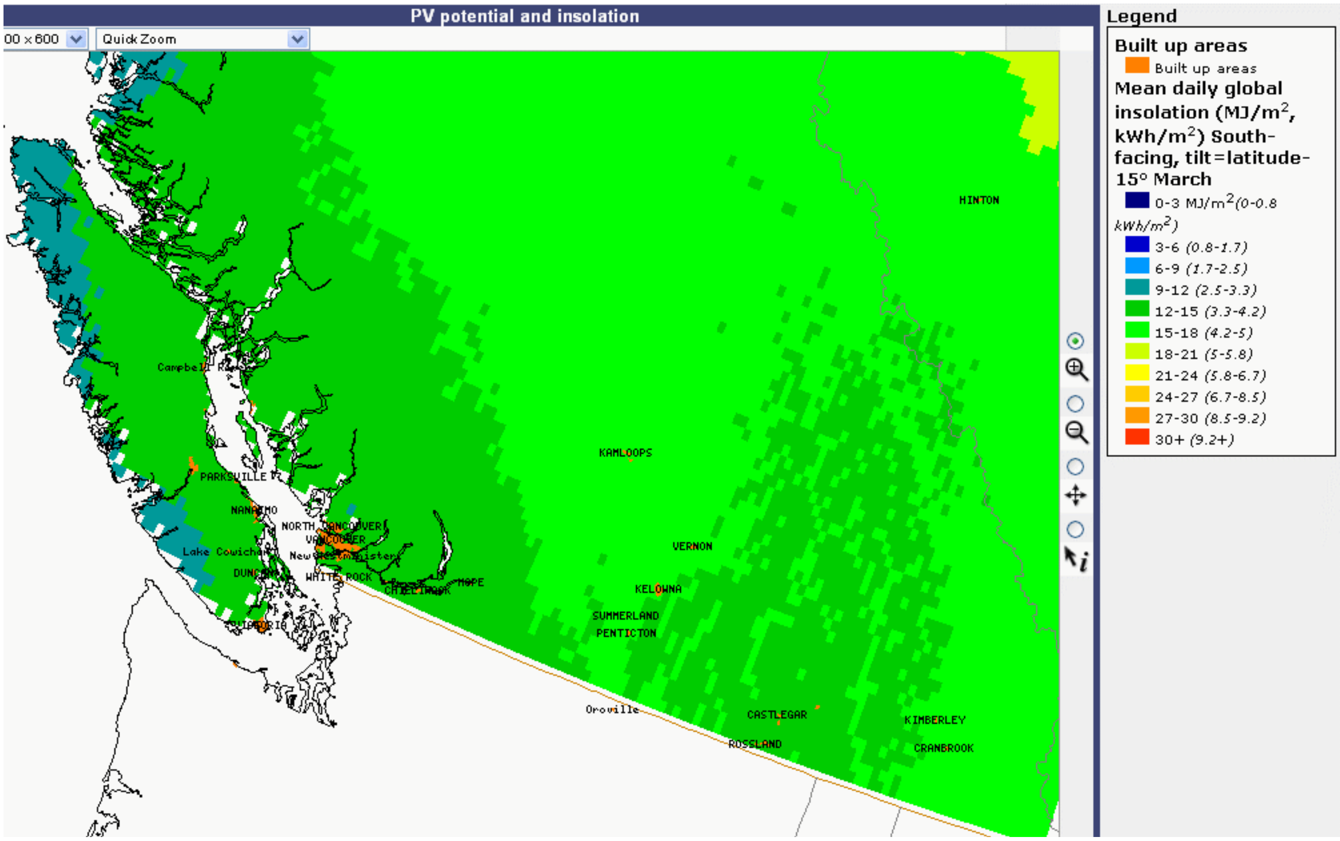
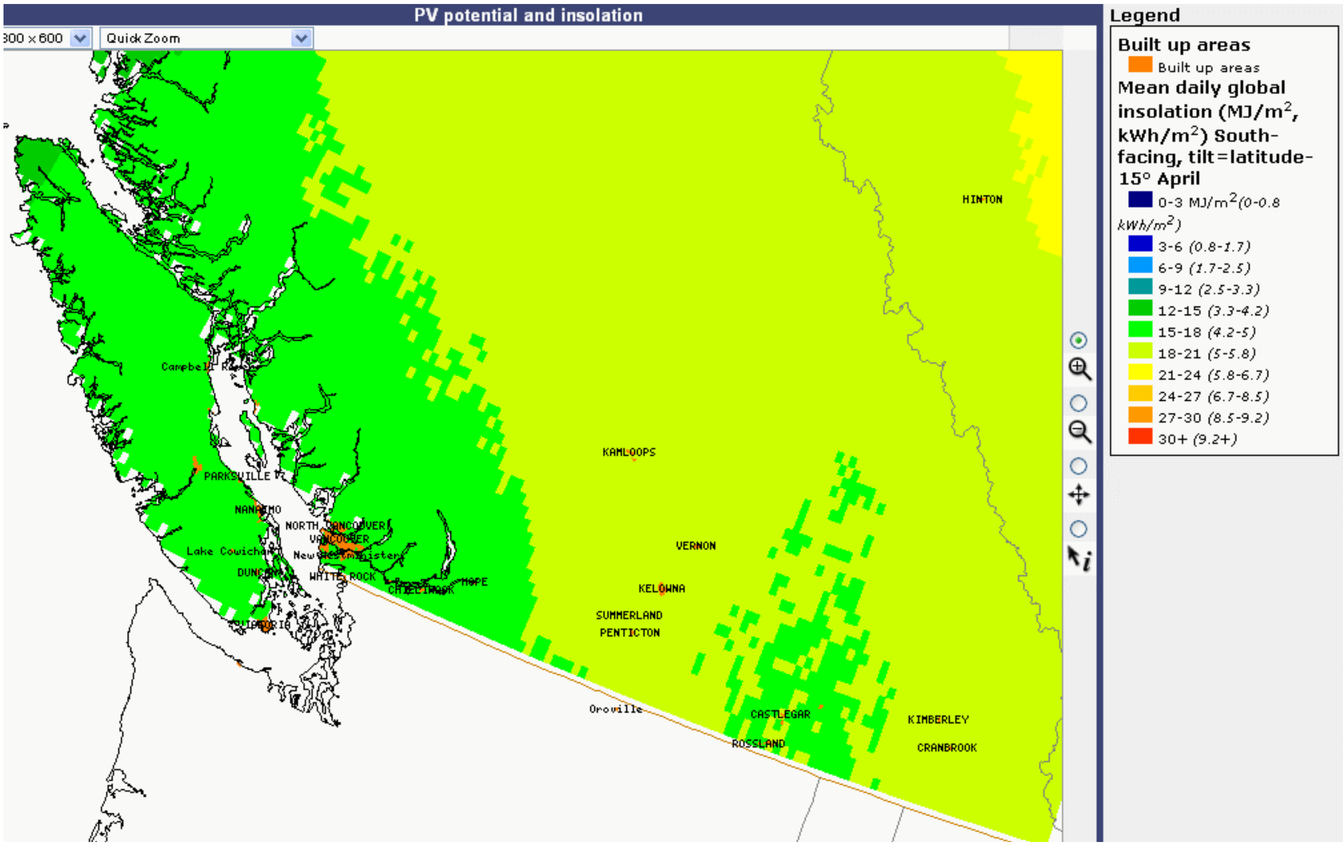

PV potential and insolation
Quick Zoom
HINTON
Campbell R
PARKSVILLE
NANAIMO
NORTH VANCOUVER
VANCOUVER
Lake Cowichan
New Westminster
DUNCAN
WHITE ROCK
CHILLIWACK
HOPE
VICTORIA
KAMLOOPS
VERNON
KELOWNA
SUMMERLAND
PENTICTON
Oroville
CASTLEGAR
ROSSLAND
KIMBERLEY
CRANBROOK
Legend
Built up areas
Built up areas
Mean daily global insolation (MJ/m², kWh/m²) South-facing, tilt=latitude-15° March
0-3 MJ/m² (0-0.8 kWh/m²)
3-6 (0.8-1.7)
6-9 (1.7-2.5)
9-12 (2.5-3.3)
12-15 (3.3-4.2)
15-18 (4.2-5)
18-21 (5-5.8)
21-24 (5.8-6.7)
24-27 (6.7-8.5)
27-30 (8.5-9.2)
30+ (9.2+)



PV potential and insolation
800 x 600
Quick Zoom
HINTON
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Built up areas
Built up areas
Mean daily global insolation (MJ/m², kWh/m²) South-facing, tilt=latitude-15° April
0-3 MJ/m²(0-0.8 kWh/m²)
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6-9 (1.7-2.5)
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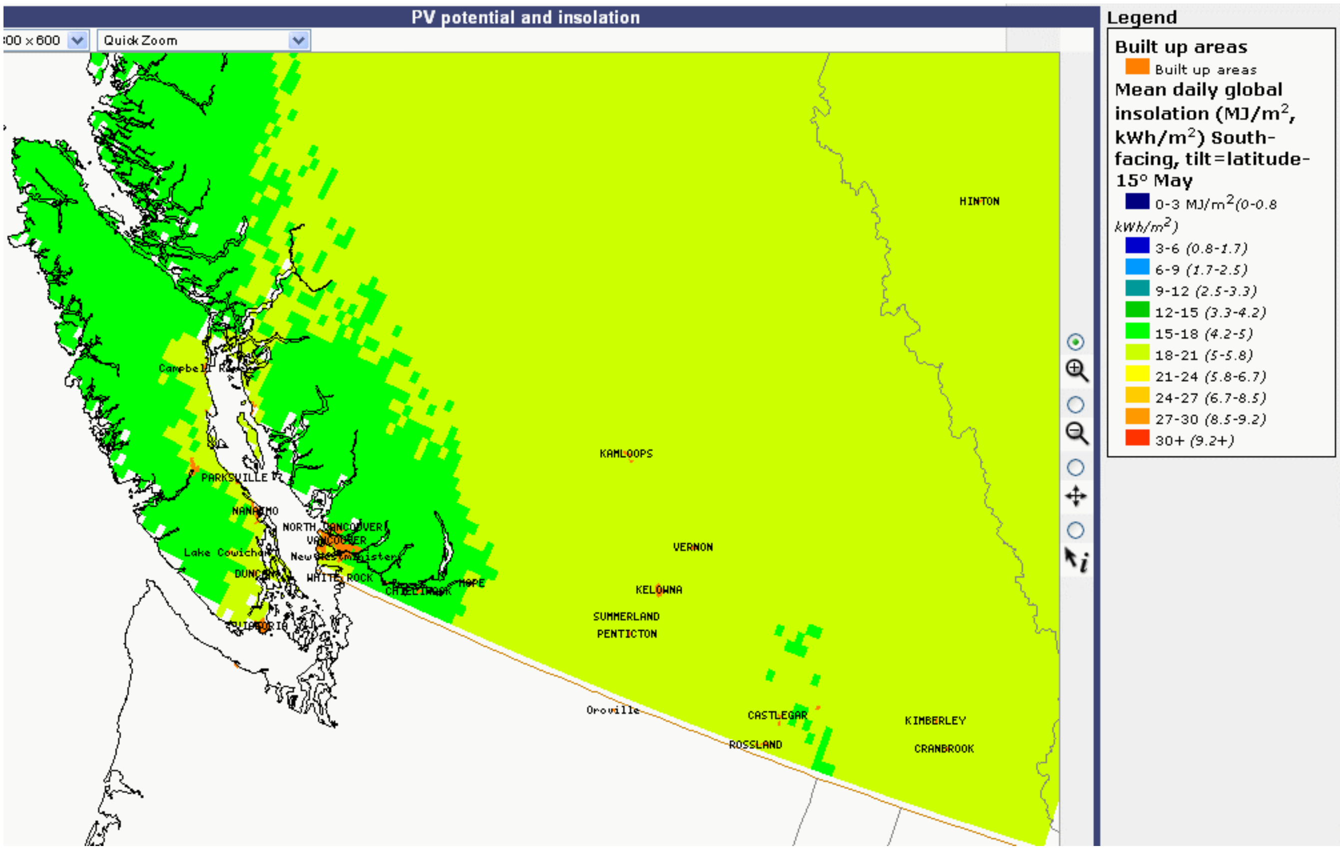

PV potential and insolation
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Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° May
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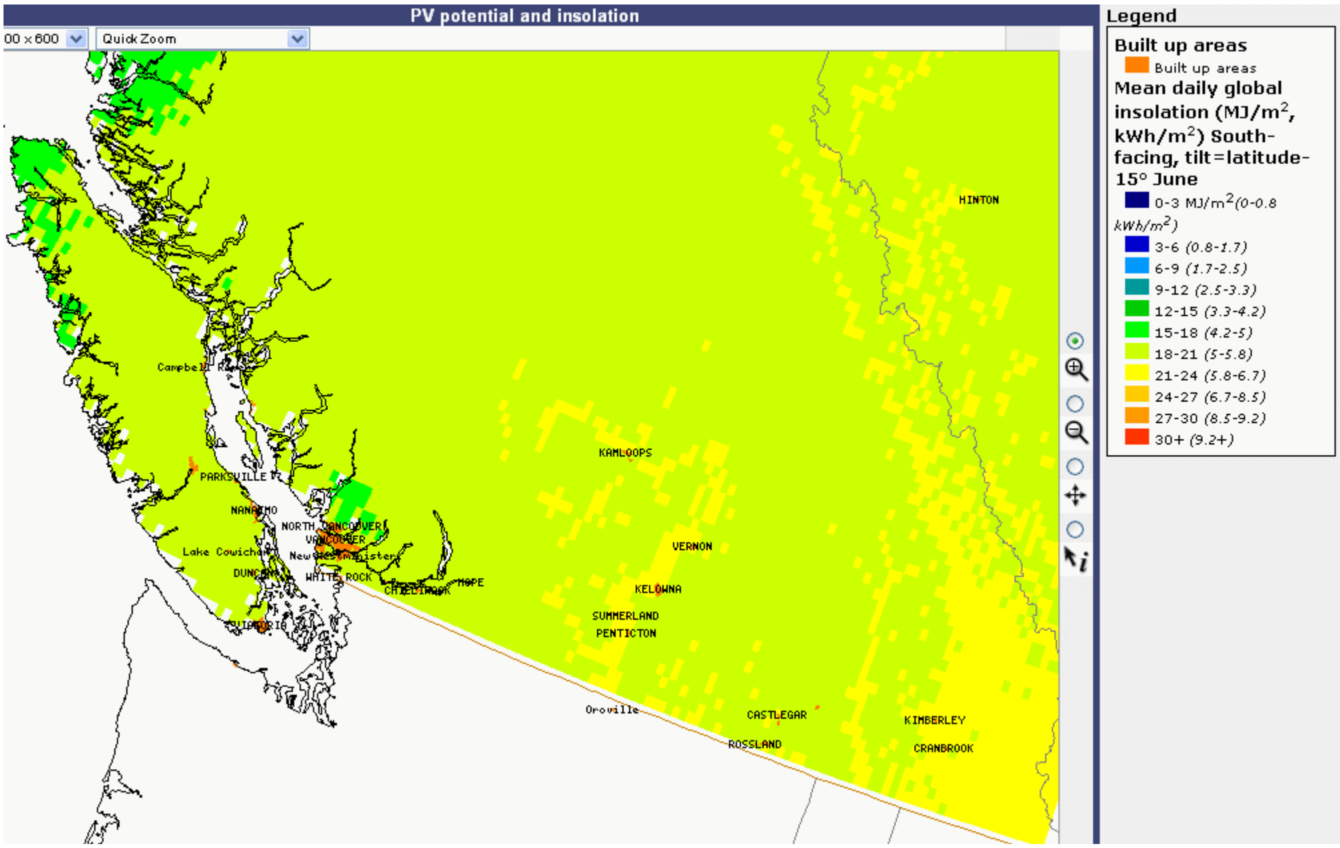
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Mean daily global insolation (MJ/m², kWh/m²) South-facing, tilt=latitude-15° June
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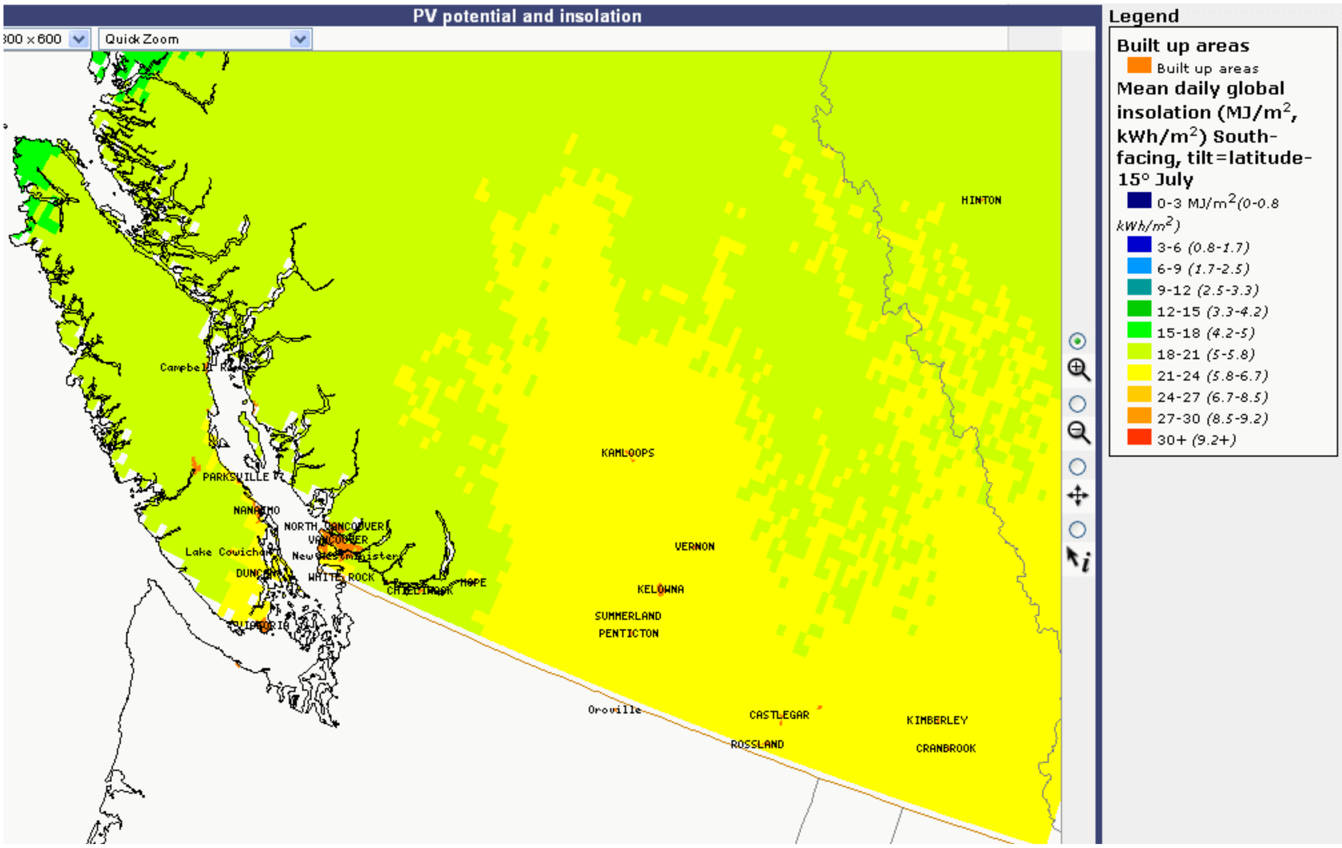
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Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° July
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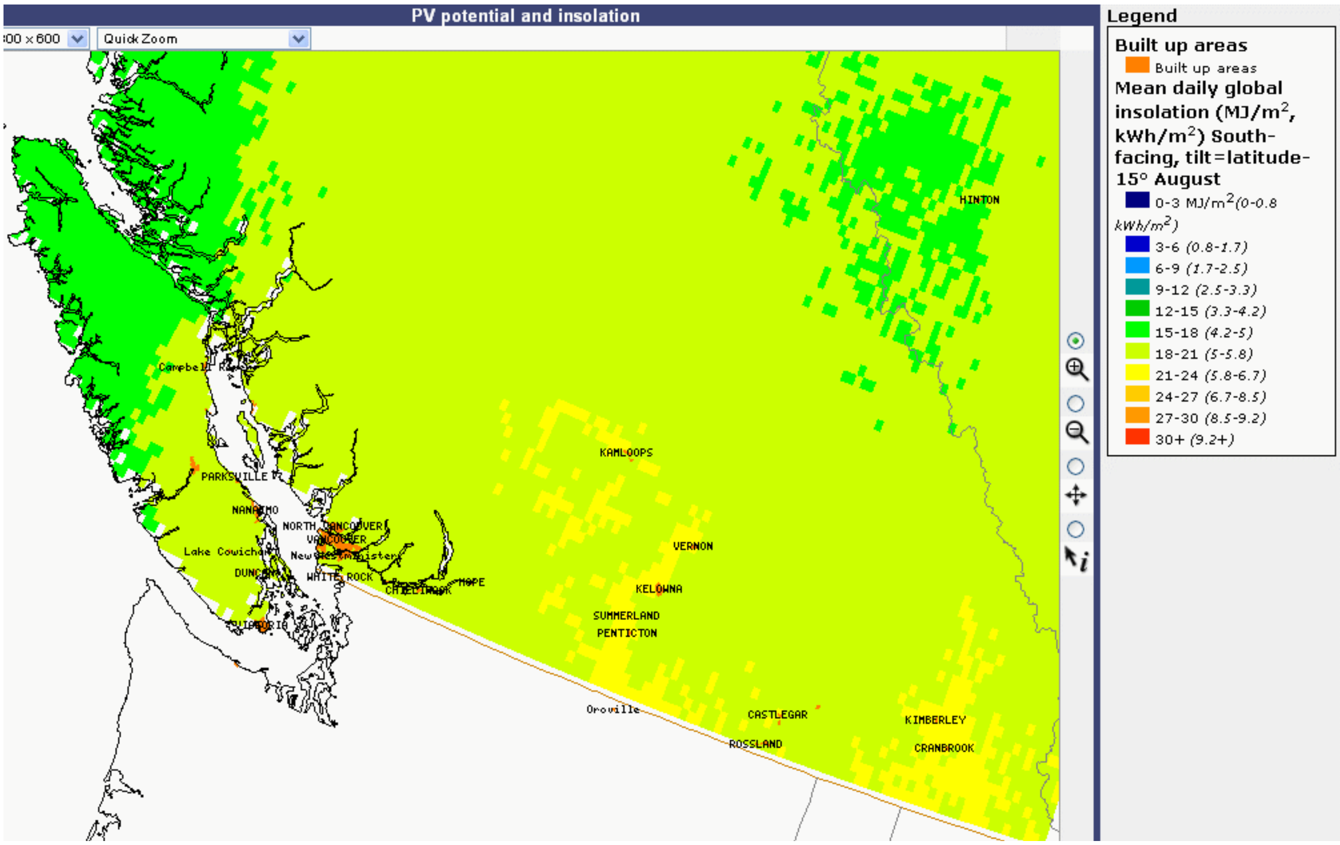

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Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° August
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12-15 (3.3-4.2)
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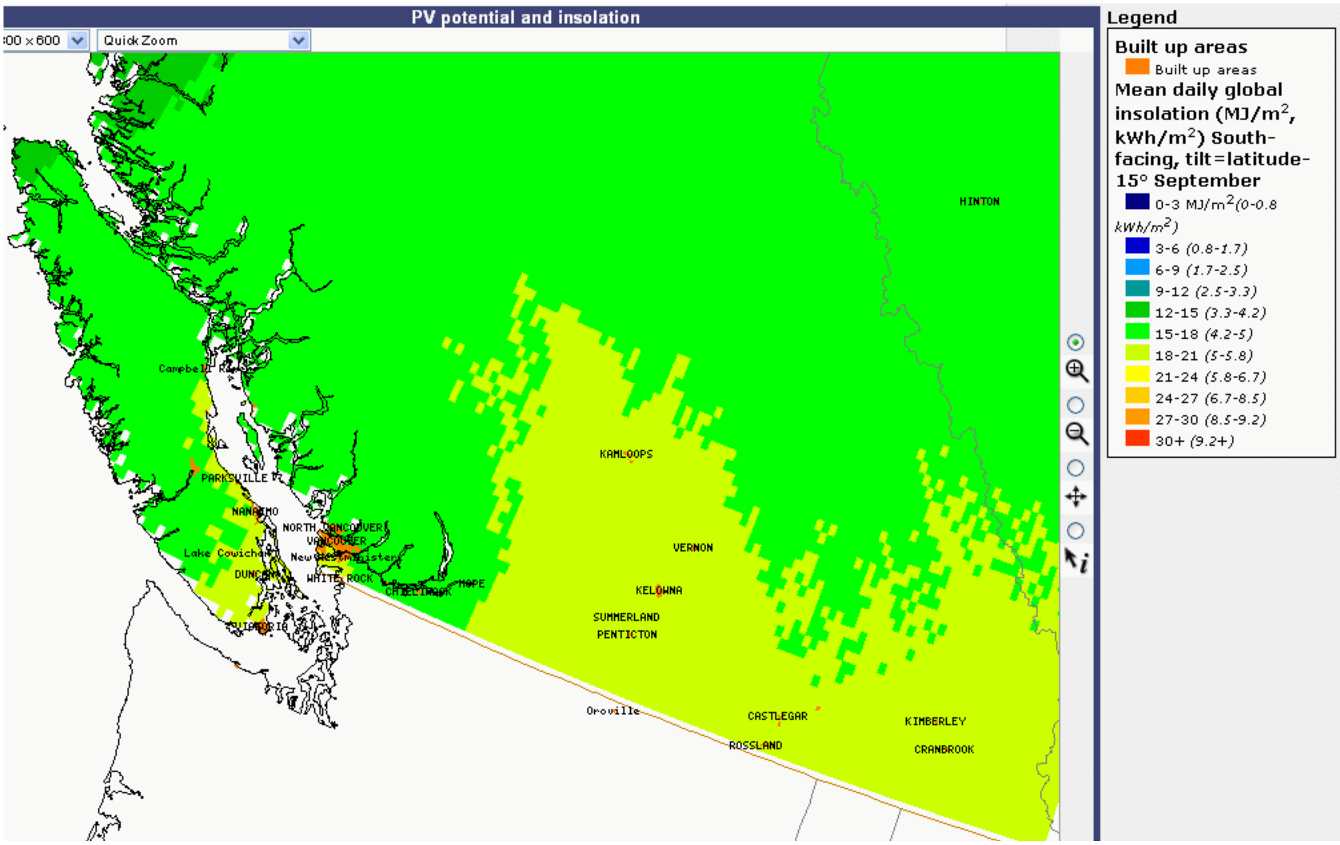
PV potential and insolation
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Built up areas
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Mean daily global insolation (MJ/m², kWh/m²) South-facing, tilt=latitude-15° September
0-3 MJ/m²(0-0.8 kWh/m²)
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6-9 (1.7-2.5)
9-12 (2.5-3.3)
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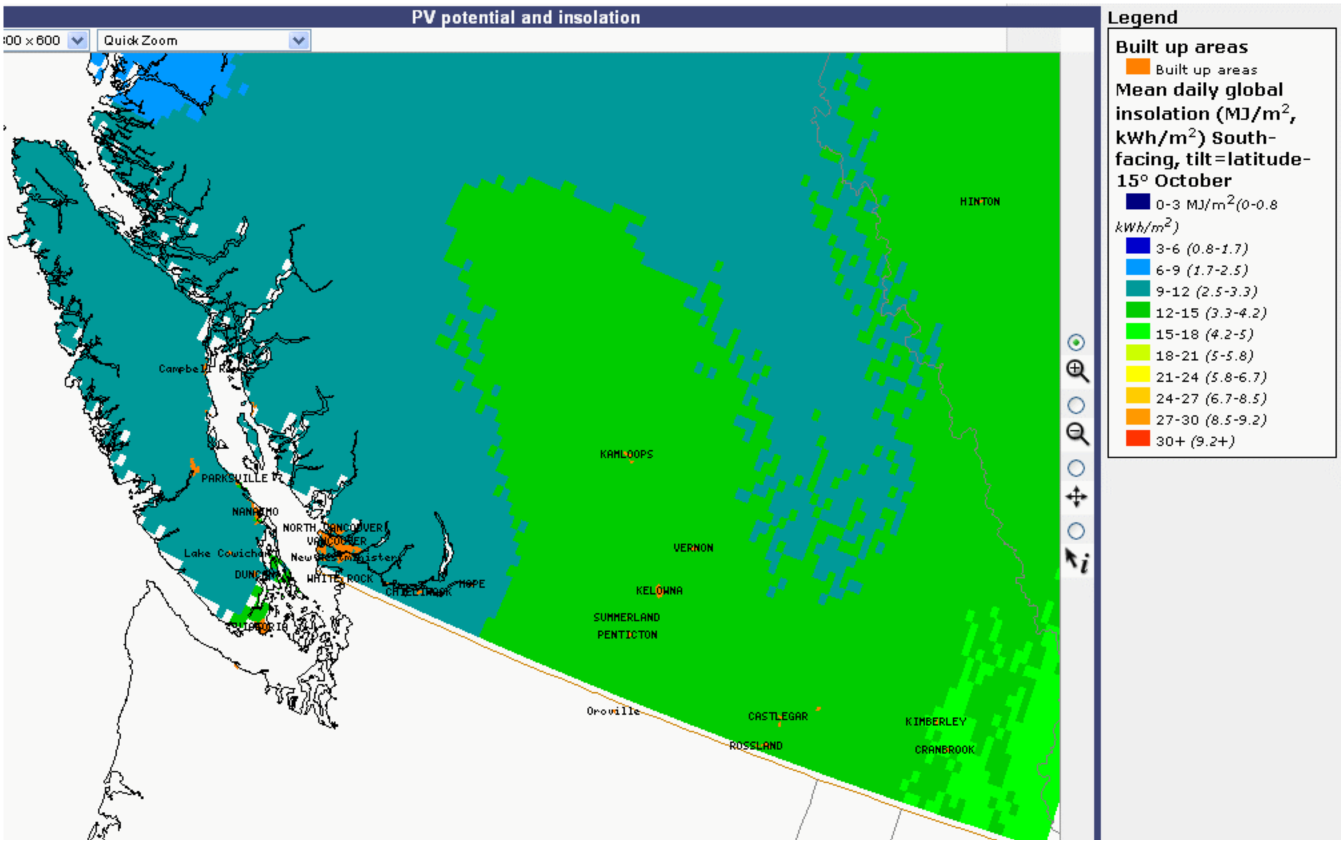
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Built up areas
Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° October
0-3 MJ/m2 (0-0.8 kWh/m2)
3-6 (0.8-1.7)
6-9 (1.7-2.5)
9-12 (2.5-3.3)
12-15 (3.3-4.2)
15-18 (4.2-5)
18-21 (5-5.8)
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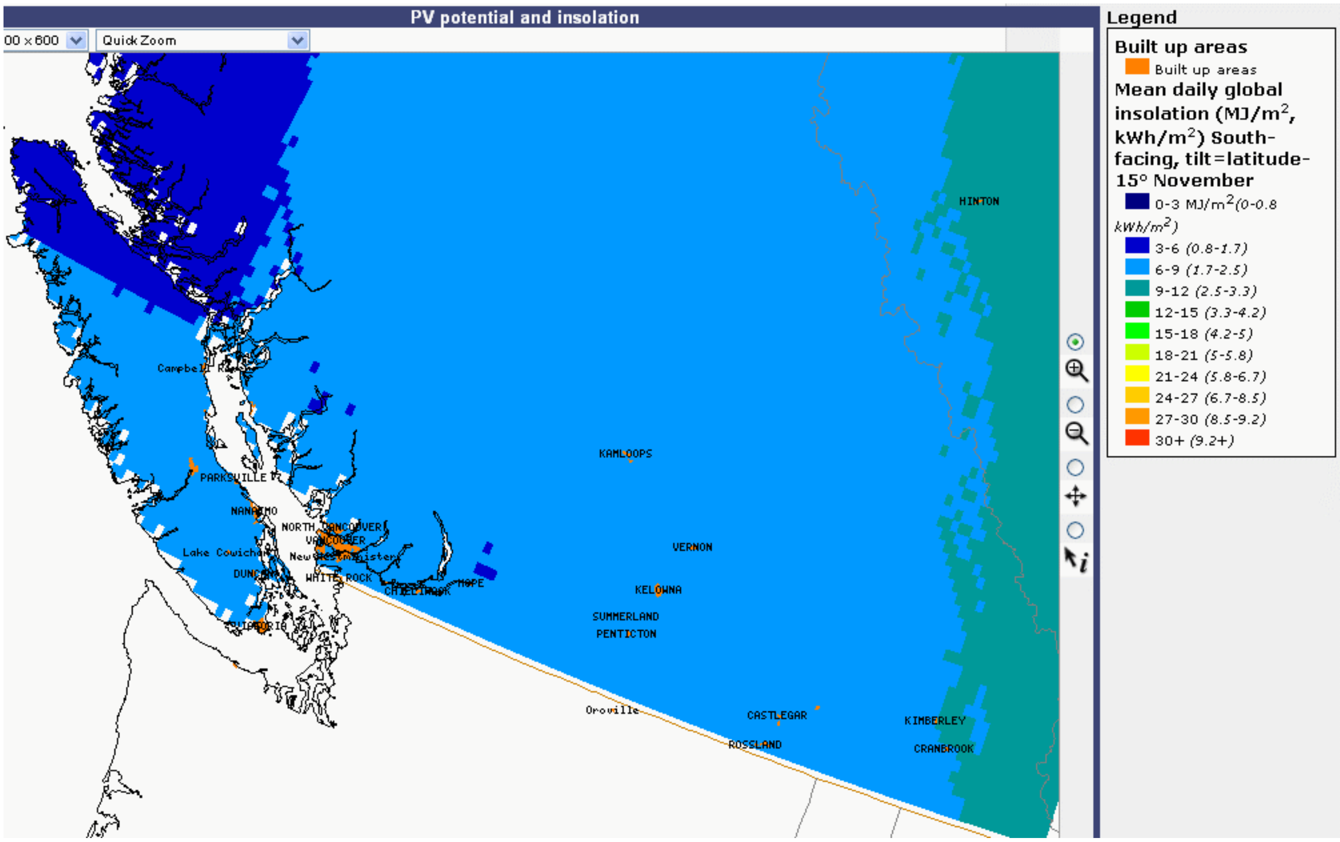

PV potential and insolation
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Legend
Built up areas
Built up areas
Mean daily global insolation (MJ/m2, kWh/m2) South-facing, tilt=latitude-15° November
0-3 MJ/m2 (0-0.8 kWh/m2)
3-6 (0.8-1.7)
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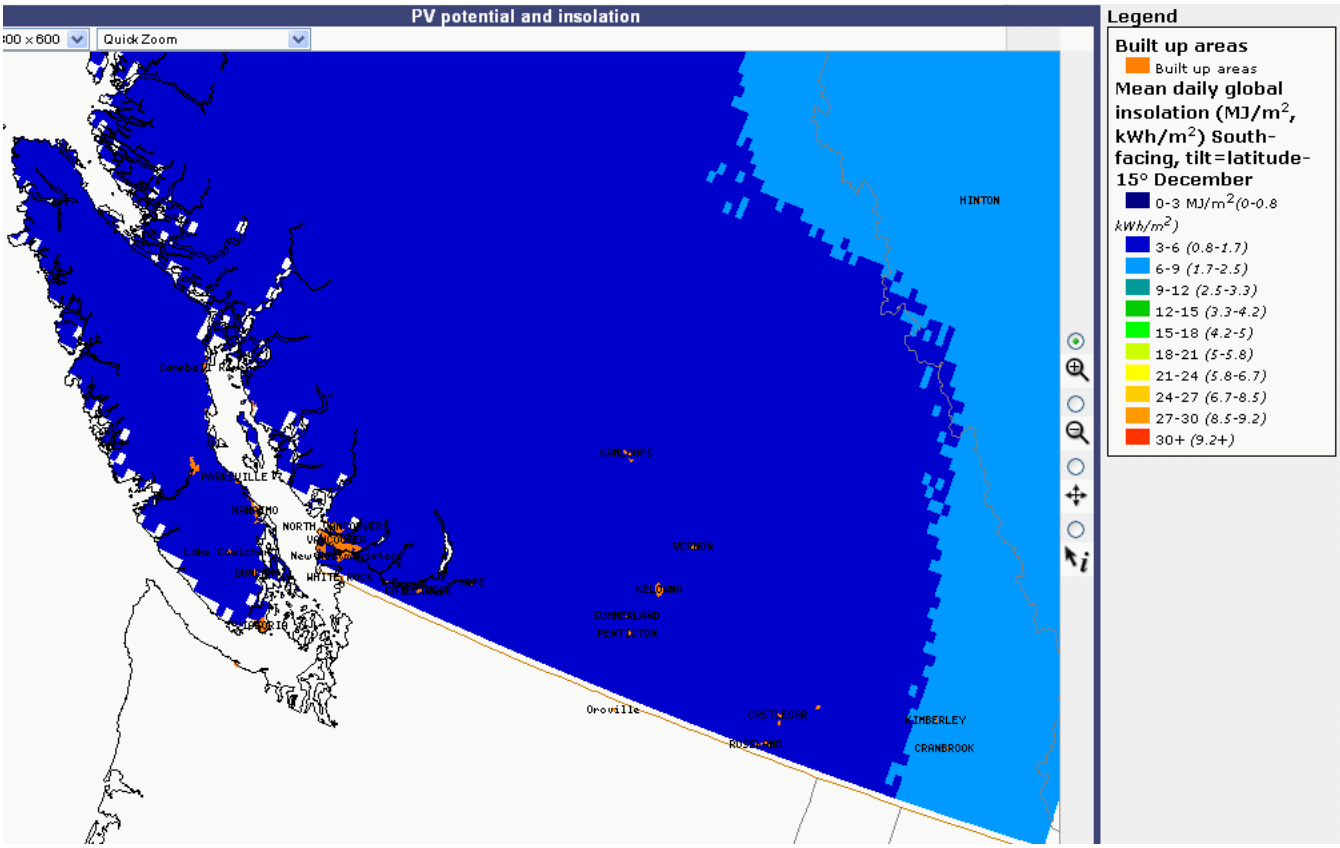
PV potential and insolation
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Built up areas
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Mean daily global insolation (MJ/m², kWh/m²) South-facing, tilt=latitude-15° December
0-3 MJ/m² (0-0.8 kWh/m²)
3-6 (0.8-1.7)
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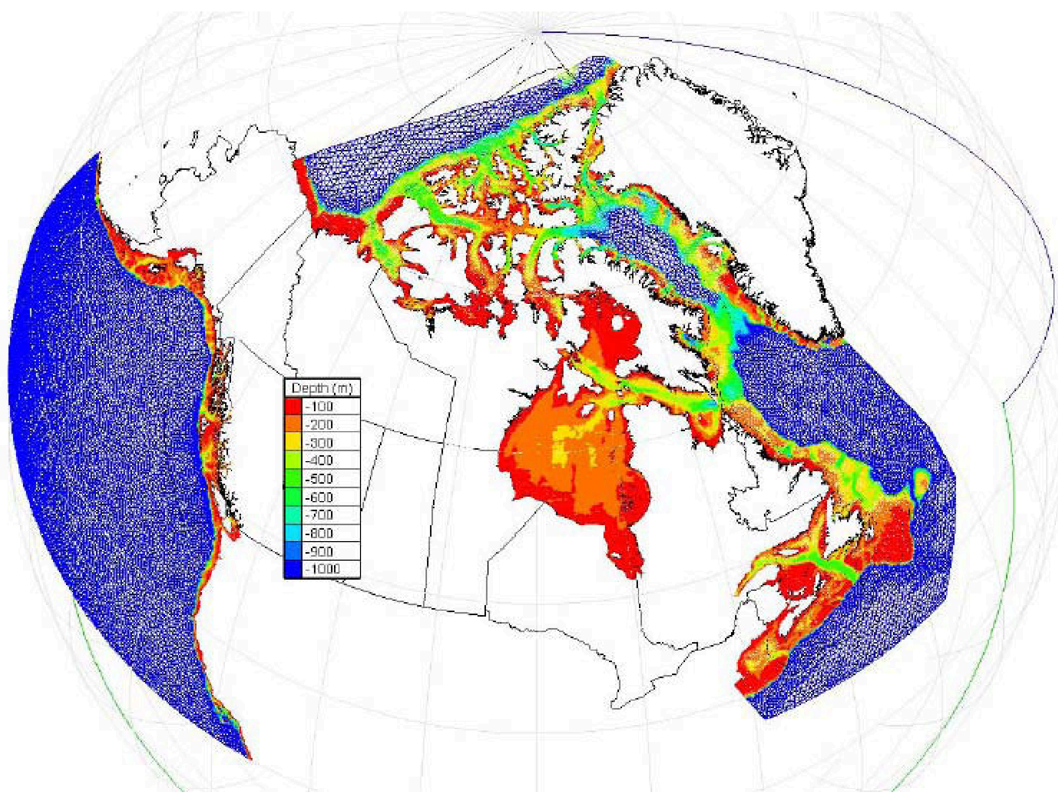
CHC CANADIAN HYDRAULICS CENTRE
CENTRE D'HYDRAULIQUE CANADIEN

INVENTORY OF CANADA'S MARINE RENEWABLE ENERGY RESOURCES



A. Cornett

CHC-TR-041
April 2006

National Research Council Canada Conseil national de recherches Canada

Appendix G

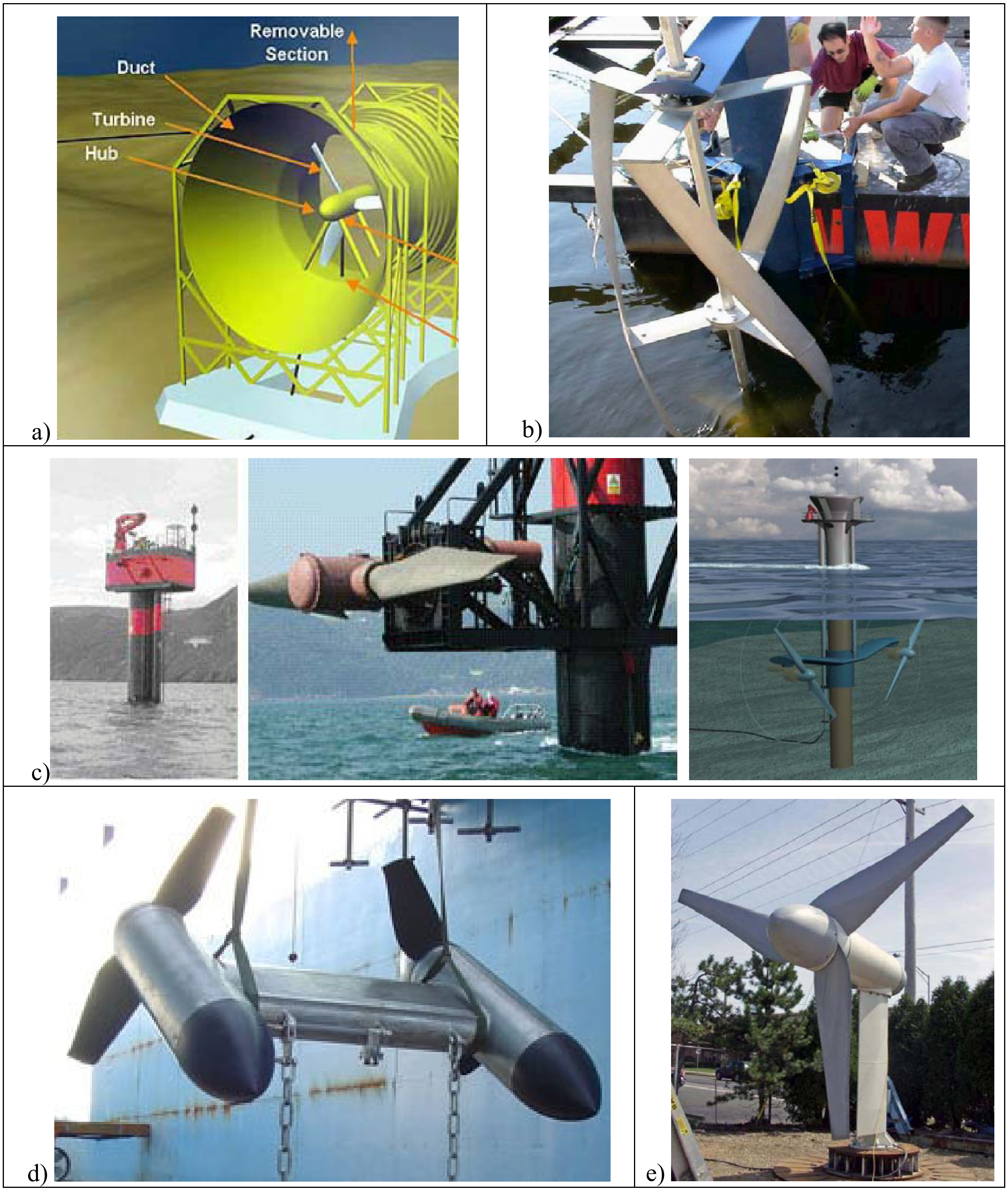


Figure 1. Five examples of kinetic hydraulic turbines: a) Lunar Energy; b) GCK Technology; c) MCT SeaGen; d) SMD Hydrovision TidEL; e) Verdant Power.

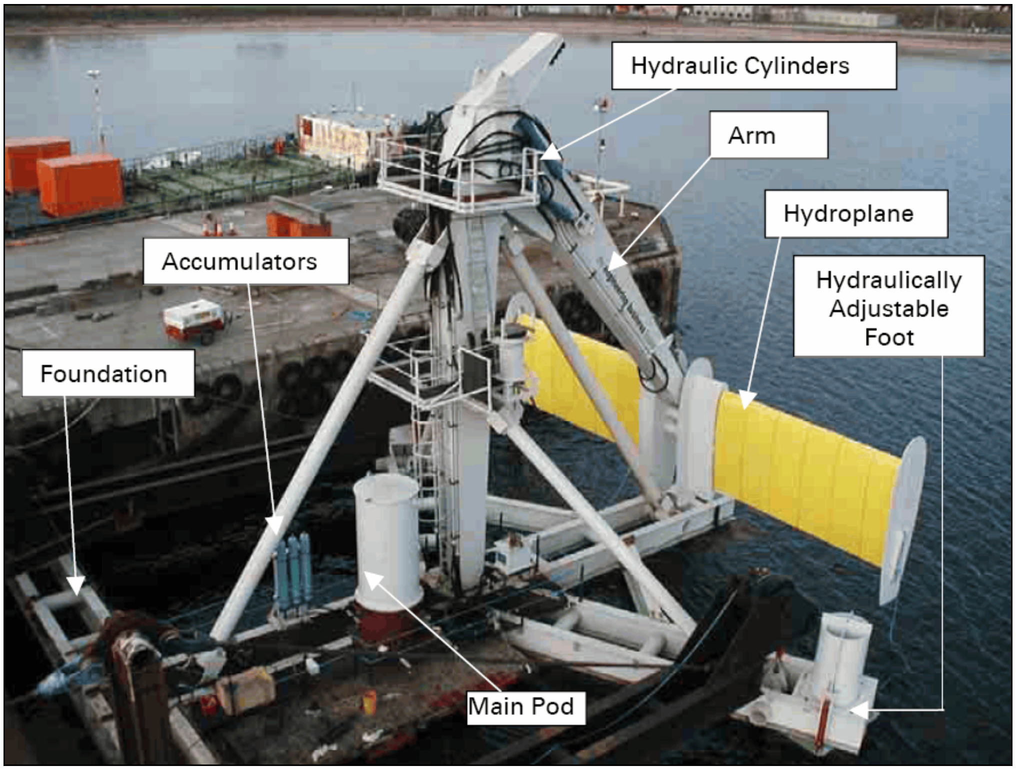


Figure 2. Stingray tidal stream generator prior to deployment.

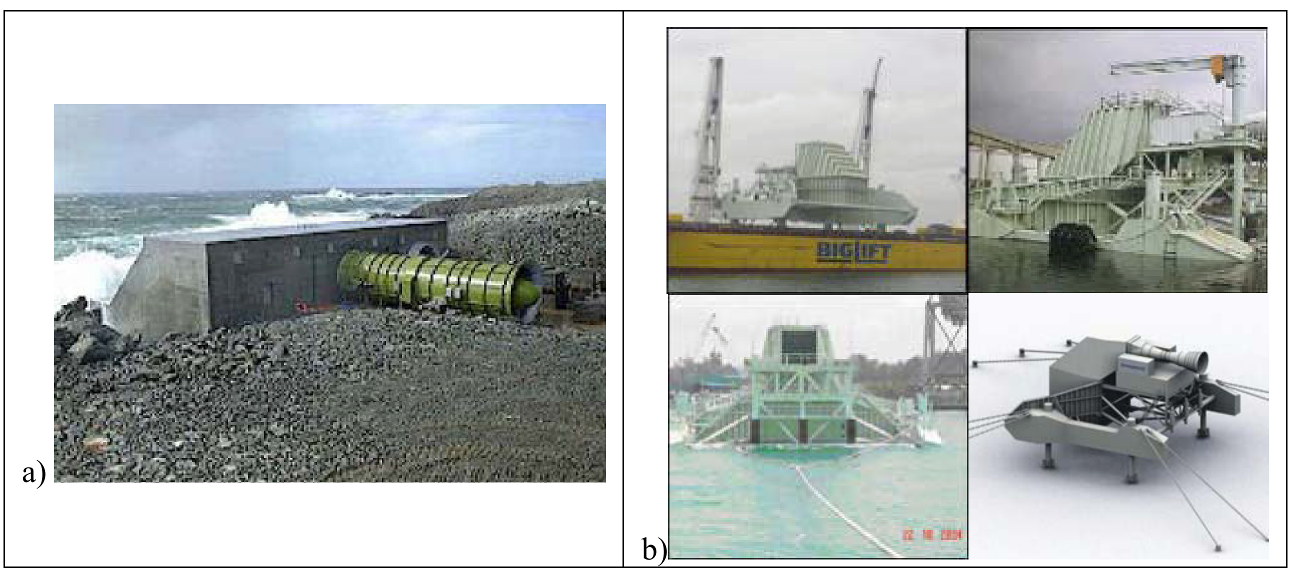


Figure 3. Two examples of nearshore wave energy converters: a) Limpet OWC; b) Energetech OWC.

Figure 4. Six examples of offshore wave energy converters: a) Pelamis; b) Archimedes Wave Swing; c) IPS Buoy; d) Technocean Hose-Pump; e) Wave Dragon; f) OPT PowerBuoy.

Station ID	Station Name	Long	Lat	Mean Wave Power (kW/m)												
				Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C46004	Middle Nomad	-135.87	50.94	53.8	89.4	80.4	64.8	51.0	27.0	17.9	11.1	14.8	33.3	64.9	96.8	113.8
C46036	South Nomad	-133.86	48.3	53.3	90.8	79.2	73.8	50.7	26.6	19.6	11.3	15.0	27.2	59.2	86.8	107.1
meds503w	Queen Charlotte	-129.97	51.3	52.9	103.4	73.8	57.6	72.9	25.3	22.7	10.5	10.5	22.3	35.9	83.9	85.8
C46184	North Nomad	-138.76	53.96	50.9	79.6	73.0	62.5	44.6	22.7	16.8	10.3	14.7	35.3	62.6	84.9	103.3
C46207	East Dellwood	-129.91	50.86	49.0	82.4	75.3	59.9	39.3	22.1	16.1	9.9	11.4	23.9	56.7	77.4	100.5
C46147	South Moresby	-131.2	51.82	49.0	79.4	82.3	64.9	42.1	21.8	16.9	10.1	11.8	26.3	63.1	79.1	101.0
meds211	Langara West	-133.32	54.45	45.7	106.2	101.3	55.9	48.7	20.7	12.3	7.8	9.6	21.0	37.7	63.3	72.3
C46208	West Moresby	-132.7	52.5	44.7	72.8	69.7	56.6	39.1	22.8	16.2	9.7	12.8	25.8	56.0	73.0	95.8
C46205	West Dixon Entrance	-133.4	54.3	43.6	73.0	57.6	53.1	40.0	23.3	15.3	9.5	13.3	28.2	53.5	81.2	91.0
meds226	Cape Scott	-128.91	50.77	43.3	101.1	53.9	49.9	54.4	22.4	11.7	7.2	13.5	15.4	55.7	29.3	53.0
C46132	South Brooks	-127.92	49.73	43.3	71.7	71.8	60.0	35.8	19.4	15.1	9.0	9.8	21.4	51.2	67.0	87.1
meds103	Tofino	-125.74	48.99	31.9	58.2	53.5	45.6	32.5	18.6	12.4	7.8	8.3	13.7	34.2	52.2	55.7
C46204	West Sea Otter	-128.74	51.38	30.7	51.8	41.6	39.7	25.5	14.7	10.6	6.7	7.7	15.4	35.9	48.8	61.2
C46185	South Hecate Strait	-129.8	52.42	23.0	42.8	34.1	27.3	20.6	11.8	7.9	5.4	5.9	10.5	23.0	36.4	47.0
meds502w	Hecate Strait	-130.33	52.2	18.2	31.7	20.4	32.3	21.8	10.3	10.6	4.9	4.1	7.9	18.3	33.0	21.2
C46145	Central Dixon Entranc	-132.43	54.38	17.7	22.2	26.0	24.0	14.5	8.2	5.0	3.4	4.8	12.7	22.0	30.7	41.7
meds213	Bonilla Island	-130.72	53.32	12.1	23.2	13.9	16.4	14.4	7.7	4.8	3.2	2.6	4.9	10.1	24.4	17.6
C46183	North Hecate Strait	-131.14	53.57	11.2	21.3	16.9	13.0	10.4	5.0	3.0	2.3	3.5	5.3	11.5	17.9	24.0
C46131	Sentry Shoal	-124.99	49.91	0.6	0.8	0.5	0.8	0.6	0.2	0.2	0.1	0.1	0.2	0.7	1.1	1.2
meds108	Roberts Bank	-123.27	49.02	0.4	0.2	0.5	0.6	0.4	0.4	0.6	0.2	0.2	0.2	0.4	0.5	0.5
meds102	Sturgeon Bank	-123.31	49.17	0.4	0.3	0.4	0.5	0.5	0.3	0.4	0.2	0.2	0.2	0.3	0.4	0.4
C46146	Halibut Bank	-123.73	49.34	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.6
meds122	Point Grey	-123.27	49.28	0.2	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.3
meds106	West Vancouver	-123.23	49.35	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
meds123	Fishermans Cove (WB)	-123.7	49.35	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1
C46181	Nanakwa Shoal	-128.84	53.82	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
meds317	Esquimalt Harbour	-123.45	48.43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
meds124	Fishermans Cove (K)	-123.27	49.35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C46134	Pat Bay Test Buoy	-123.45	48.66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
meds121	Gibsons Landing	-123.5	49.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7. Annual and monthly mean wave power for Pacific stations.

Many stations on both coasts are located in sheltered inshore locations with relatively mild wave climates. However, there are also a good number of stations in exposed sites featuring energetic wave climates. These results indicate that the mean annual wave energy flux at exposed sites in deep water off the B.C. coast is typically in the range of 45 to 55 kW/m, while the mean wave power available near the western shores of the Queen Charlotte Islands and Vancouver Island is on the order of 30 to 45 kW/m. On the Grand Banks east of Newfoundland, the mean annual wave energy flux is in the range of 42 to 45 kW/m, while the mean wave power available near the SE coast of Newfoundland is on the order of 25 to 30 kW/m. Annual mean wave power values around 20 to 25 kW/m seem representative for the waters near Sable Island, while values near 10 kW/m are representative of conditions along the southern shore of Nova Scotia.

As noted previously, the wave power along a coast can vary considerably due to sheltering and bathymetric effects such as wave diffraction and refraction. Hence, there likely will be pronounced local variations in wave conditions and energy potential close to shore. Clearly, these local variations cannot be identified and are beyond the scope of the present analysis.

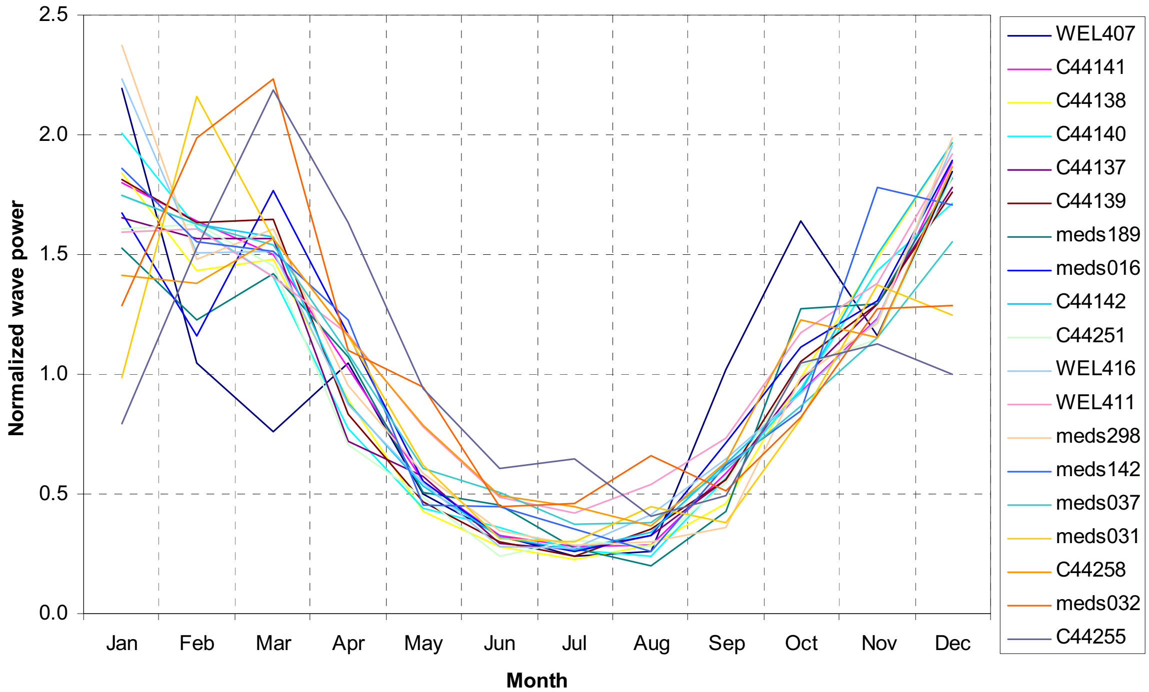


Figure 12. Seasonal variation in mean wave power for Atlantic stations.

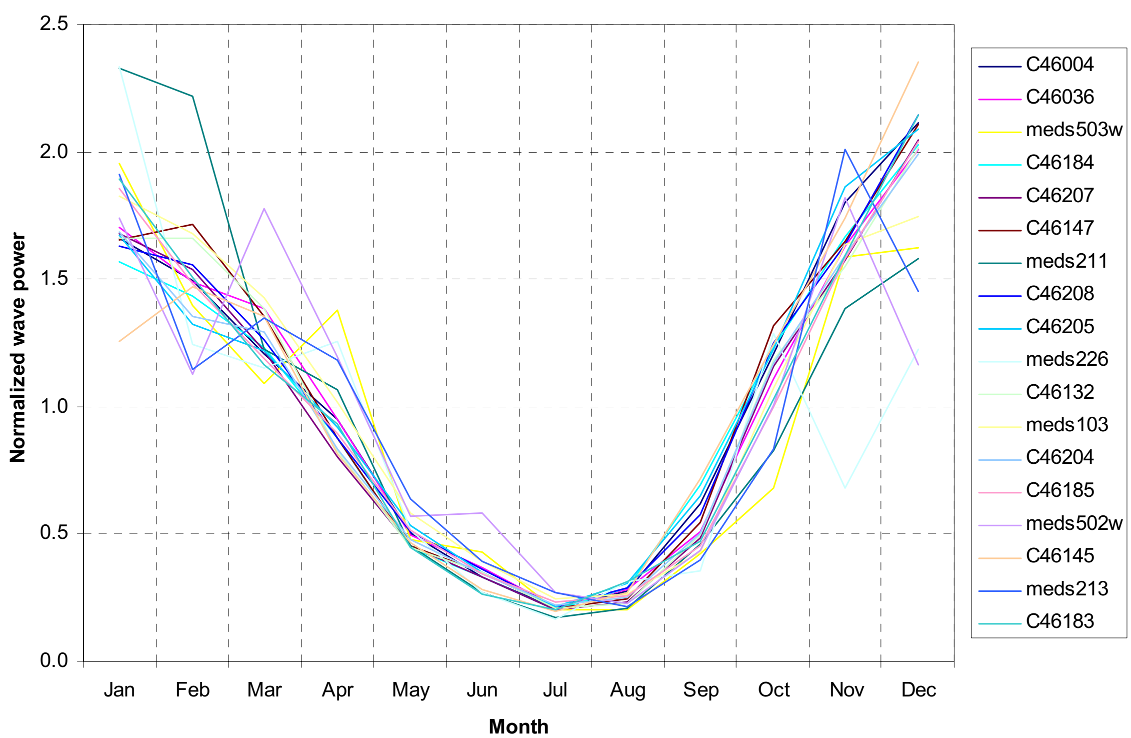


Figure 13. Seasonal variation in mean wave power for Pacific stations.

3.5.2. Results

The mean annual wave power computed from the WW3-ENP data is plotted in Figure 18. The mean wave power in winter and summer are compared in Figure 19.

Figure 20 shows the mean annual wave power computed from the WW3-WNA data. The mean wave power in summer and winter are compared in Figure 21.

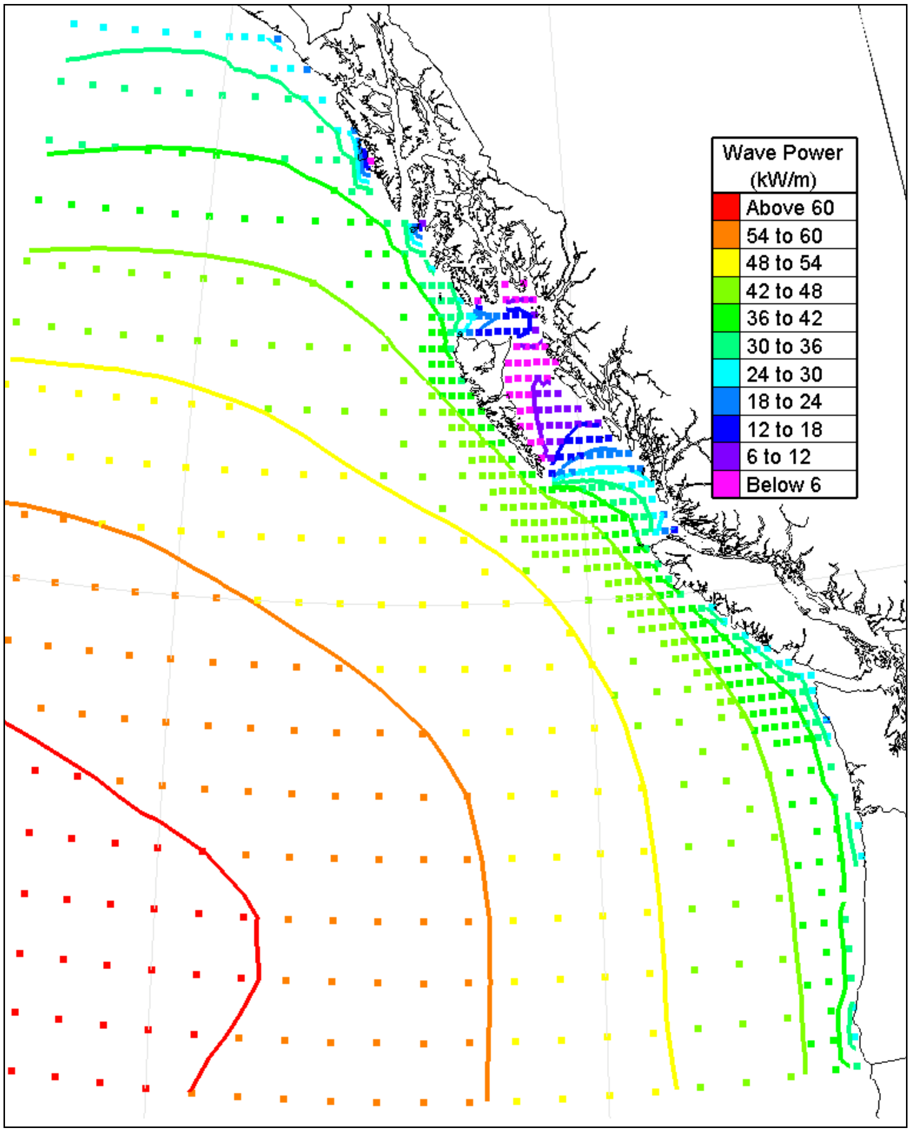


Figure 18. Mean annual wave power in the NE Pacific derived from WW3-ENP hindcast data. (points denote sub-grid nodes.)

where V_f is the maximum speed at the surface in the passage during a large flood, V_e is the maximum surface speed during a large ebb, and the factor 0.85 accounts for the lateral and vertical velocity variations across the channel. The annual mean power density is computed as

$$\overline{p} = \frac{2\rho}{3\pi} \frac{\left(a_f U_{\max}\right)^3 + \left(a_e U_{\max}\right)^3}{2} \tag{23}$$

Where $a_f U_{max}$ denotes the annual mean peak flood current velocity, and $a_e U_{max}$ denotes the annual mean of the current velocity at peak ebb. Triton assumed $a_f = 0.9$ and $a_e = 0.7$ at all locations except in British Columbia, where diurnal tidal currents are particularly strong. It was assumed that $a_e = 0.5$ for sites in southern B.C., and $a_e = 0.6$ for sites in northern B.C.. The annual mean power at the site was calculated according to

$$\overline{P} = w h_{ave} \overline{p} \tag{24}$$

where w denotes the width of the passage and h_{ave} is the average depth.

4.4.2. Results

A total of 260 potential sites were identified. Of these, 190 sites had potential mean power estimated to be greater that 1 MW. Table 10 shows the cumulative mean potential tidal current energy by Province and Territory. Nunavut has by far the greatest potential resource (30,567 MW), while British Columbia has the most sites greater than 1 MW (89 sites). Table 11 shows the distribution of mean potential power by region. Over 70% of the Canada's tidal current energy resources lie within Hudson Strait, which connects Hudson Bay with Baffin Bay and the Northwest Atlantic.

Province	Potential Tidal Current Energy MW	Number of Sites	Average Size MW
Northwest Territories	35	4	9
British Columbia	4,015	89	45
Québec	4,288	16	268
Nunavut	30,567	34	899
New Brunswick	636	14	45
PEI	33	4	8
Nova Scotia	2,122	15	141
Newfoundland	544	15	36
TOTAL	42,240	191	221

Table 10. Mean potential tidal current energy by Province and Territory.

Region	Potential Tidal Current Energy MW	Number of Sites	Average Size MW
Vancouver Island Mainland	3,580	62	58
Pacific Mainland North	353	18	20
Queen Charlotte Islands	81	9	9
Arctic	1,008	30	34
Hudson Strait	29,595	8	3,699
Ungava	4,112	10	411
St. Lawrence River	153	4	38
Gulf of St Lawrence	537	15	36
Atlantic North	65	6	11
Atlantic South	30	8	4
Bay of Fundy	2,725	21	130
TOTAL	42,240	191	221

Table 11. Mean potential tidal current energy by region.

All sites in southern and northern British Columbia with mean power greater than 1 MW are summarized in Table 12 and Table 13 respectively. Table 14 lists the sites in the Northwest Territories; Table 15 shows the sites in Nunavut; Table 16 shows the sites in Québec; Table 17 shows the sites in Newfoundland and Labrador; while Table 18, Table 19, and Table 20 list the sites in Nova Scotia, Prince Edward Island and in New Brunswick.

The leading tidal current energy sites across Canada are also mapped in Figure 76. Figure 77 , Figure 78 and Figure 79 show detailed views of this map, centred on the Pacific coast, the Arctic Archipelago, and the Atlantic coast, respectively. In these maps, the size and colour of the circles are scaled and shaded in proportion to the mean potential power of each site.

This inventory, while likely not fully comprehensive, represents the best possible pan-Canadian assessment that could be made considering the level of funding, the available information, and the vast extent of Canada's coastal waters. Despite best efforts, it is entirely possible that some good potential sites have been missed. Hence, this inventory should be considered as a lower bound estimate to both the number of sites and the total tidal stream energy resource.

Site Name	Latitude deg	Longitude deg	Maximum Current Speed Flood knot	Maximum Current Speed Ebb m/s	Mean Maximum Depth Average Current Speed m/s	Mean Power Density kW/m^2	Width of Passage m	Average Depth of Passage m	Flow Cross-sectional Area m^2	Mean Potential Power MW
Seymour Narrows	50.13	-125.35	16	14	6.56	18.16	769	41	33,331	786
N. Boundary Passage	48.79	-123.01	4	4	1.75	0.50	5,158	140	734,949	366
Discovery Pass. S.	50.00	-125.21	7	7	3.06	3.68	1,459	42	65,626	327
Boundary passage	48.69	-123.27	3.5	3.5	1.53	0.33	4,472	175	793,760	265
Current Passage 2	50.39	-125.86	6	6	2.63	1.68	1,502	80	123,931	208
Weyton Passage	50.59	-126.82	6	6	2.63	1.68	1,535	75	118,985	200
Current Passage 1	50.41	-125.87	5	5	2.19	0.97	1,398	100	143,331	139
Dent Rapids	50.41	-125.21	11	8	4.16	6.67	420	45	19,955	133
South Pender Is	48.72	-123.19	4	4	1.75	0.50	1,985	100	203,416	101
Yaculta Rapids	50.38	-125.15	10	10	4.38	7.78	539	20	12,135	94
Arran Rapids	50.42	-125.14	14	10	5.25	13.45	271	22	6,629	89
Secheldt Rapids 2	49.74	-123.90	14.5	16	6.67	27.60	261	8	2,739	76
Gillard Passage 1	50.39	-125.16	13	10	5.03	11.84	237	16	4,393	52
Scott Channel	50.79	-128.50	3	3	1.31	0.21	9,970	22	244,256	51
Active Pass	48.86	-123.33	8	8	3.50	3.98	561	20	12,628	50
Nahwitti Bar 1	50.89	-127.99	5.5	5.5	2.41	1.29	2,993	9	34,417	45
Race Passage	48.31	-123.54	6	7	2.84	2.14	884	20	19,885	42
Green Pt 2	50.45	-125.52	6	6	2.63	1.68	538	35	20,157	34
Blackney Passage	50.57	-126.69	5	5	2.19	0.97	814	40	34,598	34
GreenPt Rap. 1	50.44	-125.51	7	7	3.06	2.67	440	25	12,093	32
Porlier Pass	49.01	-123.59	9	8	3.72	4.78	339	15	5,926	28
Becher Bay	48.32	-123.62	3	3	1.31	0.21	2,148	60	134,263	28
Upper rapids 2	50.31	-125.23	9	9	3.94	5.67	242	18	4,955	28
Gillard Passage 2	50.40	-125.15	10	8	3.94	5.67	393	10	4,916	28
Whirlpool Rapids	50.46	-125.76	7	7	3.06	2.67	321	28	9,804	26
Surge Narrows	50.23	-125.16	6	6	2.63	1.68	413	30	13,432	23
Chatham Islands	48.45	-123.26	6	6	2.63	1.68	903	12	13,099	22
Quatsino Narrows	50.55	-127.56	9	8	3.72	4.78	207	18	4,240	20
Hole-in-the-Wall 1	50.30	-125.21	12	9.5	4.70	9.67	189	8	1,985	19
Village Island	50.64	-126.51	3	3	1.31	0.21	1,234	70	89,461	19
Green Pt 3	50.44	-125.57	5	5	2.19	0.97	673	25	18,498	18
Nahwitti Bar 2	50.87	-127.99	5.5	5.5	2.41	1.29	2,012	4	13,078	17
First Narrows	49.32	-123.14	6	6	2.63	1.68	418	16	7,734	13
Buckholtz Ch 2	50.49	-127.60	3	3	1.31	0.21	1,073	50	56,329	12
Buckholtz Ch 1	50.49	-127.67	3	3	1.31	0.21	997	50	52,357	11
Tallac - Erasmus Is	50.44	-125.47	3	3	1.31	0.21	665	75	51,522	11
Lower Rapids 1	50.31	-125.26	7	7	3.06	2.67	371	8	3,891	10
Picton Point	50.46	-125.40	3	3	1.31	0.21	881	50	46,235	10
Charles Bay Rapids	50.42	-125.49	5	5	2.19	0.97	664	12	9,631	9
Pearse Passage	50.58	-126.90	4	4	1.75	0.50	1,168	13	18,104	9
Welcome Passage	49.51	-123.97	3	3	1.31	0.21	746	50	39,189	8
Alert Bay	50.57	-126.93	3	3	1.31	0.21	1,771	18	36,311	8
Gabriola Pass.	49.13	-123.70	8.5	9	3.83	5.21	137	8	1,435	7

Site Name	Latitude	Longitude	Maximum Current Speed Flood	Maximum Current Speed Ebb	Mean Maximum Depth Average Current Speed	Mean Power Density	Width of Passage	Average Depth of Passage	Flow Cross-sectional Area	Mean Potential Power
	deg	deg	knot	m/s	m/s	kW/m^2	m	m	m^2	MW
Second Narrows	49.29	-123.02	6	6	2.63	1.68	254	14	4,159	7
Haddington Passage 2	50.59	-127.02	3	3	1.31	0.21	1,311	20	29,492	6
Moresby Passage	48.73	-123.34	3	3	1.31	0.21	1,191	20	26,793	6
Nitinat Narrows	48.67	-124.85	8	8	3.50	3.98	61	20	1,376	5
Stuart Narrows	50.90	-126.94	6	7	2.84	2.14	261	7	2,478	5
Hamber Island	49.32	-122.94	4	4	1.75	0.50	414	23	10,362	5
Dodds Narrows	49.14	-123.82	9	8	3.72	4.78	91	9	1,047	5
Sansum Narrows	48.78	-123.56	3	3	1.31	0.21	553	40	23,509	5
Gillard Passage 3	50.39	-125.16	10	8	3.94	5.67	92	5	686	4
Haddington Passage 1	50.61	-127.02	3	3	1.31	0.21	570	25	15,684	3
Matlset Narrowsq	49.24	-125.80	4	4	1.75	0.50	464	10	5,799	3
Tsownin Narrows	49.78	-126.65	3	3	1.31	0.21	283	45	13,460	3
Hayden Passage	49.40	-126.11	4	4	1.75	0.50	312	15	5,457	3
N Sydney Is	48.67	-123.35	3	3	1.31	0.21	1,029	9	11,833	2
Scouler Pass	50.31	-127.82	4	4	1.75	0.50	512	4	3,327	2
Dawley Passage	49.15	-125.79	3	3	1.31	0.21	289	20	6,509	1
Neilson Is - Morpheus	49.16	-125.88	5	5	2.19	0.97	202	4	1,311	1
Tsapee Narrows	49.12	-125.82	4	4	1.75	0.50	280	7	2,517	1
Felice Is - Grice Pt	49.15	-125.91	3	3	1.31	0.21	339	12	4,915	1
									Total:	3,580

Table 12. Tidal current power sites in southern British Columbia.

Site Name	Latitude	Longitude	Maximum Current Speed Flood	Maximum Current Speed Ebb	Mean Maximum Depth Average Current Speed	Mean Power Density	Width of Passage	Average Depth of Passage	Flow Cross-sectional Area	Mean Potential Power
	deg	deg	knot	m/s	m/s	kW/m^2	m	m	m^2	MW
Nakwakto Rapids	51.10	-127.50	14	16	6.56	29.06	434	10	5,643	164
Otter Passage	53.00	-129.73	6	6	2.63	1.86	620	50	32,860	61
Beaver Passage	53.73	-130.37	4	4	1.75	0.55	810	100	83,430	46
Outer Narrows	51.09	-127.63	7	10	3.72	5.29	210	17	4,206	22
Perceval Narrows	52.33	-128.38	5	5	2.19	1.08	382	25	10,709	12
Hiekish Narrows	52.88	-128.49	4	4.5	1.86	0.66	571	25	16,000	11
Draney Narrows`	51.47	-127.56	9	9	3.94	6.28	139	8	1,463	9
Kildidt Narrows	51.89	-128.11	12	12	5.25	14.88	75	2	375	6
Hidden Inlet	54.95	-130.33	9	9	3.94	6.28	142	3	781	5
Porcher Narrows	53.90	-130.47	7	7	3.06	2.95	120	10	1,560	5
Freeman Passage	53.85	-130.58	4	4	1.75	0.55	150	32	5,250	3
Tuck Narrows	54.40	-130.26	6	6	2.63	1.86	138	7	1,379	3
Eclipse Narrows	51.09	-126.77	6	5	2.41	1.43	141	6	1,269	2
Clement Rapids	53.20	-129.04	6	6	2.63	1.86	80	7	800	1
Schooner Channel	51.06	-127.52	6	6.5	2.73	2.10	72	6	648	1
Hawkins Narrows	53.41	-129.42	8	8	3.50	4.41	55	3	301	1
Higgins Passage 2	52.48	-128.71	5	5	2.19	1.08	173	3	1,039	1
Nelson Narrows 1	51.77	-127.43	3.5	3.5	1.53	0.37	313	6	2,817	1
Masset Sound	53.98	-132.00	5	5.5	2.30	1.25	750	20	17,250	21
Rose Spit	54.25	-131.52	2.5	2.5	1.09	0.13	11,000	8	121,000	16
Houston Stewart Channe	52.16	-131.12	5	5	2.19	1.08	610	17	12,200	13
Parry Passage	54.18	-133.00	5	3	1.75	0.55	594	28	18,414	10
Skidigate Entrance	53.36	-131.90	3	3	1.31	0.23	1,322	30	43,626	10
Fairbairn Channel	53.04	-131.68	3	3	1.31	0.23	710	25	19,880	5
Skuttle Passage	52.66	-131.68	2	3	1.09	0.13	510	45	24,480	3
Alexandra Narrows	54.05	-132.57	2	2.5	0.98	0.10	420	25	11,760	1
Tasu Narrows	52.74	-132.11	1.5	1.5	0.66	0.03	425	82	36,125	1
									Total:	434

Table 13. Tidal current power sites in northern British Columbia.

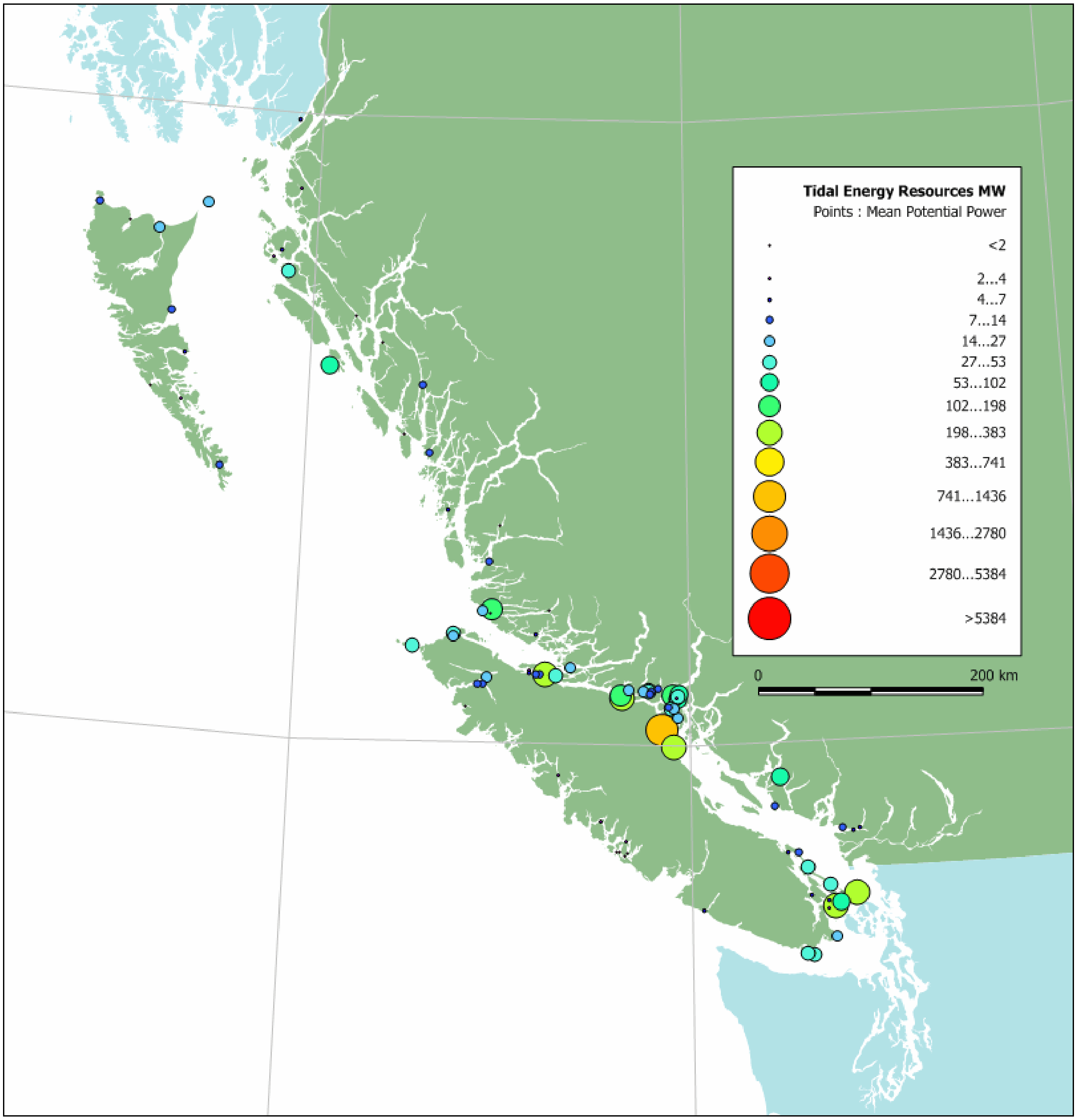


Figure 77. Leading tidal current power sites, Pacific coast.

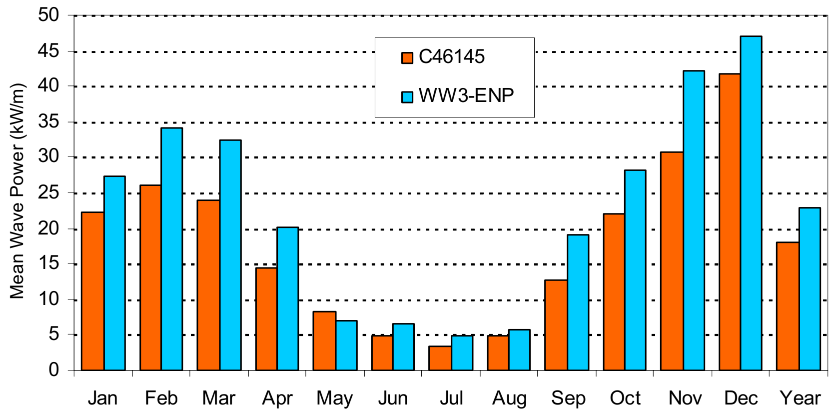


Figure 40. Comparison of mean monthly wave power from buoy measurements and WW3-ENP hindcast, station C46145.

3.7. Discussion of Results

Canadian electricity demand now totals roughly 580 TWh per year, or roughly 18 MWh annually per person. This is equivalent to a mean power of 66,165 MW or roughly 2 kW/person. The three leading electricity demand sectors are manufacturing (38%) residential (28%) and commercial and institutional (22%). Assuming that only 10% of the available wave power is converted into electrical energy, a 1 km wide site with a mean annual power of 25 kW per meter of wave crest could potentially generate 21.9 GWh per year, enough to supply the residential electrical needs of over 4,300 typical Canadians.

Wave energy resources in the NE Pacific are largest in the open ocean far from shore, and decrease as you cross the continental shelf and approach land. The annual mean wave energy flux for exposed deep-water sites located 100 km off Canada's Pacific coast is on the order of 40 to 45 kW/m. Approaching Vancouver Island from the west along the 49°N parallel, the mean annual wave power decreases from ~43 kW/m 150 km offshore, to ~39 kW/m 75 km offshore, to ~25 kW/m at the coast. Moving east along the 53°N parallel, the mean annual wave power decreases from ~44 kW/m 100 km offshore to ~36 kW/m at the western shore of the Queen Charlotte Islands. Wave energy resources in the northeast Pacific also feature a strong seasonal variability – the mean wave energy flux in winter (December to Februrary) is typically around six to eight times larger than in summer (June to August).

Meanwhile, the annual mean wave power at exposed deep-water sites near the edge of the continental shelf in the northwest Atlantic varies from around 21 kW/m off southern Nova Scotia to around 50 kW/m on the edge of the Grand Banks east of Newfoundland. The continental shelf in the northwest Atlantic is much wider than in the northeast Pacific, and there is generally more attenuation of wave energy across the shelf, so that the wave energy resources close to shore are often significantly smaller than at the shelf edge. For example, on a line projected across the Scotian Shelf southeast from Halifax, the mean annual wave energy increases from ~9 kW/m at the coast, to ~20 kW/m roughly 200 km offshore, and to ~30 kW/m roughly 400 km offshore. Wave energy resources in the northwest Atlantic also feature a strong seasonal variability – the mean wave energy flux in summer is typically around one-third of the annual value. In eastern

Canada, the richest wave energy resources close to land lie near the southeastern tip of Newfoundland and around Sable Island. The mean annual wave power in these nearshore regions is on the order of 25 kW/m.

By comparison, the mean annual wave energy at exposed deep-water locations off the western coast of Europe varies between ~25 kW/m near the Canary Islands, up to ~75 kW/m off Ireland and Scotland (Pontes, 1998). The European resource is also seasonally variable: the mean wave power in summer is typically between 25% to 50% of the annual value. The European resource also decreases as you approach shore. For example, Pontes et al. (2003) reports that the nearshore wave energy resource along the coast of Portugal varies between ~8 kW/m and ~25 kW/m, while the offshore resource is on the order of 39 kW/m.

The new results presented here are generally consistent with recent analyses of wave energy resources along the Atlantic and Pacific coasts of the U.S. performed by the Electrical Power Research Institute (EPRI, 2005). The EPRI studies indicate that the mean annual wave power at exposed deep-water sites off the coasts of Washington State and Maine are about 40 kW/m, and 25 kW/m, respectively.

The total mean annual wave power off Canada's Atlantic and Pacific coasts has been estimated by integrating the power density along the 1,000m isobath and along the outer edge of the 200-mile fishing zone. The results, summarized in Table 8, show that the mean wave power along the 1,000 m isobath off Canada's Pacific coast totals roughly 37,000 MW or over 55% of Canadian electricity consumption, while the mean waver power along the 1,000 m isobath off Canada's Atlantic coast sums to 146,500 MW, or more than double current electricity demand.

The waters off Canada's Pacific and Atlantic coasts are endowed with rich wave energy resources. The results presented here define the scale of these resources, as well as their significant spatial and seasonal variations. It is important to recognize that due to various factors including environmental considerations and losses associated with power conversion, only a fraction of the available wave energy resource can be extracted and converted into useful power. Even so, the Canadian resources are considered sufficient to justify further research into their development as an important source of renewable energy for the future.

This work has aimed to quantify and map Canadian offshore wave energy resources. As noted previously, the wave power along a coast (above the ~150 m depth contour) can vary considerably due to sheltering and bathymetric effects such as wave shoaling, refraction and diffraction. These processes will create pronounced local variations in wave conditions and energy potential close to shore, particularly in regions with complex bathymetry. Clearly, these important local variations are beyond the scope of the present analysis.

Further work is clearly required to improve the definition of Canada's nearshore wave energy resources. Shallow water wave transformation models can be applied to study and quantify nearshore wave conditions provided that the necessary high-resolution bathymetry data is available. A logical next step is to apply such models to extend the present results into selected nearshore regions. Further work is also planned to consider the directionality of the Canadian wave energy resources described herein, and to assess the implications of directionality on resource assessment and energy extraction.

Line of integration	from latitude deg	to Latitude deg	Length km	Mean annual wave power MW	Mean annual power density kW/m
Pacific Ocean					
200 mile limit	46.54	53.49	1,070	54,300	50.7
1,000m isobath	48.13	54.31	915	37,000	40.4
Atlantic Ocean					
200 mile limit	40.0	45.0	1,660	62,667	37.8
200 mile limit	45.0	50.0	590	27,616	46.8
200 mile limit	50.0	55.0	600	29,079	48.5
200 mile limit	55.0	60.0	680	29,196	42.9
200 mile limit	60.0	65.0	570	12,062	21.2
200 mile limit	65.0	70.0	590	1,334	2.3
200 mile limit	40.0	70.0	4,690	161,955	34.5
Atlantic Ocean					
1,000m isobath	41.1	45.0	1,840	61,897	33.6
1,000m isobath	45.0	50.0	800	36,603	45.8
1,000m isobath	50.0	55.0	660	24,955	37.8
1,000m isobath	55.0	60.0	760	16,024	21.1
1,000m isobath	60.0	64.1	540	7,047	13.0
1,000m isobath	41.1	64.1	4,600	146,525	31.9

Table 8. Summary of offshore wave energy resources near Canadian waters.

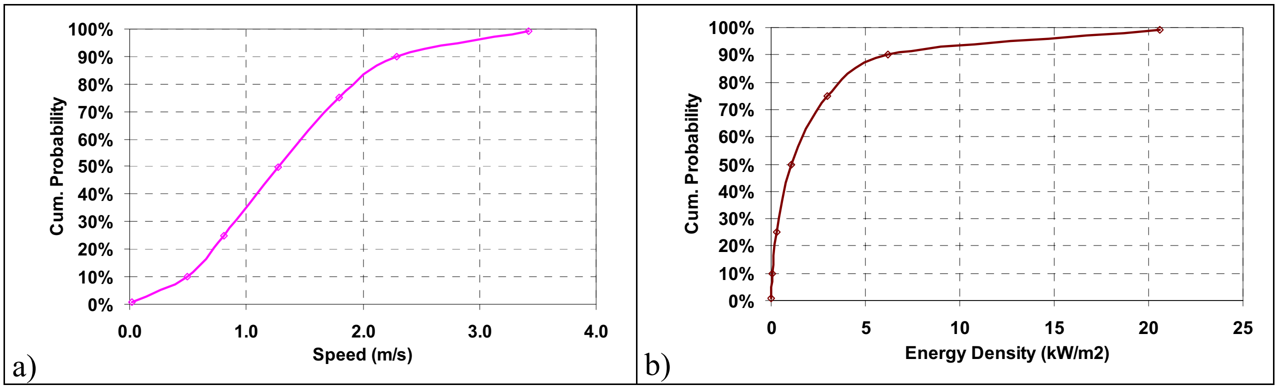


Figure 55. Cumulative distribution of a) depth averaged speed and b) depth averaged power density near Cape St. James.

4.3.3. Results

Selected results from the preceding analysis will be presented in what follows, arranged by ocean, starting with the Pacific.

Pacific Ocean

Figure 56 shows the mean tide range along the BC coast. The rms velocity of the tidal flows throughout the region, as predicted by the tidal models discussed above, is presented in Figure 57 to Figure 59. The mean power density of the tidal flows is plotted in Figure 60 to Figure 62.

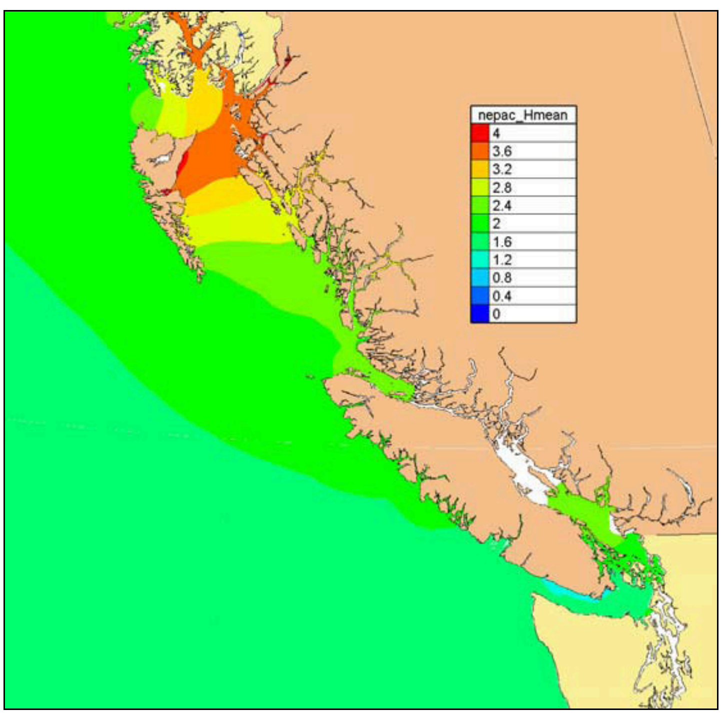


Figure 56. Mean tide range along the BC coast (m).

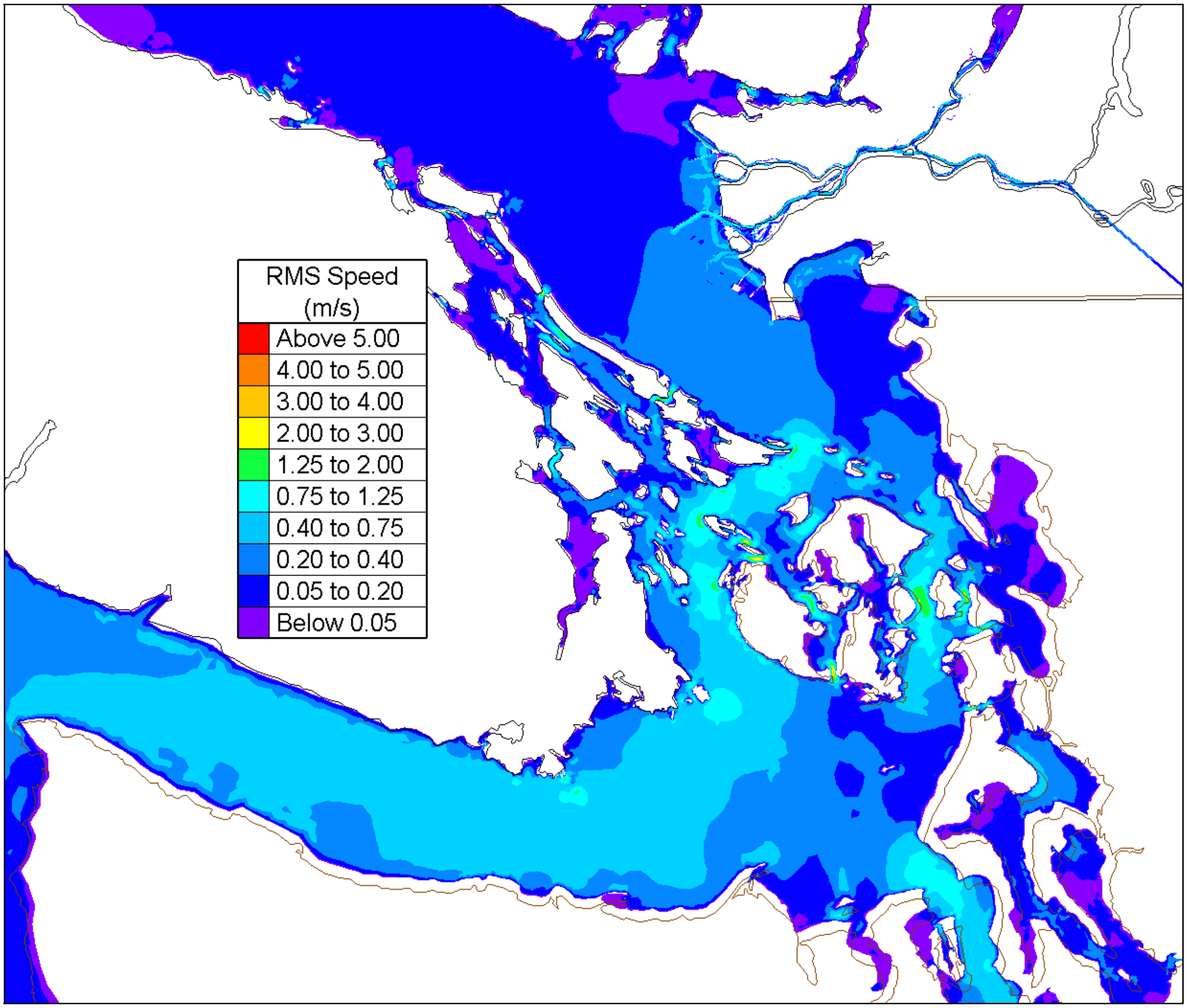


Figure 57. Root-mean-square tidal current speed, southern Vancouver Island.

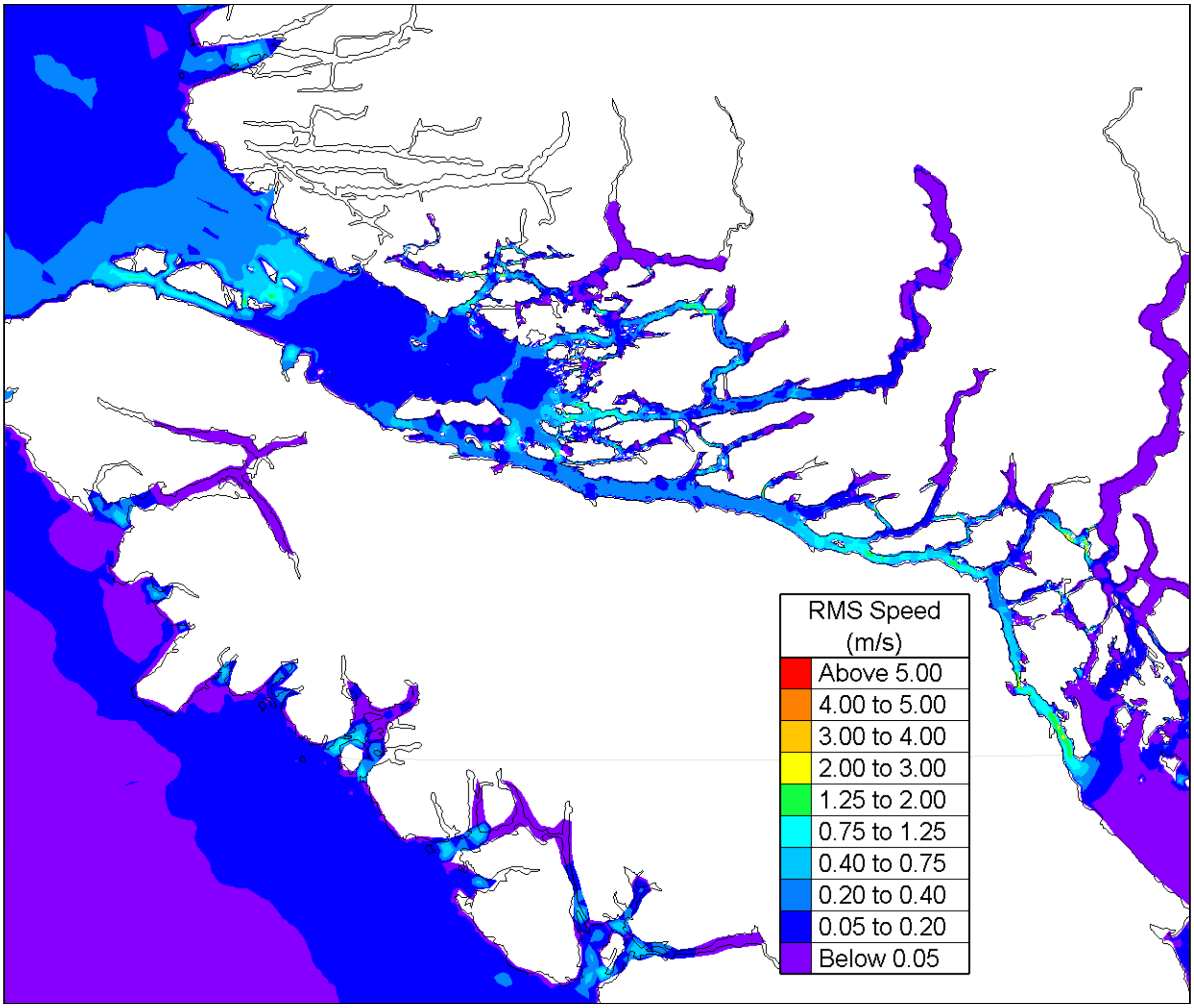


Figure 58. Root-mean-square tidal current speed, northern Vancouver Island.

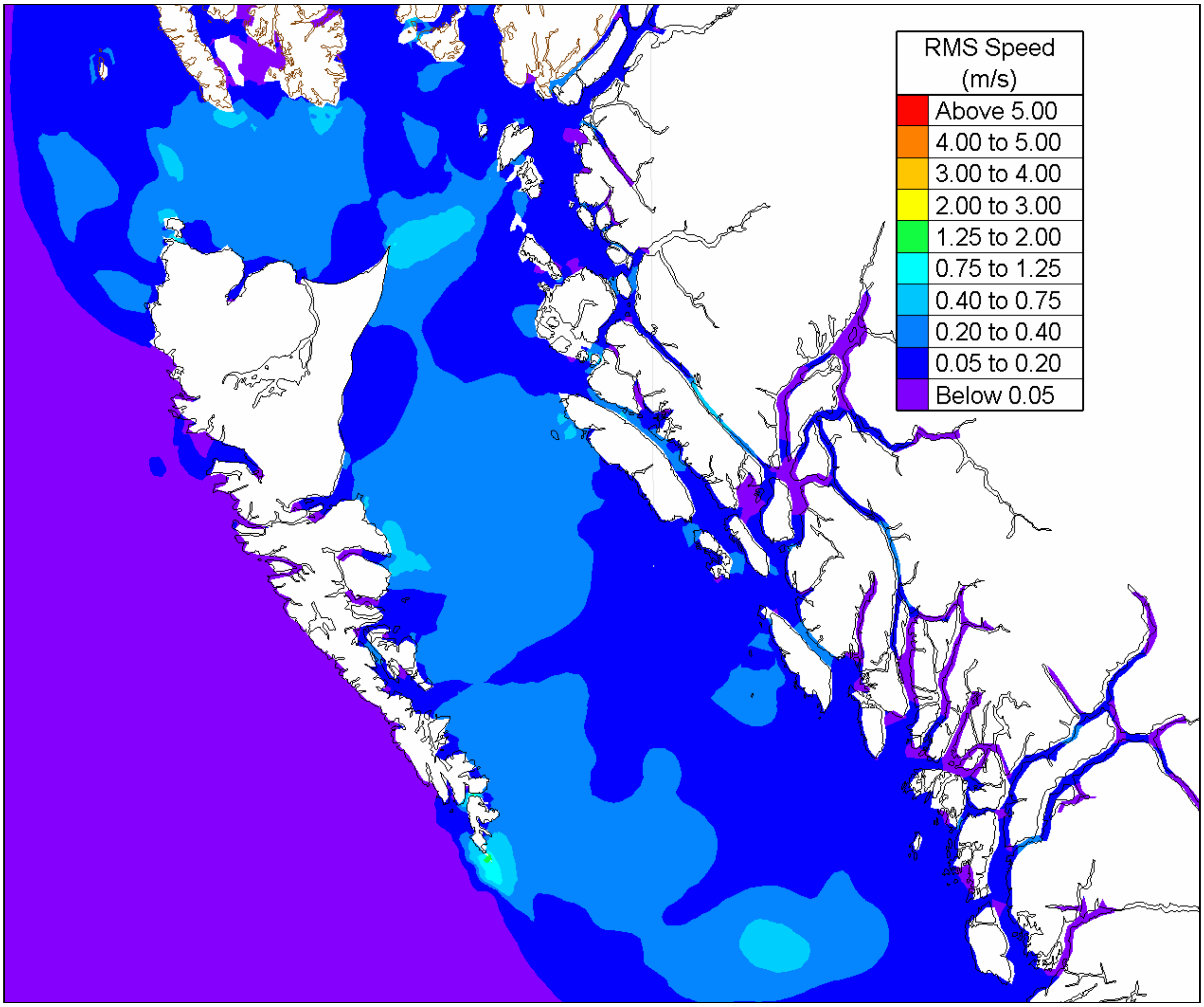


Figure 59. Root-mean-square tidal current speed, Queen Charlotte Islands.

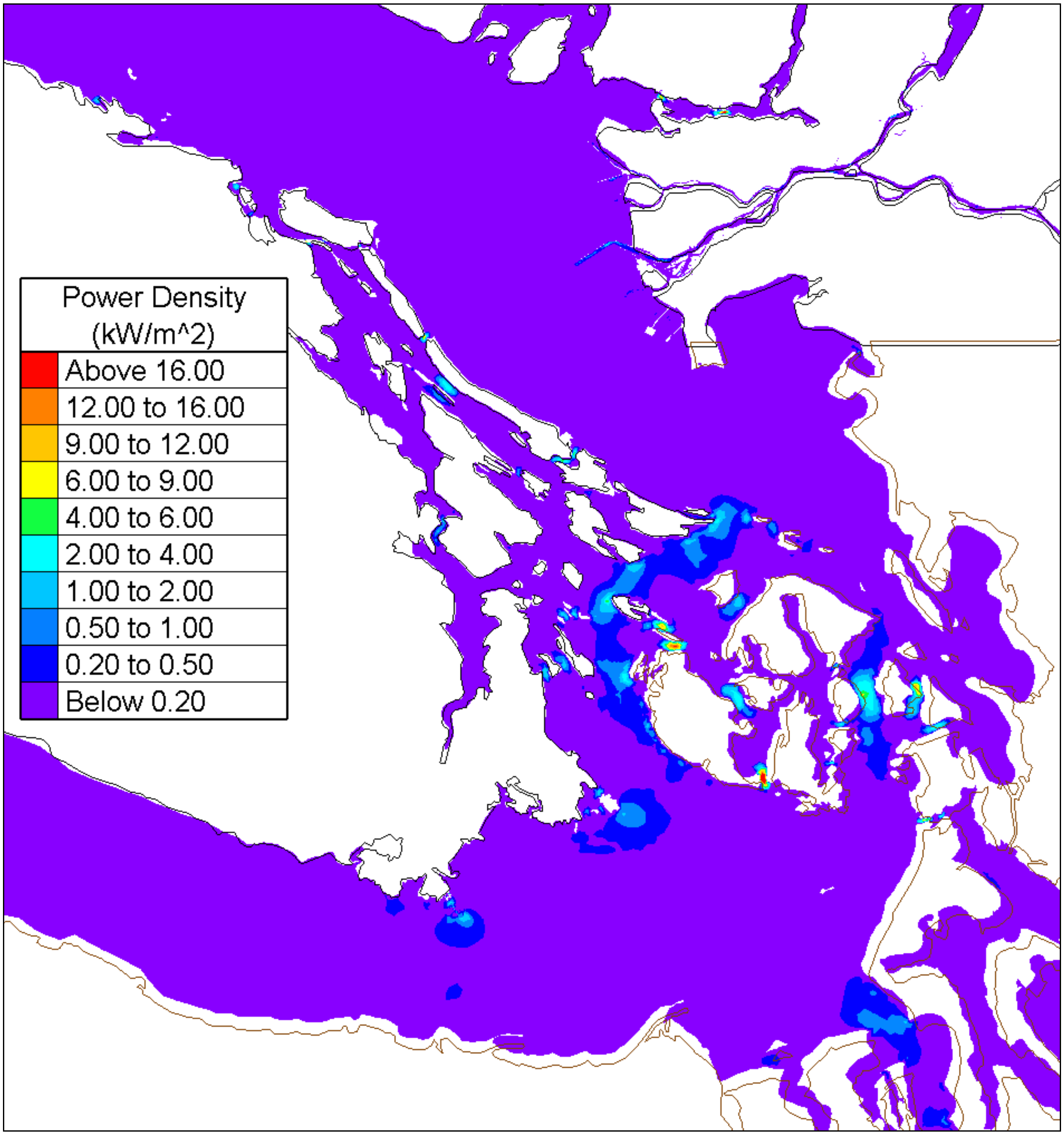


Figure 60. Mean power density, southern Vancouver Island.

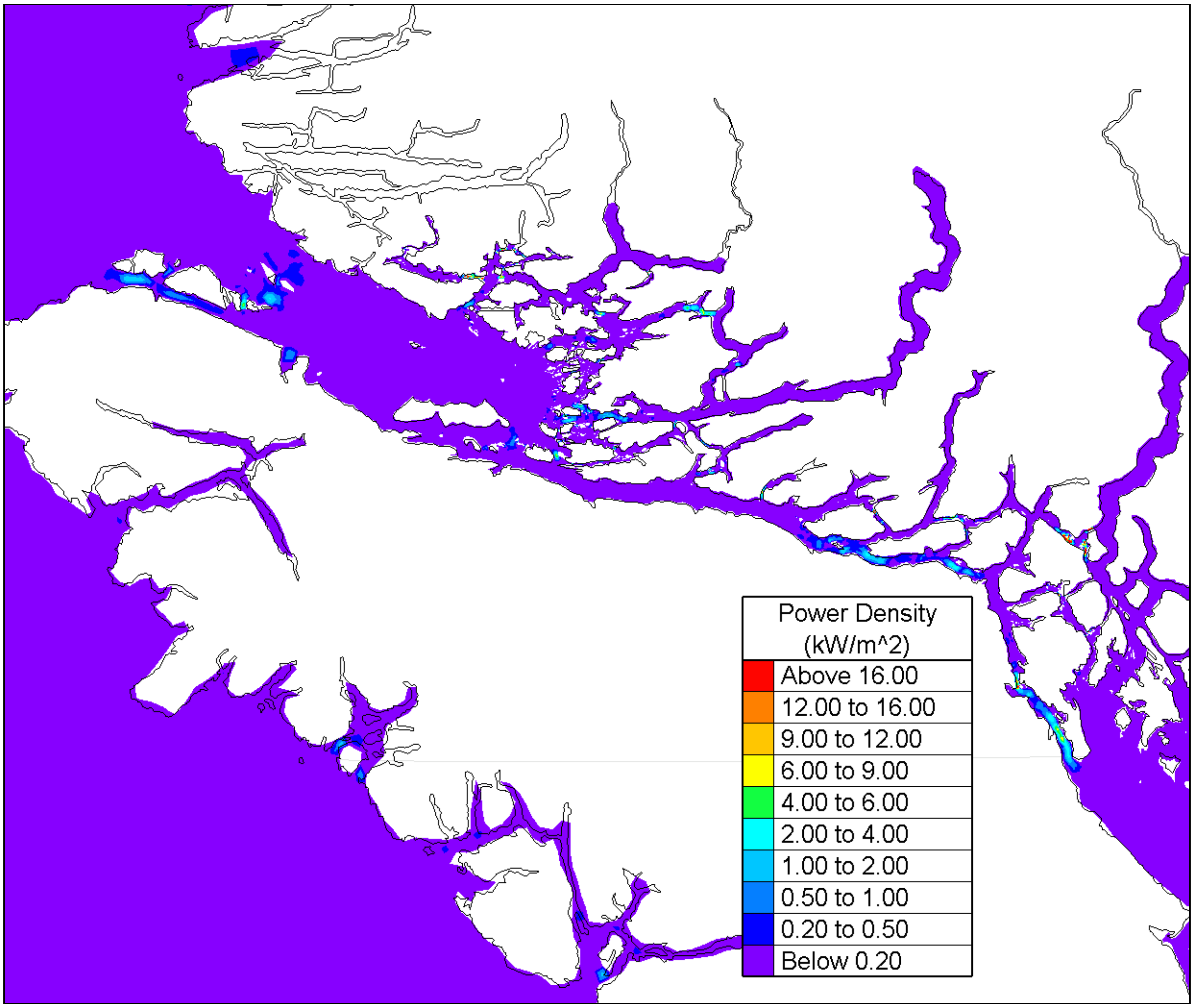


Figure 61. Mean power density, northern Vancouver Island.

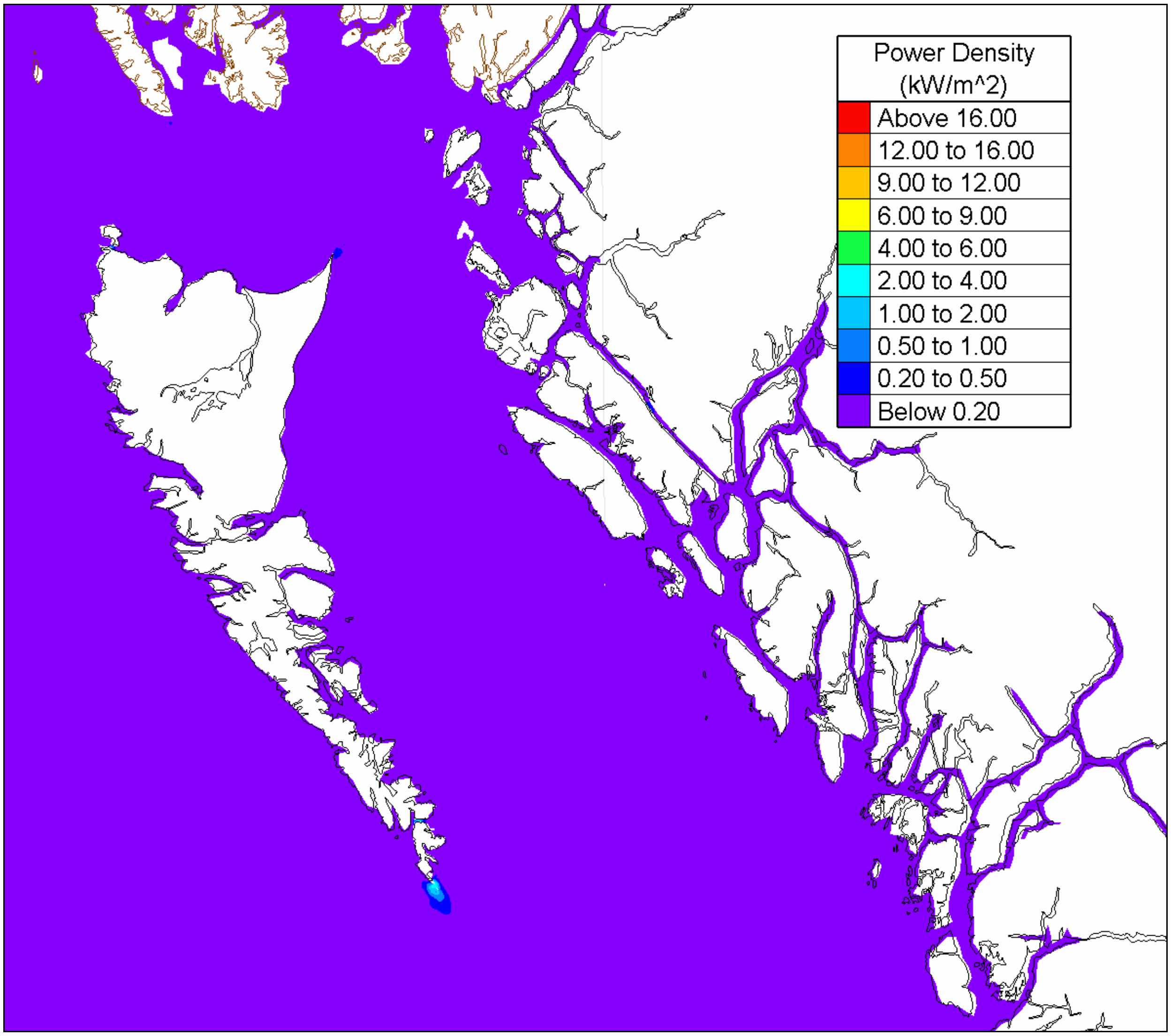


Figure 62. Mean power density, Queen Charlotte Islands.

4. SELECTED STUDY RESULTS

4.1 POTENTIAL TIDAL CURRENT ENERGY SUMMARY TABLES

Table 5 shows the estimated mean potential tidal current energy by Provinces in Canada for sites with a mean power greater than 1 MW.

Table 5: Canada Potential Tidal Current Energy by Province

Province	Potential Tidal Current Energy (MW)	Number of Sites (-)	Average Size (MW)
Northwest Territories	35	4	9
British Columbia	4,015	89	45
Quebec	4,288	16	268
Nunavut	30,567	34	899
New Brunswick	636	14	45
PEI	33	4	8
Nova Scotia	2,122	15	141
Newfoundland	544	15	36
TOTAL	**42,240**	**191**	**221**

Table 6 shows the distribution of mean potential power by Regions with Canada. Note that more than 80% of potential tidal current power is in regions presently impacted by winter ice conditions.

Table 6: Canada Potential Tidal Current Energy by Region

Region	Potential Tidal Current Energy (MW)
Vancouver Island Mainland	3,580
Pacific Mainland North	353
Queen Charlotte Islands	81
Arctic	1,008
Hudson Strait	29,595
Ungava	4,112
St. Lawrence River	153
Gulf of St Lawrence	537
Atlantic North	65
Atlantic South	30
Bay of Fundy	2,725
TOTAL	**42,240**

Table 7 shows the 50 largest potential tidal current power sites in Canada. Table 8 shows the 50 sites in Canada with the largest Mean Power Density (MW/m^2).

Table 7: Canada Tidal Current Power Sites (50 largest sites)

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Hudson Strait	Nunavut	Mill Island-Salisbury Island	5450	63.81	-77.50		8	8		0.887	32054	204	6571070	10426
Hudson Strait	Nunavut	Mill Island-Baffin Island	5450	64.15	-77.57		8	8		1.020	26125	229	6008750	7584
Hudson Strait	Nunavut	Gray Strait	5456	60.54	-64.69		6	6	2.63	2.110	6000	550	3307800	6979
Hudson Strait	Nunavut	Nottingham Island-Ungava	5450	62.83	-77.93		8	8		0.136	64098	228	14678442	1972
Bay of Fundy	Nova Scotia	Minas Basin	4010	45.35	-64.40		7.5	7.5	3.28	6.036	4376	56	274113	1903
Hudson Strait	Nunavut	Salisbury Island-Nottingham Island	5450	63.45	-77.41		8	8		0.360	22146	147	3277608	1704
Ungava	Quebec	Smoky Narrows	5468	58.92	-69.27		12	12	5.25	16.880	1500	55	92400	1560
Ungava	Quebec	Algernine Narrows	5468	58.79	-69.60		10	10	4.38	9.768	2000	59	130400	1274
Vancouver Island Mainland	British Columbia	Seymour Narrows	353902	50.13	-125.35	5000	16	14	6.56	18.160	769	41	33331	786
Hudson Strait	Nunavut	Lacy/Lawson Islands	5456	60.60	-64.62		7	7	3.06	3.351	2750	80	223575	749
Ungava	Quebec	Riviere George Entrance	5335	58.76	-66.12		8	8	3.50	5.001	3000	35	125100	626
Gulf of St Lawrence	Newfoundland	Strait of Belle Isle	4020	51.45	-56.68					0.201	26069	49	1298236	373
Vancouver Island Mainland	British Columbia	N. Boundary Passage	346201	48.79	-123.01		4	4	1.75	0.498	5158	140	734949	366
Vancouver Island Mainland	British Columbia	Discovery Pass. S.	353901	50.00	-125.21		7	7	3.06	3.676	1459	42	65626	327
Arctic	Nunavut	Labrador Narrows	7487	69.71	-82.59		6	6	2.63	2.110	1500	100	151950	321
Vancouver Island Mainland	British Columbia	Boundary passage	344101	48.69	-123.27		3.5	3.5	1.53	0.334	4472	175	793760	265
Ungava	Quebec	Riviere Arnaud (Payne) Entrance	5352	59.98	-69.84		9	9	3.94	7.121	2300	9	32200	229
Bay of Fundy	New Brunswick	Clarks Ground	4340	44.59	-66.64		6	6	2.63	2.110	4092	22	102300	216
Vancouver Island Mainland	British Columbia	Current Passage 2	354401	50.39	-125.86		6	6	2.63	1.681	1502	80	123931	208
Vancouver Island Mainland	British Columbia	Weyton Passage	354601	50.59	-126.82		6	6	2.63	1.681	1535	75	118985	200
Ungava	Quebec	Koksoak Entrance	5376	58.52	-68.17		6	6	2.63	2.110	2000	40	92400	195
Hudson Strait	Nunavut	Cape Enouolik	7065	64.95	-78.33		5	5	2.19	1.221	5000	25	142500	174

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
Pacific Mainland North	British Columbia	Nakwakto Rapids	355001	51.10	-127.50	6700	14	16	6.56	29.062	434	10	5643	164
Vancouver Island Mainland	British Columbia	Current Passage 1	354401	50.41	-125.87		5	5	2.19	0.973	1398	100	143331	139
Vancouver Island Mainland	British Columbia	Dent Rapids	354301	50.41	-125.21	5530	11	8	4.16	6.672	420	45	19955	133
Vancouver Island Mainland	British Columbia	South Pender Is	344101	48.72	-123.19		4	4	1.75	0.498	1985	100	203416	101
Bay of Fundy	New Brunswick	Devils Half Acre	4340	44.54	-66.69		6	6	2.63	2.110	2133	18	44793	95
Vancouver Island Mainland	British Columbia	Yaculta Rapids	354301	50.38	-125.15		10	10	4.38	7.782	539	20	12135	94
St. Lawrence River	Quebec	Passage de Ile aux Coudre	1233	47.43	-70.43		5	6	2.41	1.625	1700	30	56100	91
Vancouver Island Mainland	British Columbia	Arran Rapids	354301	50.42	-125.14	5600	14	10	5.25	13.447	271	22	6629	89
Ungava	Quebec	Nakertok Narrows	5352	60.00	-70.27		9	9	3.94	7.121	1100	6	12100	86
Bay of Fundy	New Brunswick	Old Sow	4114	44.92	-66.99		6	6	2.63	2.110	625	60	39375	83
Arctic	Nunavut	Bellot Strait	7752	72.00	-94.48		8	8	3.50	5.001	1000	16	16400	82
Arctic	Nunavut	Cache Pt Channel	7710	68.62	-113.55		5	5	2.19	1.221	6000	10	62400	76
Vancouver Island Mainland	British Columbia	Secheldt Rapids 2	351403	49.74	-123.90	9999	14.5	16	6.67	27.599	261	8	2739	76
Arctic	Nunavut	James Ross Strait	7083	66.69	-95.87		5	5	2.19	1.221	5900	10	61360	75
Bay of Fundy	New Brunswick	Head Harbour Passage 1	4114	44.95	-66.93		5	5	2.19	1.221	890	65	60520	74
Bay of Fundy	Nova Scotia	Northwest Ledge	4118	44.30	-66.42		4	4	1.75	0.625	5334	18	117348	73
Ungava	Quebec	Mikitok Narrows	5352	60.00	-70.27		9	9	3.94	7.121	700	8	9590	68
Arctic	Nunavut	Egg Island	7735	68.55	-97.40		7	7	3.06	3.351	750	25	19050	64
Pacific Mainland North	British Columbia	Otter Passage	3742	53.00	-129.73	8535	6	6	2.63	1.860	620	50	32860	61
Vancouver Island Mainland	British Columbia	Gillard Passage 1	354301	50.39	-125.16	5500	13	10	5.03	11.835	237	16	4393	52
Vancouver Island Mainland	British Columbia	Scott Channel	362501	50.79	-128.50		3	3	1.31	0.210	9970	22	244256	51
Vancouver Island Mainland	British Columbia	Active Pass	344201	48.86	-123.33	3000	8	8	3.50	3.984	561	20	12628	50
Bay of Fundy	New	Gran Manan Channel	4340	44.78	-66.86		2.5	2	0.98	0.111	5446	80	452018	50

Region	Province	Site Name	Chart	Latitude	Longitude	Current Station	Max. Speed Flood (knots)	Max. Speed Ebb (knots)	Mean Max. Depth Ave. Speed (m/s)	Mean Power Density (kW/m2)	Passage Width (m)	Average Depth of Passage (m)	Flow Cross-sectional Area (m2)	Mean Potential Power (MW)
	Brunswick													
Arctic	Nunavut	Seahorse Point	7065	63.83	-80.13		5	5	2.19	1.221	2000	20	40800	50
Bay of Fundy	Nova Scotia	The Hospital	4242	43.44	-66.00		4	4	1.75	0.625	3600	18	79200	50
Gulf of St Lawrence	Newfoundland	Pointe Armour	4020	51.45	-56.86		4	5	1.97	0.890	1500	35	53700	48
Gulf of St Lawrence	Newfoundland	Forteau	4020	51.41	-56.95		4	5	1.97	0.890	1500	35	53700	48
Pacific Mainland North	British Columbia	Beaver Passage	3747	53.73	-130.37	8545	4	4	1.75	0.551	810	100	83430	46
Arctic	Nunavut	Nettilling Fiord	7051	66.72	-72.83		8	8	3.50	5.001	1700	5	9180	46
Vancouver Island Mainland	British Columbia	Nahwitti Bar 1	354901	50.89	-127.99		5.5	5.5	2.41	1.295	2993	9	34417	45
TOTAL														**40697**

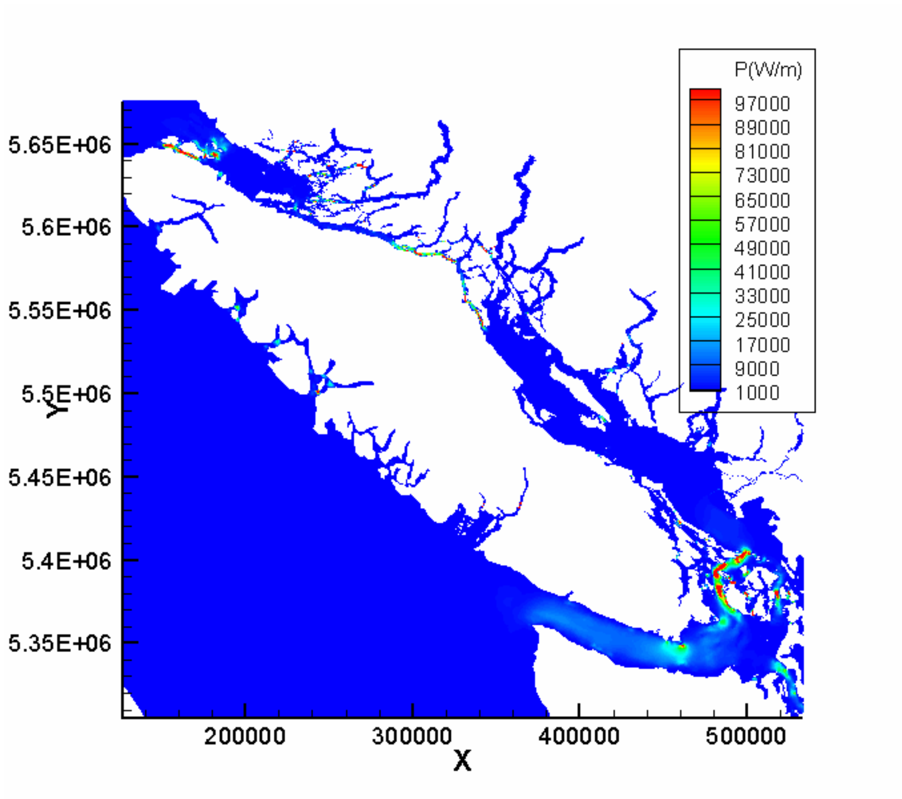
Notes:

1. The tidal current site data shown in yellow in Table 7 and Table 8 were derived from tidal model results (see Section 4.3 and Section 2.3.
2. Some of the tidal current sites shown in Table 7 and Table 8 are located in close proximity to each other in the same tidal channel or tidal inlet (e.g. Seymour Narrows/Discovery Passage in BC and Smoky Narrows and Algernine Narrows in Leaf Bay, Ungava, PQ). The total extractable power available from such adjacent sites will depend on the specific characteristics of the driving tidal dynamics, site geometry and the energy extraction technology used.

4.3 POTENTIAL TIDAL CURRENT ENERGY DENSITY MAPS

Figure 13 through Figure 16 show maps of power density in units W/m for the Pacific Coast, Hudson's Strait, Atlantic Coast and Bay of Fundy North respectively. The power density colour scales for all four maps are similar. These maps were developed from tidal model results.

Figure 13: Power Density - Pacific Coast



A Feasibility Study:

Tidal Power Generation for a Remote, Off-Grid Community on the British Columbia Coast

For

Janice Larson

British Columbia Ministry of Energy, Mines and Petroleum Resources

Prepared by

Bob Davidson
bob.2davidson@community.royalroads.ca

February 21, 2007

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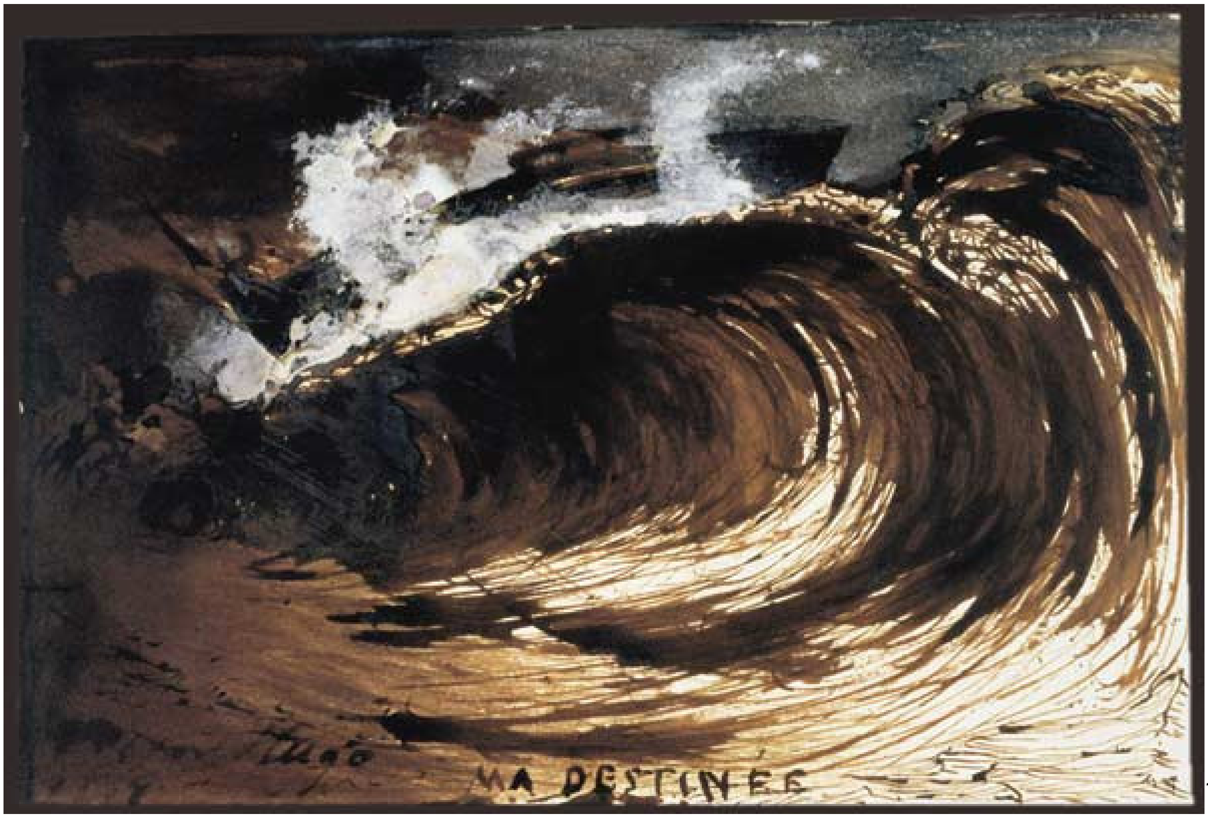


[1]

"Reflect on the motion of the waves, the flux and reflux, the ebb and flow of the tides. What is the ocean? An enormous force wasted. How stupid the earth is not to make use of the ocean." [2]

Victor Hugo, 1888

[1] Ma Destinee, painting by Victor Hugo, image source http://expositions.bnf.fr/hugo/grands/005.htm

[2] Victor Hugo, *Ninety-Three, Volume II*, translated from the French by Helen B. Dole, (New York: Thomas Y. Crowell & Co., 1888), p. 258

Executive Summary

Tidal power generation is about extracting clean power from a reliable and renewable energy source – the ocean. New technology is making ocean energy a viable source of power that, along with other forms of alternative energy, can supplant fossil fuels as the planet's dominant energy source.

This paper investigates the feasibility of developing a package solution using tidal power generation for a remote BC coastal community, Stuart Island. This study was conducted for Royal Roads University as part of the requirements for a Master of Business Administration degree and for the BC Ministry of Energy, Mines and Petroleum Resources.

Stuart Island is not on the power grid, and because of the high cost of connection to the grid, it is unlikely to be connected in the near future. Presently, diesel generators supply all power on the island. Stuart Island is adjacent to some of the best potential sites for tidal power generation on the BC coast. The existing situation in the Stuart Island area is examined in the paper, followed by a discussion of alternative energy and power generation in remote off-grid locations and how these things relate to Stuart Island.

Secondary research was conducted into ocean energy in BC. This paper reviews government agencies and non-governmental organizations involved in ocean energy in BC, followed by a discussion of the active tidal power projects in the province. Stepping back a bit for a wider view, this paper reviews ocean energy activities, government agencies and programs and organizations across Canada. An even wider view is taken by examining international organizations involved in tidal energy generation and the tidal power activities in a number of countries around the world.

Turning the focus back on BC, the tidal resource potential along the coast of the province is investigated. Primary research then concentrates on the resources near Stuart Island, which are examined and to determine suitability.

The paper describes the available tidal power technologies, including the progress of the technology developers towards commercialization. Installation methods and challenges are

discussed, followed by a discussion of energy storage methods and their significance to off-grid applications.

The financial analysis compares the costs of diesel and tidal power generation. The investigation reveals that there is too much uncertainty to estimate the cost of the supply and installation of a tidal power generation device at Stuart Island at this time. A discussion of feasibility looks at the triple bottom line, and concludes with a discussion of the technological uncertainties.

The paper discusses how tidal energy development in BC can progress to meet the needs of remote communities in BC, with an eye to future export possibilities. The report concludes with a number of recommendations for the Ministry of Energy, Mines and Petroleum Resources to assist the tidal energy industry to move forward in BC.

Appendix I

Introduction

Imagine a remote island on the coast of British Columbia. On this Island there are a few resorts where people can enjoy terrific salmon fishing in a spectacular wilderness setting. Ecotourism thrives, with opportunities for visitors to see eagles, grizzly bears and orcas in their natural environment.

Unfortunately this vision is marred by the sight and sound of the numerous diesel generators that provide electrical power to the resorts and residents. These generators make it possible for the resorts to exist, and therefore for people to visit the area. But there is a price to be paid for this power. The financial price is high and possibly increasing if the price of diesel fuel climbs higher. The price to be paid also includes other, non-monetary costs – air pollution, noise pollution and the threat of water pollution from diesel spills during storage or transportation.

Now picture this place with the power provided by clean energy extracted from the ocean currents. Imagine clean, reliable power coming from a turbine far beneath the waves, blades silently turning in the powerful tidal stream. There is no smell of diesel exhaust to mask the pristine fragrance of the evergreen forest in the salty ocean breeze. No diesel engine noise to compete with the cries of the seagulls or the waves breaking on the rocks.

Wouldn't it be wonderful if the second vision could be made real? Is it possible? Is it feasible? These are questions this study will endeavor to answer.

Stuart Island

This place is real - it is called Stuart Island. It is located on the BC coast about two hundred kilometers northwest of Vancouver. The area includes the islands and mainland surrounding Cardero Channel. The waters around Stuart Island boast powerful tidal currents, among the strongest in Canada.

In the winter, it is a quiet place in human terms, with only a few permanent residents and resort caretakers living there. Mother Nature, however, can be noisy with howling winds and crashing waves. Summertime is a different story, with the resorts full of guests and the air punctuated with the excited cries of the fishermen hooking into Spring Salmon. Through it all, the ocean currents are constant, flooding and ebbing in their eternal cycle. The currents are strong here because the tidal flow on the east side of Vancouver Island is constricted in a few relatively narrow channels by the many islands between Johnson and Georgia Straits. The same conditions that make Stuart Island an ideal place for salmon and orcas make it an ideal place for tidal power generation.

Sustainability

What is sustainability, besides one of the most overused words in the English language? Merriam-Webster defines sustainable as relating to a method of harvesting or using a resource so that the resource is not depleted or permanently damaged.[3] Given that diesel fuel is an oil derivative - a non-renewable resource - its use as a power source for Stuart Island is not sustainable over the long term. In fact, the Society of Petroleum Engineers estimates the world's remaining oil reserves will last as little as 44.6 years at 2003 consumption levels.[4] While it is true that more reserves may well be discovered and so the world will not run out of oil in two generations, it is clear that alternative energy sources will be needed.

[3] Merriam-Webster's Online Dictionary, http://www.m-w.com/dictionary/sustainability , accessed December 2006
[4] Society of Petroleum Engineers, "How Much Oil and Natural Gas is Left?," Society of Petroleum Engineers website http://www.spe.org/spe/jsp/basic/0,,1104_1008218_1109511,00.html accessed December 2006

The British Columbia Ministry of Energy, Mines and Petroleum Resources

The client for the study is the BC Ministry of Energy, Mines and Petroleum Resources (MEMPR). The primary contact is Janice Larson, Director of the Bioenergy and Renewables Branch.

MEMPR is the lead agency in BC for alternative energy promotion and development and has taken an active role in establishing a strategic direction for the province. In 2005, the MEMPR published *Alternative Energy and Power Technology: A Strategy for BC*. This document describes a ten year vision to make the province a world leader in alternative energy and power technology.[5]

This view is endorsed by the Premier's Technology Council, which has concluded that export revenue and jobs in BC can be substantially increased by deploying power technology solutions in BC and then selling them abroad.[6] As Premier Gordon Campbell says, "BC has the people and the resources to help drive the global shift toward alternative energy and power technology as part of our goal of leading the world in sustainable environmental management. Innovative power technology developed here in BC is improving the quality of life for people around the world, by improving how power is generated, delivered and used. Demand for that expertise will only continue to grow."[7]

One of the market opportunities identified by the Council is remote power solutions for rural communities. In particular, an area of interest is investigating the use of alternate energy generation to meet the power requirements of remote BC communities.

[5] BC Ministry of Energy, Mines and Petroleum Resources, "Alternative Energy and Power Technology: A Strategy for BC," BC Ministry of Energy, Mines and Petroleum Resources website, http://www.gov.bc.ca/empr/down/alternative_energy_task_force_strategy_final_april_5_05.pdf, accessed January 2007
[6] Ibid.
[7] Ibid.

Present Situation at Stuart Island

The area referred to as Stuart Island in this study refers to land surrounding the portion of Cardero Channel bounded by Sonora Island on the west, Dent Island to the northwest, the Mainland on the north and Stuart island on the east. Of course, it is the water between those islands that is most important to this study. Of particular interest are Gillard Passage, Barber Passage, Innes Passage and Yaculta Rapids.

[8]

There is no electrical service in the Stuart Island area as the nearest connection to the electrical grid is about 20 kilometres away. Because of this, all of the electrical power in the area is generated by diesel generators (commonly called gensets). Being forced to use diesel gensets has several consequences for the residents and businesses of the area. The largest factor is the cost of diesel fuel, which must be barged in monthly. Other factors include the necessity of fuel storage tanks, noise pollution and diesel exhaust emissions.

There are twelve permanent residences in the area that are occupied year round. In addition to these residences are several seasonal residences that are typically occupied in the summer. A small community centre with public dock, postal outlet and small general store is located in Big Bay. The community centre and Post Office is run by the Stuart Island Community Association.

[8] Image source: Google Earth, http://earth.google.com/

There are several resorts located in the area, most on Stuart Island, one on Sonora Island, one on Little Dent Island and a couple on the mainland. Some of the resorts are public and are open to guests in the summer season. Others are private facilities and are used by the companies that own them to accommodate customers and associates of the company. The resorts range in size and can accommodate from a dozen guests to more than one hundred. The map below illustrates the layout of the area and the location of the resorts and residences.

[9]

9 Map drawn and provided by Jode Morgan, Morgan's Landing Lodge, http://morganslanding.bc.ca/

Appendix I

Every residence and resort generates its own power, and so every one has its own genset. The size and number of gensets varies by the size, and therefore the power requirement, of the facility. Resorts typically have more than one genset so that backup power is available in the event of an equipment failure. Often the gensets have different generating capacity so varying load conditions can be efficiently supplied. In addition to diesel power generation, most residents and resorts also use propane for cooking and as an alternate lighting or heating source.

Residents and resort operators are well aware of the powerful tidal currents in the Stuart Island area and are also aware of the concept of tidal power generation. Responses to enquiries during the preparation of this study were unanimously favourable to the possibility of using tidal energy to generate power for the area.

Appendix I

Alternative Energy

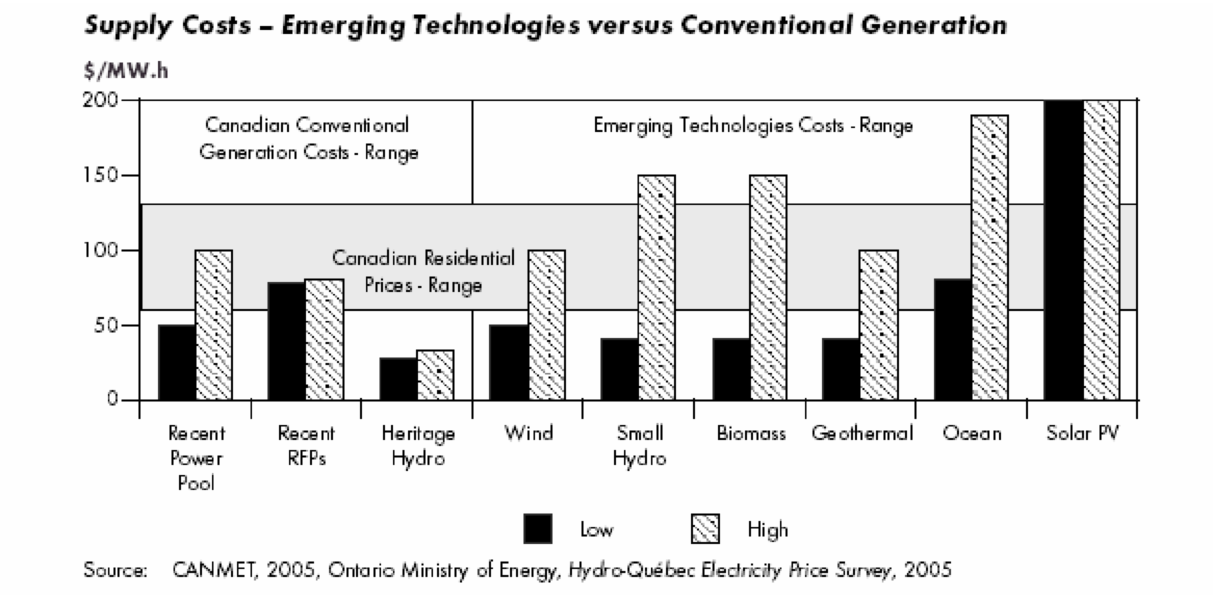
Alternative energy is a somewhat misleading term. In contemporary usage, it means energy that is produced by methods other than the burning of fossil fuels, large hydroelectric or nuclear power. However, long before these power generation methods were being used, people were harnessing "alternative" energy. People have harnessed wind and water power for millennia. The first windmill may have been used in Babylon about 4,000 years ago.[10] Waterwheels have also been in use since ancient times. Alternative energy has predated the modern conventional forms of power generation by thousands of years.

Nowadays, the term alternative energy refers to a number of distinct technologies:

- Wind
- Solar – photovoltaic
- Geothermal
- Biofuels / bioenergy
- Microhydro
- Ocean Energy
    - Wave
    - Tidal stream

Of the different technologies, small hydro and wind generation are the most widely used to date and are the most advanced. Wind power generation has achieved full commercialization and wind farms have become a familiar sight in many countries. A fully developed wind industry has been created and wind generated power is competitive with the cost of power generated by new conventional facilities such as hydro dams, coal-fired or nuclear plants. A National Energy Board report points out that "electricity rates do not reflect actual costs because they are based on historical costs and are, therefore, below the cost of developing new generation." [11] The following graph compares the cost ranges for emerging technologies compared with new conventional energy costs and heritage hydro costs. The graph on the next page clearly illustrates how alternative energy can be competitive with new conventional energy facilities.

[10] Iowa Energy Center, "A History of Wind Energy," Iowa Energy Center website, http://www.energy.iastate.edu/renewable/wind/wem/wem-04_history.html accessed December, 2006
[11] National Energy Board, "Emerging Technologies in Electricity Generation – An Energy Market Assessment March 2006," p. xiv, http://www.neb-one.gc.ca/energy/EnergyReports/EMAEmergingTechnologiesElectricity2006_e.pdf accessed February 2007



[12]

It is now possible for supporters of clean energy to "buy" wind energy – by paying a higher rate or paying an annual fee. The Pembina Institute has a program where the amount of power consumed by the average computer over a three year period has been calculated. Then an equivalent amount of wind power credits have been purchased, which in effect allows the computer user to pay the premium for the wind generated power that is supplied to the electrical grid.[13] This study was produced on a wind-powered computer.

Ocean energy power generation technology is in its infancy, but it is growing fast. A wide variety of devices are being built and tested by brilliant inventors and bold entrepreneurs around the globe. Energy can be extracted from the ocean in several ways; thermal gradient, salinity gradient, wave energy and tidal energy. Tidal energy technology can be further divided into tidal stream and barrage type power generation. Both wave and tidal stream technologies are at similar stages of development, with many different designs being designed and tested now. The first full scale models of both wave and tidal stream power generation devices will occur in 2007. Barrage type tidal power has been in use for many years, notably in Canada at the Annapolis power plant in Nova Scotia and also in France.

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[12] Ibid. p.7

[13] The Pembina Institute, "The Power to Make a Difference," Pembina Institute website, http://www.pembina.org/wind/wind_power.php, accessed January 2007

Remote Off-Grid Locations

Remote off-grid locations are especially significant for alternative energy generation because they are special cases where conventional energy solutions are not available or practical.

Remote locations, as the name implies, are places where small communities are isolated and do not have access to the modern conveniences enjoyed by most Canadians. Things that others take for granted, like telephone service, cable television, internet connectivity or natural gas piped to the house are often simply not available. Or if they are available, they come in a different form that is undoubtedly more expensive and often unreliable. In such places, electrical power usually comes from gasoline or diesel powered generators.

Off-grid locations are those where no connection to the electrical power grid is available. Often these are small communities that are accessible only by air or water. They can be more than a hundred kilometers from the nearest power lines. And this distance can be misleading, as it is measured as the seagull flies, with the most rugged terrain imaginable or bodies of water hundreds of feet deep standing between the community and the power lines. Running power lines to such communities is a tremendously expensive proposition.

The North American Power Grid refers to the electrical system that covers most of the continent. This network includes power generation facilities, distribution complexes, high voltage transmission lines and local power lines. All of these components are interconnected, which allows the demand for electricity to be balanced against electrical generation on a continent-wide scale. In control rooms across North America, technicians are monitoring the load on their portion of the grid and adjusting the generation capacity to suit regional demand. The principal control rooms are often located at a power generation facility, which may be a hydroelectric dam, a coal-fired plant or a nuclear power plant. The grid has been shown to be somewhat vulnerable in the past few years, as when an overload at a distribution centre in Ohio caused a huge blackout over most of Eastern Canada and the Northeastern United States in 2004.

So remote off-grid locations are places where there is no electrical service, and connection is unlikely in the foreseeable future. The growth potential of these communities is limited by the lack of reliable electrical power, and in some cases the very viability of the community is threatened.

Appendix I

The Significance of Remote Off-Grid Communities

There are many remote off-grid communities in British Columbia, but this phenomenon is by no means limited to BC. There are remote off-grid communities all over the world. In developing countries where the national electrical grid infrastructure is not well developed there are thousands of communities where electrical power, if available at all, is provided by diesel generators. The billions of dollars required to build a large scale power generation plant are not easy to come by. These locations are ideal places for smaller scale alternative energy projects.

Reliable power has great significance for these countries and for these communities. Reliable power permits the development of essential community assets such as health care facilities and communication infrastructure. One aspect of this infrastructure that is easily overlooked is reliable refrigeration, which has been described as the technology of survival and enhancement.[14] "Refrigeration is a vital part of the infrastructure necessary to deliver vaccines worldwide. Thousands of lives have been saved by vaccines for diseases such as polio, measles, chicken pox and hepatitis. Yet as many as three million children die every year from diseases that are preventable with available vaccines."[15] Reliable refrigeration is essential for these vaccines and other medical supplies to stay at the cool, stable temperatures that they require, and that requires reliable power.

In developed countries, remote communities' access to the outside world is a very important aspect of the people's development. Schoolchildren's educational opportunities are enhanced by access to the internet and the view of the outside world that it brings. And First Nations artists in a remote coastal village can find markets for their art through online galleries.

[14] Ronald P. Vallort, "Refrigeration: Technology for Survival," *ASHRAE Journal*, August 2004, http://web.ebscohost.com.ezproxy.royalroads.ca/ehost/pdf?vid=5&hid=4&sid=c1434199-55ec-441e-9852-19d99dbb0944%40sessionmgr3 , accessed December 2006

[15] Ibid.

Ocean Energy in British Columbia – Government and NGOs

The Alternative Energy Task Force

The Premier of the Province of British Columbia created the Premier's Technology Council to advise him on technology related issues that affect British Columbia and its citizens. The Council produced an alternative energy strategy for BC, and one of the market opportunities identified in the strategy is "Remote power solutions for rural communities, including off-grid distributed generation from a variety of established and emerging alternative sources." [16] The Premier also established the Alternative Energy Task Force to provide advice and recommendations on how to implement the alternative energy strategy. British Columbia can be a world leader in sustainable energy. Government and Industry can create high-value jobs in profitable businesses by supplying smart, sustainable energy solutions to B.C., to Canada and to the world.[17]

BC Progress Board

Established by the Premier in 2001, the BC Progress Board is "tasked with benchmarking BC's economic and social performance over time and relative to other jurisdictions." [18] In November 2005, the BC Progress Board tabled a discussion paper on energy with the provincial government. The paper, "Strategic Imperatives for British Columbia's Energy Future", was prepared for the Board by Sage Group Management Consultants. This document surveys BC's current energy situation, outlines energy opportunities for BC and specific actions that should be taken. The first of six Strategic Imperatives says that BC must protect and promote its real advantages in the energy sector. It describes how growing the energy sector in BC will underpin economic growth for the province and that growth needs to come from both conventional and alternative sources of supply. [19]

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[16] BC Ministry of Energy, Mines and Petroleum Resources, "Alternative Energy and Power Technology: A Strategy for BC," BC Ministry of Energy, Mines and Petroleum Resources website, http://www.gov.bc.ca/empr/down/alternative_energy_task_force_strategy_final_april_5_05.pdf, accessed January 2007

[17] BC Ministry of Energy, Mines and Petroleum Resources, "A Vision and Implementation Plan for Growing a Sustainable Energy Cluster in British Columbia" BC Ministry of Energy, Mines and Petroleum Resources website, http://www.em.gov.bc.ca/AlternativeEnergy/AEPT_report.pdf, accessed January 2007

[18] BC Progress Board, "Strategic Imperatives for British Columbia's Energy Future," BC Progress Board website, http://www.bcprogressboard.com/2005Report/EnergyReport/Energy_Final.pdf, accessed January 2007

[19] Ibid.

BC Innovation Council (BCIC)

The BC Innovation Council (BCIC) is a crown agency of the Province of British Columbia whose mandate is "to accelerate and expand science and technology-based economic development to make British Columbia one of the world's top ten technology centres by 2010." [20] BCIC supports innovation through targeted initiatives to build on the strengths and abilities of the province and of the companies and organizations within it. One of these initiatives is the Ocean Renewable Energy Group (OREG). BCIC was instrumental in the launching of OREG and has provided invaluable support to permit the organization to develop. BCIC provides funding for a range of programs from scholarships to research and development to support and encourage innovation.[21]

BC Energy Plan

The last Energy Plan was issued by the Province of BC in 2002. The plan reflects the government's vision of the energy sector, the goals it has set and the path to achieving those goals in an environmentally responsible way.[22] A new version of the Energy Plan has been under development over the last year and is eagerly awaited by the alternative energy industry. While the report has not yet been released at the time of writing, the Throne Speech of February 13, 2007 reveals some of the initiatives that will be in the new Energy Plan:

- All electricity produced in BC will have net zero greenhouse gas emissions by 2016,
- At least 90 per cent of BC's electricity will come from clean, renewable sources,
- Bioenergy, geothermal energy, tidal, run-of-the-river, solar, and wind power are all potential energy sources in a clean, renewable, low-carbon future,
- A new $25-million Innovative Clean Energy Fund will be established to encourage the commercialization of alternative energy solutions and new solutions for clean remote energy that can solve many challenges we face right here in B.C.[23]

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[20] BC Innovation Council, "Welcome," BC Innovation Council website, http://www.bcinnovationcouncil.com/ accessed February 2007
[21] BC Innovation Council, "Overview," BC Innovation Council website, http://www.bcinnovationcouncil.com/programs/ accessed February 2007
[22] BC Ministry of Energy, Mines and Petroleum Resources, "Energy For our Future: A Plan For BC," BC Ministry of Energy, Mines and Petroleum Resources website, http://www.gov.bc.ca/empr/down/energy_for_our_future_sept_27.pdf, accessed January 2007
[23] The Government of British Columbia, "Speech From The Throne," BC Government website, http://www.leg.bc.ca/38th3rd/4-8-38-3.htm accessed February 2007

BC Hydro Integrated Electricity Plan (IEP)

Every two years, BC Hydro is required to submit an Integrated Electricity Plan (IEP) with the BC Utilities Commission, in accordance with the regulator's resource planning guidelines. The last IEP was filed in March 2006. It is a long term plan that outlines how BC Hydro intends to meet the needs of its customers over the next 20 years by ensuring that a reliable and cost-effective supply of electricity is available to its customers, while considering key environmental and social issues.[24] The plan recognizes that energy infrastructure involves very large expenditures and long development times, so it is based on long term forecasts and resource options. The current load forecast indicates that BC's energy needs will grow between 25 and 40 percent over the next 20 years. There is an electricity gap between this forecast and the projected capacity that must be filled by conserving more, building new capacity and buying more power from Independent Power Producers (IPPs).[25] IPPs are viable options for BC Hydro to add clean energy generating capacity through the development of projects using technologies including wind power, biomass, microhydro and, of course, ocean energy.

BC Hydro Remote Community Electrification Program (RCE)

BC Hydro has a desire to supply remote communities with power at prices comparable to what BC Hydro's customers pay in other parts of the province. Under the RCE program, BC Hydro would assume responsibility for the supply of electricity for remote communities that meet the selection criteria, and provide the power to the community at standard rates. BC Hydro has prepared a list of communities that have at least ten permanent residences and has conducted a survey to determine the level of need and the willingness of the community to participate in the program. The results of this survey have determined the priority list for the program.[26]

For a community to qualify for the RCE program, there must be a minimum of 10 permanent residences. In the Stuart Island area, there are 12 permanent residences according to the official records of Canada Post. These residences are on the islands and mainland surrounding Cardero Channel. BC Hydro would have to confirm that the Stuart Island area qualifies for the

[24] BC Hydro, "What is the 2006 Integrated Electricity Plan (IEP)?" BC Hydro website, http://www.bchydro.com/info/epi/epi8970.html, accessed January 2007
[25] BC Hydro, "Challenges and Choices," BC Hydro website, http://www.bchydro.com/rx_files/info/info43492.pdf, accessed January 2007
[26] BC Hydro, 2006 Annual Report, (Vancouver: BC Hydro, 2006), http://www.bchydro.com/info/reports/2006annualreport/report45822.html, accessed January 2007

program, but if accepted, this program could be of tremendous benefit to the residents and businesses of the Stuart Island area.

BC Hydro's has established rates for its customers by zones:

- Zone I - The integrated system served mainly by hydroelectric (water) generation, to which 99% of customers are connected.
- Zone II - The non-integrated system (areas with no access to the integrated system) where electricity is generated by diesel and some small hydroelectric plants. [27]

Currently, the Zone II residential rate is 6.33 cents per KWh for the first 3000 KWh and 10.87 cents per KWh after that. The rate for businesses is 12 cents per KWh, compared to the cost of power generated by the diesel gensets in the Stuart Island area, which is about 29 cents per KWh.

Under the RCE program, there would be an opportunity for an IPP to sell power to the Non Integrated Electrical System. BC Hydro would buy power from the IPP and supply it to residents and businesses at Zone II rates. Customers are responsible, however, for providing a distribution line from the generators, built to BC Hydro standards. BC Hydro's objective is to supply 50% of the power for RCE from renewable sources.[28]

Triton Consultants Report

In 2002, Triton Consultants completed a study for BC Hydro that detailed the nature and extent of tidal energy resources in British Columbia.[29] This comprehensive report provides an extensive overview of the potential for the development of tidal power in BC as a source of Green Energy. The Triton report is a tremendous resource for anyone interested in tidal power in BC and has been invaluable in the preparation of this study on tidal power potential in the Stuart Island area.

The Triton study included five principal elements;

- a detailed assessment of the tidal current resource available in BC,

[27] BC Hydro, "How Your Rates Are Determined," http://www.bchydro.com/policies/rates/rates759.html, accessed January 2007
[28] Nick Hawley, telephone interview by author, January 19, 2007
[29] Triton Consultants, "Green Energy Study for British Columbia. Phase 2: Mainland. Tidal Current Energy," http://homepage.mac.com/max.larson/Triton/download/environment3928.pdf accessed January 2007

- preliminary tidal modeling studies,
- case studies of one large (800 MW rated capacity) and one small (43 MW rated capacity) potential tidal current power site, including indicative energy costs,
- an initial evaluation of environmental issues,
- and a review of selected tidal current technologies which are in various stages of development.[30]

The study presents a number of key conclusions, including findings that tidal current energy is predictable, regular, will not be affected by global climate change and has small environment impact. It determines that tidal current energy generation costs are competitive with other green energy sources at 11 cents per KWh for a large site and 25 cents per KWh for a small site. These costs are expected to reduce as the technology matures.

The Triton study also notes there are some challenges that the tidal power industry faces:

- The technology is in its infancy
- Tidal power generation fluctuates significantly over a typical day
- There is no significant government funding in Canada, which is a serious impediment to the development of tidal power technologies.[31]

[30] Ibid. p.7
[31] Ibid. p.8

BC Ocean Energy Industry

In British Columbia there has been considerable development activity in tidal power energy generation. The most advanced development site is the Pearson College / Clean Current site at Race Rocks, which has been in the water and generating power since late 2006. This project has done a great deal to raise the profile of tidal energy in BC and in Canada. The turbine is rated at 65 KW and thus is not at commercial scale, but it is an off-grid installation which makes it germane to this study. The turbine is providing power to the weather station and instrumentation at Race Rocks, near Victoria, BC, and is reducing dependence on the diesel generators that have been providing the power there for decades.

In addition to Race Rocks, there are currently three more development sites in the province. Investigative Use Permits have been granted for the following sites:

Maude Island/Canoe Pass - Canoe Pass Tidal Energy Corp
Discovery Passage - 6420800 Canada Ltd (Lunar Energy)
Discovery Passage - BC Tidal Energy Corp[32]

The Canoe Pass project is working its way through the approval process and is scheduled to conduct design work in 2007 with installation targeted for 2008. This project employs a unique installation design that features a span across the narrow channel to facilitate access during installation and testing, and ease of power connections.

Lunar Energy plans to begin work at the Discovery Passage site in late 2009, after testing of the 1 MW device at the EMEC facility in Scotland in late 2008. The site is near Seymour Narrows, one of the largest tidal power resources in Canada.

There are a number of technology developers working in BC – more information on them can be found in the Technology section.

[32] Neil Banera, MEMPR, email correspondence with author, January 24, 2007

Ocean Energy in Canada – Government and NGOs

The two lead organizations for ocean energy in the Government of Canada are Natural Resources Canada and the National Research Council. As it is the government ministry with responsibility for alternative energy initiatives, Natural Resources Canada is the primary vehicle for direct government funding of ocean energy. However, as ocean energy is in the developmental and demonstration phases, the National Research Council may play a larger role in a project.

Natural Resources Canada (NRCan)

Natural Resources Canada is the name for the natural resources department in the government of Canada and is represented in government by a Minister at the Cabinet table. NRCan works to ensure the responsible development of Canada's natural resources, including energy, forests, minerals and metals. NRCan also uses our expertise in earth sciences to build and maintain an up-to-date knowledge base of Canada's landmass and resources.[33] The funds available for NRCan are determined each year through the federal budgeting process. Therefore the priorities of the government in power determine the emphasis to be placed on the ministry and its activities, so often this is a purely political decision. Such is the case with alternate energy, which has not received a great deal of attention from the Government of Canada through 2006.

However, on January 17, 2007, Minister Gary Lunn announced that 230 million dollars would be allocated as incentives to industry to reduce greenhouse gas emissions and to develop alternative energy technologies.[34] Only two days later, Prime Minister Harper announced the ecoEnergy Renewable Initiative, which will provide up to 1.5 billion dollars in incentives over ten years to increase clean, renewable energy production in Canada. While critics argue that this initiative is essentially a resurrection of the previous government's proposed program, and that this is not a large amount of money relative to Canada's total annual budget, it is nevertheless a step in the right direction and will help to raise the profile of alternate energy technology developers in the minds of the public.

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[33] Natural Resources Canada, "About Us," Natural Resources Canada website, http://www.nrcan-rncan.gc.ca/inter/aboutus_e.html, accessed January 2007

[34] Natural Resources Canada press release, "Canada's New Government Launches ecoEnergy Technology Initiative," January 17, 2007, Natural Resources Canada website, http://www.nrcan-rncan.gc.ca/inter/aboutus_e.html, accessed January 2007

CANMET Energy Technology Centre (CETC)

The CANMET Energy Technology Centre is a federal government organization under the umbrella of Natural Resources Canada. CETC has a mandate to work with Canadian businesses to develop and alternative and renewable energy technologies. CETC has available laboratory facilities and research expertise. These facilities and services can be available on a cost-shared basis. One of CETC's stated priorities is the development of alternative and renewable energy technologies.[35] CETC has an Emerging Technologies Program that can provide up to 50% repayable funding assistance for technical assessments, prototype development and field trials. This program supports, among other things, the development of technical solutions that contribute to a cleaner environment.[36]

Sustainable Development Technology Canada (SDTC)

Sustainable Development Technology Canada (SDTC) was established by the Government of Canada in 2001 as a not-for-profit foundation to help finance the development of clean technologies. The foundation draws from an investment fund of $ 550 million and reports to Parliament through NRCan. SDTC's mission is to act as a catalyst to build a sustainable technology infrastructure in Canada. SDTC helps entrepreneurs bridge the gap between research and commercialization by assisting them through the crucial phases of development and demonstration.[37] The phase in a product or technologies development that can incur the most cost and risk is the time when it must be proven in real world conditions, with models approaching full scale. SDTC grants help clean energy developers move through this stage towards full commercialization of the product.

In British Columbia, SDTC has made investments in tidal stream power generation demonstration projects at Race Rocks and Canoe Pass. These investments have made an important contribution to the development of tidal power generation in BC and in Canada.

[35] CANMET Energy Technology Centre, "Frequently Asked Questions About CETC-Ottawa," CETC website, http://www.nrcan.gc.ca/es/etb/ctec/cetc01/htmldocs/FAQs/index_e.htm accessed February 2007.
[36] CANMET Energy Technology Centre, "Emerging Technologies Program," CETC website, http://www.nrcan.gc.ca/es/etb/ctec/cetc01/htmldocs/Groups/Funding%20Programs/fundprog_emerging_technologies_e.htm accessed February 2007.
[37] Sustainable Development Technology Canada, "About SCTC – SDTC Profile," SDTC website, http://www.sdtc.ca/en/about/index.htm, accessed January 2007

National Research Council (NRC)

One of the main access points to the federal government for technology developers is the National Research Council (NRC). NRC was created in 1916 as the Canadian government's agency for research and development; it falls under the Ministry of Industry. The mandate for NRC is laid out in the NRC Act and the first mandate is "undertaking, assisting or promoting scientific and industrial research in different fields of importance to Canada."[38]

National Research Council – Institute for Ocean Technology (NRC-IOT)

The NRC is organized into more than twenty institutes and programs.[39] One of these institutes is the Institute for Ocean Technology (NRC-IOT) which was established in 1985 to support Canada's ocean technology industry by providing technical expertise. IOT conducts ocean engineering research through modeling of ocean environments, predicting and improving the performance of marine systems, and developing innovative technologies that bring benefits to the Canadian marine industry.[40] NRC-IOT works with Canadian companies to develop prototypes of various kinds of surface and underwater technologies, then commercialize them. In 2003 the NRC-IOT opened the Ocean Technology Enterprise Centre (OTEC) in St. John's Newfoundland. OTEC provides a place for ocean technology companies to conduct research and develop their technologies and business opportunities.[41] Resources such as office equipment and conference facilities are provided and the Canada Institute for Scientific and Technical Information is nearby.

NRC Industrial Research Assistance Program (IRAP)

The Industrial Research Assistance Program (IRAP) is a program to provide assistance to small and medium-sized Canadian enterprises (SME). This assistance takes many forms and includes technological and business advice and financial assistance. IRAP funding can help SMEs to make investments in people or research and development programs to realize the full

[38] National Research Council Canada, "Our Mandate," NRC website, http://www.nrc-cnrc.gc.ca/aboutUs/mandate_e.html, accessed January 2007
[39] National Research Council Canada, "Corporate Overview," NRC website, http://www.nrc-cnrc.gc.ca/aboutUs/corporateoverview_e.html, accessed January 2007
[40] National Research Council – Institute for Ocean Technology, "About Us," NRC-IOT website, http://iot-ito.nrc-cnrc.gc.ca/about_e.html, accessed January 2007
[41] National Research Council – Institute for Ocean Technology, "Ocean Technology Enterprise Centre," NRC-IOT website, http://iot-ito.nrc-cnrc.gc.ca/enterprise_e.html, accessed January 2007

potential of their innovations.[42] IRAP's mandate is to stimulate wealth creation for Canada through technological innovation. It does this by providing assistance to the SMEs that make up the majority of businesses in Canada. In addition to funding, IRAP helps Canadian companies by making available technology advisors that can provide confidential advice to help build their innovation capability.[43]

NRC Canadian Hydraulics Centre (NRC-CHC)

The Canadian Hydraulics Centre is a business unit of the NRC. Located in Ottawa, it is one of the largest hydraulic engineering laboratories in North America and is equipped with some of the world's most advanced technology for wave generation and coastline physical modeling. The centre is equipped to investigate and solve problems through numerical models, then validate those numerical models with large scale physical models.[44] In 2006, the CHC produced a technical report entitled Inventory of Canada's Marine Renewable Energy Resources which detailed the location and size of wave and tidal energy resources.[45]

The Ocean Renewable Energy Group (OREG)

The Ocean Renewable Energy Group (OREG) is a Canadian organization dedicated to leading the effort to make Canada a leader in ocean energy technologies. OREG is a valuable resource for information on ocean energy technologies and developers from around the world. OREG has produced a plan called *The Path Forward*, which outlines a plan for Canada in the world of renewable ocean energy.[46] In the words of OREG Chairman Chris Knight, "This Plan has two purposes. First we need to identify immediate actions that will springboard the Canadian ocean energy sector to a world-wide leadership position alongside the UK and other European Union countries. Secondly, we need to set out a broader sectoral development plan as the foundation to maintain that leadership position and make ocean renewable energy a fundamental part of

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[42] NRC-IRAP, "Innovation at work in Canada," NRC-IRAP website, http://irap-pari.nrc-cnrc.gc.ca/main_e.html, accessed January 2007

[43] NRC-IRAP, "About NRC-IRAP," NRC-IRAP website, http://irap-pari.nrc-cnrc.gc.ca/aboutirap_e.html, accessed January 2007

[44] NRC Canadian Hydraulics Centre, "Coastal Engineering- Physical and Numerical Modelling," NRC-CHC website, http://chc.nrc-cnrc.gc.ca/English/Coastal/Coastal_e.html, accessed January 2007

[45] A. Cornett, "Inventory of Canada's Marine Renewable Energy Resources CHC-TR-041," http://www.oreg.ca/docs/Atlas/CHC-TR-041.pdf accessed January 2007

[46] OREG, "The Path Forward," OREG website, http://www.oreg.ca/docs/OREG%20docs/OREG%20_The%20Path%20Forward_v7sm.pdf, accessed January 2007

Canada's business, economic, energy and environmental future."[47] OREG has organized symposia that have brought tidal power experts from around the world to share their wisdom and insights with Canadians from industry, government and academia. More information on OREG can be found in the Organizations section of this paper.

Western Economic Diversification

Western Economic Diversification Canada (WD) was established to help broaden the economic base of the western provinces and receives an annual allocation, approved by Parliament, for grants and contributions that support a wide range of programs responding to Western Canada's economic development needs and priorities.[48] WD has made investments in BC ocean energy projects and so is a valuable contributor to the development of tidal energy expertise in the province.

Nova Scotia Power

Canada is home to one of the first tidal power generating facilities in the world. The Annapolis Power Station at Annapolis Royal, Nova Scotia is a barrage-type tidal power generation plant that harnesses potential energy from the tides of the Bay of Fundy. The plant became operational in 1984, and until recently was one of only three tidal power plants in the world. Owned and operated by Nova Scotia Power, the Annapolis Power Station can produce up to 20 MW daily.[49]


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[47] Ibid.
[48] Western Economic Diversification, "WD Programs," Western Economic Diversification website, http://www.wd.gc.ca/programs/default_e.asp, accessed January 2007
[49] Nova Scotia Power, "Ebb and Flow,"Nova Scotia Power website, http://www.nspower.ca/environment/green_power/tidal/index.shtml, accessed January 2007
[50] Nova Scotia Power, "Helping Return Whale To Bay of Fundy," http://www.nspower.ca/about_nspi/in_the_news/2004/08242004.shtml accessed February 2007

In January 2007, Nova Scotia power announced that it will continue to be a leader in ocean energy generation with a new tidal stream demonstration project in the Bay of Fundy. The project will use a turbine designed and manufactured by OpenHydro of Ireland. If the demonstration project is successful, Nova Scotia plans to install more turbines to create the largest in-stream tidal unit integrated into an electricity grid in the world.[51]

EnCana

EnCana Corporation deserves a mention here because it is a major sponsor of the tidal power demonstration project at Race Rocks and is demonstrating to industry that investing in clean energy is good business. The Encana Environmental Innovation Fund contributed three million dollars to the project.[52]

[51] "Nova Scotia Power Takes Another Step Towards Tidal Power Pilot Project," Nova Scotia Power press release (Halifax, NS, January 12, 2007). From Nova Scotia Power website, http://www.nspower.ca/about_nspi/in_the_news/2007/01122007.shtml, accessed January 2007

[52] EnCana Corporation, "Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks," Encana website, http://www.encana.com/responsibility/eif/fundedprojects/P1162484703969.html, accessed January 2007

Appendix I

Tidal Resources in Canada

Canada is richly endowed with tidal resources – a 2006 study identified more than 42,000 MW of potential tidal energy resources in the oceans surrounding the country. Expressed differently, that represents about 365 Terawatt hours per year, which is approximately seventy percent of Canada's present electrical power consumption.[53] In 2006, the Canadian Hydraulics Centre produced a technical report entitled Inventory of Canada's Marine Renewable Energy Resources which detailed the location and size of wave and tidal energy resources.[54] Triton Consultants, of Vancouver, was engaged to conduct a study that identified tidal resources over 1 MW and locate them geographically. Triton's methodology included identification of passages or reaches with strong currents, determining the basic parameters of each site and estimating the mean power density and annual mean power from those parameters.[55] Triton's findings are included in the CHC report, which is the first step in a three year project to create a Digital Atlas of Canadian Marine Renewable Resources. In Canada, a total of 190 sites were identified with potential mean power over 1 MW. The largest number of sites is in British Columbia, but the largest resources by far are in Nunavut.[56]

Another organization that has taken an interest in Canada's ocean energy resources is EPRI. In 2006, EPRI released a series of studies of tidal resources on the East Coast of North America. Two Canadian locations in the Bay of Fundy were included in the studies, Minas Basin in Nova Scotia and Head Harbour Passage in New Brunswick. Comprehensive feasibility studies were produced that detailed the potential for tidal power generation facilities in the waters of the Bay of Fundy.

Bay of Fundy and Minas Basin

To produce practical amounts of tidal power with a barrage system, a difference of a least five metres between high and low tide is needed. There are only about 40 sites around the world

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[53] Michael Tarbotton and Max Larson, *Canada Ocean Energy Atlas (Phase 1)Potential Tidal Current Energy Resources Analysis Background,* Annex A of Inventory of Canada's Marine Renewable Energy Resources CHC-TR-041, National Research Council Canada, April 2006, p.15, http://www.oreg.ca/docs/Atlas/CHC-TR-041.pdf accessed January 2007

[54] A. Cornett*, Inventory of Canada's Marine Renewable Energy Resources CHC-TR-041*, National Research Council Canada, April 2006, http://www.oreg.ca/docs/Atlas/CHC-TR-041.pdf accessed January 2007

[55] Ibid., page 82

[56] Ibid., page 83

with this kind of tidal range. Currently in Canada, the only practical site is the Bay of Fundy.[57] Minas Basin is a branch of the upper end of the Bay of Fundy.

“Today, the Basin’s oceanography is dominated by tides that exceed those of any other location in the world. They are even 1.5 metres higher than in nearby Chignecto Bay, because the "Coriolis Force", produced by the rotation of the Earth, nudges the tidal bulge towards the southeastern side of the Bay of Fundy. The average tidal range is an impressive 13 metres, while spring tides up to 16 metres are common. The large tidal amplitude causes more than 10 cubic kilometres of seawater, weighing 10 billion tonnes, to flow into and out of the Basin twice daily, more than forty times the flow of the St. Lawrence River. As the Basin fills, the weight of water causes the surrounding land to dip slightly under the load. The water squeezes through the 5 kilometre wide gap at Cape Split, a bottleneck that causes the incoming water to pile up in Scots Bay, producing a noticeable difference in the height of the sea surface. The inrushing flow reaches speeds of 4 metres per second (8 knots), swirling past Cape Split in a maelstrom of turbulent currents and gyres.”[58]

Naturally, the enormous tidal range and powerful currents at Minas Basin have attracted a great deal of interest from people and organizations involved in tidal power generation. There are two key advantages to the Minas Basin site – proximity to the North American power grid and ease of transportation of material and equipment for installation of a tidal power generation facility. In January 2007, Nova Scotia Power took the first step towards realizing the potential of the resource when it awarded a contract for the supply and installation of a tidal power generation device for a demonstration project to OpenHydro.

Hudson’s Strait and Ungava Bay

Over 70% of Canada’s potential tidal energy resources are in Hudson’s Strait, which connects the waters of Hudson’s Bay to the North Atlantic Ocean.[59] Two locations adjacent to Mill Island and another at Gray Strait are enormous resources, with potential resources of several thousand MW each, totaling just under 25,000 MW. Ungava, a bay off Hudson’s Strait in Northern Quebec, has three locations with potential tidal resources totaling more than 3,000

[57] Nova Scotia Power, “Tidal Technology,”Nova Scotia Power website, http://www.nspower.ca/environment/green_power/tidal/ technology.shtml, accessed January 2007
[58] Bay of Fundy Ecosystem Partnership, “Fundy’s Minas Basin - Multiplying The Pluses of Minas,” Bay of Fundy Ecosystem Partnership website, http://www.bofep.org/minas1.htm, accessed January 2007
[59] Cornett*, Inventory of Canada’s Marine Renewable Energy Resources* p.83

MW.[60] The sheer magnitude of these resources merits further investigation into the possibility of developing these sites to extract clean energy. Unfortunately, the remoteness of the locations means that a great deal of money would have to be invested in power transmission infrastructure to connect to the North American electrical grid. This is particularly true of the locations near Mill Island which are hundreds of kilometers from the nearest grid connection point. This means that these resources likely will not be developed for many years. On the positive side, both tidal power generation technology and power transmission technology will have had time to evolve in the intervening years, possibly making the resource more financially feasible to develop.

British Columbia Coast

Triton Consultants identified 89 sites on the BC coast with potential tidal resources greater than 1 MW.[61] The great advantage of many of the BC sites is their relative proximity to the grid, often within a few kilometers – in some cases the tidal resource is virtually adjacent to a grid connection point. In fact, the Canoe Pass site is situated directly under a 25 KV distribution line.[62] However, the extremely rugged terrain of the BC coast means that a relatively short distance as the seagull flies might prove to be a formidable challenge when contemplating laying subsea cable or stringing overhead wires. Further details can be found in the Tidal Resources in BC section of this report.

Marine traffic is a concern along the BC coast and so this has the effect of limiting the feasibility of developing some tidal power resources or limiting the devices that might be used. This factor is compounded by the fact that the largest tidal stream resources occur in relatively narrow channels or passages where transit by marine traffic cannot be suspended for weeks or months while tidal power generators are installed.

[60] Tarbotton and Larson, *Canada Ocean Energy Atlas (Phase 1)* p.16
[61] Cornett*, Inventory of Canada's Marine Renewable Energy Resources* p. 83
[62] Canoe Pass Tidal Energy Consortium, *Canoe Pass Tidal Energy Demonstration Project – Detailed Project Description*, March 8, 2006

Tidal Power Internationally

Tidal power generation is not well known in North America, in spite of the fact that Canada boasts one of only a few commercially operating tidal power plants in the world at Annapolis Royal, Nova Scotia. This facility will be discussed in detail in the Canadian section. Ocean energy, including both tidal and wave energy, has attracted much more attention internationally, especially in Europe. A number of companies developing technology to extract clean, renewable energy from the ocean and demonstration projects are underway in several countries. The following is a review of tidal energy activities around the world.

France

Completed in 1967, the Rance Tidal Power Plant, at Mont Saint-Michel is by far the largest in the world with a generating capacity of 240 MW.[63] A barrage type system, the power plant required the construction of a structure 750 metres long and 13 metres high. Twenty four axial flow turbines each 5.3 metres in diameter produce 10 MW each. The plant has operated without major incidents or breakdowns and produces electricity at a cost that is lower than Electricité de France's average generation costs.[64]

Russia

In the late sixties, a small experimental system with an installed capacity of 400 KW was built in Russia at Kislogubsk near Murmansk.[65] Design studies followed at four locations, two in the White Sea and two in the Sea of Okhotsk.[66] The study of the Tugur tidal power station in the far eastern area of Russia rated its capacity at 6,800 MW but the remoteness of the location makes it unlikely to be developed in the near future.[67] In December 2006, an experimental floating tidal

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[63] Electricitie de France, "The Rance tidal power plant, power from the ocean," EDF website, http://www.edf.fr/html/en/decouvertes/voyage/usine/retour-usine.html, accessed December 2006
[64] Ibid.
[65] World Energy Council, "Survey of Energy Resources – Tidal Power," WEC website, http://www.worldenergy.org/wec-geis/publications/reports/ser/tide/tide.asp, accessed December 2006
[66] Research Institute for Sustainable Energy, "Tidal Power Around the World," RISE website, http://www.rise.org.au/info/Tech/tidal/index.html, accessed December 2006
[67] Victor N. Minakov, "Transmission Line Project Linking the Russian Far East with the DPRK (Chongjin)" paper presented at Energy Forum held in Niigata, February 2004 http://www.nautilus.org/aesnet/Minakov_Niigata_2004_Peport.pdf, accessed December 2006

power plant was launched and is being towed to an existing test site at Kislogubskaya Tidal Power Plant in the Barents Sea.[68]

China

China has been experimenting with tidal power generation for many years, and in 1984, eight tidal power plants were in operation. At least two of these plants are still in operation. The Jiangxia power plant in Zhejiang province has a capacity of 3.2 MW from five turbine units. Noteworthy for this study of the use of tidal power generation for remote communities is the Haishan power plant on Maoyan Island, also in Zhejiang province. This small plant, with a capacity of only 0.25 MW, serves an isolated community of 760 people. It has been in continuous operation since 1975.[69] More recently, China has developed two experimental tidal stream power generators, Wanxiang I and Wanxiang II, which are currently under test.[70]

The United Kingdom

The preeminent demonstration project of tidal stream generation technology has been in place since 2003. Seaflow is a marine current turbine that generates 300 KW and is installed off Lynmouth on the North Devon Coast of UK, making use of the strong tides within the Bristol Channel. Seaflow is a test site for the technology, to measure the performance and loads on the turbine, and to develop techniques for installing and operating such machines in a marine environment.[71] The project was sponsored by the UK Department of Trade and Industry (DTI) and the European Commission and was designed, manufactured and installed by a consortium that included companies and organizations from the UK and Germany.

The Seaflow project uses a single rotor mounted on a monopole installed in the seabed. The equipment is manufactured by Marine Current Turbines (MCT) and one of the principal design features is the ability to raise the turbines above sea level for servicing and maintenance. More

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[68] "UES tests tidal generation," *International Water and Dam Construction*, November 29, 2006, http://www.waterpowermagazine.com/story.asp?sc=2040562&ac=7959438, accessed December 2006
[69] E Van Walsom, "Barriers against tidal power," *International Water and Dam Construction*, September 3,2003, http://www.waterpowermagazine.com/story.asp?storyCode=2022354, accessed December 2006
[70] Zhang Liang, "Activities For Ocean Energy Exploration In China" presentation at 11th IEA-OES meeting Lisbon, Portugal, November 14-15, 2006, http://www.iea-oceans.org/presentations/China.pdf, accessed December 2006
[71] IT Power, "Seaflow Marine Current Turbine," IT Power website, http://www.itpower.co.uk/seaflow.htm, accessed December 2006

about the MCT device can be found in the section on tidal stream generator technologies. In 2005 MCT received a grant from DTI to begin development of a 1 MW demonstration unit.

The UK government has made a strong investment in research and development by opening the New and Renewable Energy Centre (NaREC). NaREC is a Centre of Excellence, fast-tracking concept evaluation, feasibility studies and prototype evaluation and testing through to early commercialization.[72] NaREC was built to meet the challenges put forward to enable development of green energy technologies. Construction began in 2003 and the facilities in Blyth were completed in 2006. The Marine Test Facility includes wave and current generators for testing at 1/10 scale.[73]

The European Marine Energy Centre (EMEC) is located in the Orkney Islands off the North coast of Scotland. EMEC was established to help take the development of ocean energy devices to the commercial stage. “As the first centre of its kind to be created anywhere in the world, we offer developers the opportunity to test prototype devices in unrivalled wave and tidal conditions. Wave and tidal energy converters are connected to the National Grid via seabed cables running from open-water test berths. Testing takes place in a wide range of sea and weather conditions, with comprehensive, round-the-clock monitoring.”[74] The tidal test facility, completed in 2006, is located in the Fall of Warness off the island of Eday. It features five test berths at water depths ranging from 25 to 50 metres, each with its own connection cable to the local power grid and control facility.[75]

No discussion of ocean energy in the UK would be complete without mentioning the Pelamis. This wave energy device is manufactured by Ocean Power Delivery (OPD) of Scotland. The Pelamis is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure oil through hydraulic motors via smoothing accumulators. The hydraulic motors drive electrical generators to produce electricity.[76] Three Pelamis wave energy

[72] NaREC, “Harnessing the potential of technology,” NaREC website, http://www.narec.co.uk/index.php, accessed December 2006
[73] NaREC, “Marine Test Facility,” NaREC website, http://www.narec.co.uk/facilities-wave-and-tidal-dock.php, accessed December 2006
[74] EMEC, “Home,” EMEC website, http://www.emec.org.uk/index.asp, accessed December 2006
[75] EMEC, “Tidal Site,” EMEC website, http://www.emec.org.uk/tidal_site.asp, accessed December 2006
[76] OPD Ltd., “The Pelamis Wave Energy Converter,” OPD website, http://www.oceanpd.com/Pelamis/default.html, accessed December 2006

generators were delivered to Portugal in late 2006 for the initial phase of the world's first commercial application of wave energy power generation.[77]

Northern Ireland

The government of Northern Ireland has made strong commitments to renewable energy and tidal power generation. In February 2006 the government launched its £59 million Environment & Renewable Energy fund, which will help harness the country's natural resources to produce power and reduce dependence on fossil fuels.[78]

MCT's SeaGen, scheduled to be installed in Strangford Lough in late 2006, will be connected to the local grid and will provide electricity to approximately 800 homes in the Portaferry and Strangford areas.[79] The device installed will be a twin turbine with design capacity of 1 MW installed on a surface piercing monopole for easy of access for testing or maintenance. Installation challenges at the site have pushed the installation back to the spring or early summer of 2007.[80]

Ireland

Ireland has made a significant commitment to ocean energy through the organization Sustainable Energy Ireland (SEI). Secure funding for ocean energy technology development has been assured through 2025. Phase 1 activities of the Ocean Energy Strategy include the establishment of the Galway Bay test Site. Quarter scale testing of two wave energy devices, the Wavebob and the OE Bouy, are underway.[81] Ireland is also home to OpenHydro, a tidal stream power technology developer that was recently selected as the device supplier for a new demonstration project in the Bay of Fundy.

[77] Rich Bowden, "Portugal Announces New Wave Energy Project," *Renewable Energy Access*, http://www.renewableenergyaccess.com/rea/news/story?id=46206, accessed December 2006

[78] "Hain aims to make NI European leader in renewable energy," Northern Ireland Office press release, February 27, 2006. From Northern Ireland Office website, http://www.nio.gov.uk/media-detail.htm?newsID=12785, accessed December 2006

[79] "MCT Welcomes Northern Ireland's Funding Commitment To Renewable Energy," MCT press release, February 27, 2006. From MCT website, http://www.marineturbines.com/mct_text_files/MCT%20WELCOMES%20NORTHERN%20IRELAND'S%20FUNDING%20COMMITMENT%20TO%20RENEWABLE%20ENERGY%2027FEB06.pdf, accessed December 2006

[80] Peter Fraenkel, Marine Current Turbines, email correspondence with author, January 9, 2007

[81] Katrina Polaski and Tony Lewis, "Ocean Energy in Ireland National Policies and Strategies for RD&D and Commercialisation of Ocean Energy" presentation at 11th IEA-OES meeting Lisbon, Portugal, November 14-15, 2006, http://www.iea-oceans.org/presentations/Ireland.pdf, accessed December 2006

Appendix I

New Zealand

In December 2006, the New Zealand government announced a 8 million dollar funding package to help the country become a world leader in ocean energy technology. Fourteen marine energy projects are currently being planned, with a 200 MW tidal power plant at Kaipara Harbour being the closest to implementation. Crest Energy predicts the first of 200 turbines could be in place within two years. A massive project being contemplated by Neptune Energy could see as many as 13,000 turbines tapping the tidal stream resource at Cook Strait.[82]

Portugal

Wave energy has been the focus for Portugal and it has the distinction of hosting the first commercial installation of the Pelamis wave energy device. The site is five kilometers off the coast of northern Portugal, near Póvoa de Varzim. Three Pelamis units will be used in the initial phase with a total capacity of 2.25 MW. A further 28 units will be supplied if the first phase performs well.[83] As of this writing, the project is waiting for suitable weather to permit installation of the mooring system. The project is expected to be operational early in 2007.

United States

In the United States, EPRI has taken the lead role in promoting ocean energy and in conducting research into suitable locations for both tidal and wave energy projects. On the west coast, EPRI has conducted detailed tidal stream energy feasibility studies on three locations: Golden Gate (San Francisco, CA), Tacoma Narrows (Tacoma, WA) and Knik Arm (Anchorage, AK). These feasibility studies include selection of available technologies, location criteria and financial models. On the East coast, EPRI tidal energy feasibility studies have been completed for four areas in the Northeast area; Muskeget Channel, MA and Western Passage, ME in the United States and Canadian locations at Minas Basin, NS and Head Harbour Passage, NB. There are two American companies with active tidal energy projects, Verdant Power and Underwater Electric Kite (UEK). Verdant has a demonstration project in New York's East River,

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[82] "$8 million support for tide power," *The Dominion Post*, December 12, 2006, http://www.stuff.co.nz/stuff/0,2106,3896680a11,00.html, accessed December 2006

[83] Hydro Technology Ventures, "Wave power units to Portugal," Hydro Technology Ventures website, http://www.hydro.com/en/press_room/news/archive/2006_03/wavepower_portugal_en.html#, accessed January 2007

and UEK has a project at Indian River Inlet, Delaware. Verdant's East River demonstration project became operational in December 2006 and is supplying part of the power for Roosevelt Island.[84] Refer to this paper's Technology section for more information on the devices used by these companies.

Denmark

Denmark has been involved in wave energy technology development since the 1980s.[85] A member of the International Energy Agency – Ocean Energy Systems (IEA-OES) executive committee, Denmark has been taking a leadership role in facilitating the development of wave energy devices and technology. There are a number of wave energy device developers working in Denmark and sea tests are proceeding, notably with the Wave Dragon and Wave Star technologies.[86]

Norway

Also a member of the IEA-OES executive committee, Norway has been active in supporting and promoting the advancement of ocean energy technology. The Norwegian government has two programs to provide support for renewable energy projects, including ocean energy. Pilot projects in both wave and tidal energy are planned. Norwegian projects include shore based and platform wave energy generation devices, and the first phase of a 10 MW full scale wave farm project using the FO^3 wave energy device is expected to be installed in 2007. Plans are in place to develop and build the Morild tidal energy demonstration project based on turbines suspended below a floating structure.[87]

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[84] Beth Fertig, "Tidal Energy Used for Electric Power," *WNYC New York Public Radio*, December 31, 2006, http://www.wnyc.org/news/articles/71358, accessed January 2007

[85] Kim Nielsen, "Development of Ocean Energy in Denmark" presentation at Canada & the World of Ocean Energy Symposium, May 4 - 5, 2006, http://www.oreg.ca/docs/May%20Symposium/Nielsen.pdf, accessed February 2007

[86] Kim Nielsen, "National Ocean Energy Activities - Denmark" presentation at 11th IEA-OES meeting Lisbon, Portugal, November 14-15, 2006, http://www.iea-oceans.org/_fich/4/DK.pdf, accessed February 2007

[87] Petter Hersleth, "Recent developments in Norway" presentation at 11th IEA-OES meeting Lisbon, Portugal, November 14-15, 2006, http http://www.iea-oceans.org/_fich/4/Norway.pdf, accessed February 2007

Tidal Power Organizations

Several organizations have formed that are dedicated to the advancement of alternative energy in general and ocean energy in particular. These organizations provide a valuable service by conducting research, hosting symposia and acting as repositories for information on ocean energy. The following is a review of four of these organizations and their activities.

Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI) was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.[88] EPRI's mission statement includes helping to chart the course to a sustainable energy future by identifying the technology needed to transform the electrical system.[89]

To this end, EPRI has formed a division dedicated to ocean energy, both wave energy and tidal stream energy. On the tidal stream side, EPRI has created the Tidal In Stream Energy Conversion Project (TISEC). TISEC has conducted a number of studies that look at various locations around the United States and their potential for tidal stream power generation. These studies have investigated which generation technologies are most suitable for each location and produced financial models. The studies have examined costing models based on both demonstration and commercial installations. The TISEC studies have found that tidal stream power generation on a commercial scale can produce energy at a cost only slightly higher than other forms of energy generation, and could be a valuable addition to the US west coast energy portfolio.[90] Development of tidal stream generation technology has the potential to create a brand new industry and the associated economic benefits. As Roger Bedard, the EPRI ocean

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[88] EPRI, "Corporate Overview – About the Electric Power Research Institute," EPRI website, http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=CommunityPage&parentid=2&in_hi_userid=2&control=SetCommunity&CommunityID=200&PageID=-200, accessed December 2006
[89] EPRI, "Introducing Electric Power Research Institute," EPRI website, http://my.epri.com/portal/server.pt?Product_id=000000000001014423, accessed December 2006
[90] EPRI, "060426 Final West Coast Tidal Briefing," EPRI website, http://www.epri.com/oceanenergy/attachments/streamenergy/briefings/060426_Final_West_Coast_Tidal_Briefing.pdf, accessed December 2006

energy leader, says “A small investment today might stimulate an industry which may employ thousands of people and generate billions of dollars of economic output while using an abundant and clean natural resource.”[91]

International Energy Agency – Ocean Energy Systems (IEA-OES)

The International Energy Agency (IEA), based in France, was formed during the oil crisis of 1973 – 1974 and is comprised of 26 member countries. The IEA acts as policy advisor to its member countries and promotes reliable, affordable and clean energy for the world’s consumers. At the 2005 G8 meeting, the IEA was asked for strategic advice for a clean, sustainable and clean energy future.[92] Promoting safer, more efficient technologies is a major goal of the IEA, as is its work on policies and technologies to reduce greenhouse gas emissions.[93] The IEA also provides analysis of long term energy trends through its World Energy Outlook publication.

A division of the IEA has been formed dedicated to Ocean Energy Systems (IEA-OES) to enhance international collaboration to make ocean energy technologies a significant energy option in the mid-term future. Through the promotion of research, development, demonstration and information exchange and dissemination, the Agreement's objective is to lead to the deployment and commercialization of Ocean Energy Technologies.[94] The IEA-OES promotes international cooperation by organizing and participating in symposia relating to the development of ocean energy technology. The presentations made at the Executive Committee meetings are published on the IEA-OES website and these are a tremendously valuable resource for the member countries and are accessible to the public. Country reviews, which describe the ocean energy situation in fourteen member countries, are available from the 11th executive committee meeting.[95]

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[91] Roger Bedard, “060426 Final West Coast Tidal Briefing,” EPRI website, http://www.epri.com/oceanenergy/attachments/streamenergy/briefings/060426_Final_West_Coast_Tidal_Briefing.pdf, accessed December 2006

[92] IEA, “What is the International Energy Agency,” IEA website, http://www.iea.org/journalists/faq.asp, accessed December 2006

[93] IEA, “What does the IEA do?,” IEA website, http://www.iea.org/journalists/faq.asp, accessed December 2006

[94] IEA-OES, “About IEA-OES,” IEA-OES website, http://www.iea-oceans.org/about/index.htm, accessed December 2006

[95] IEA-OES, “Presentations,” IEA-OES website, http://www.iea-oceans.org/presentations/index.htm, accessed December 2006

Ocean Renewable Energy Group (OREG)

The Ocean Renewable Energy Group (OREG) is a collaboration between industry, academia and government formed to mobilize proven Canadian energy project implementation experience, together with new and emerging ocean technologies, to lead an effort to ensure that Canada is a leader in providing ocean energy solutions to a world market. OREG is a Canadian national organization headquartered in British Columbia.[96] The OREG website is a tremendous resource, with a great deal of information on ocean energy activities in Canada and internationally. OREG was formed in 2004 and has hosted symposia in 2005 and 2006 that attracted presenters from around the world. The presentations from these symposia are posted on the OREG website and are publicly accessible.

Some of OREG's stated goals are:

- to represent the interests of the Canadian ocean energy community with regard to the development of policies,
- supporting the industry by facilitating the research, development and deployment of projects,
- forming strategic alliances with other organizations,
- to promote discussion, forums, and workshops in an effort to increase public awareness and understanding, and
- to lead the way towards commercialization of ocean energy in Canada.[97]

British Wind Energy Association (BWEA)

The British Wind Energy Association (BWEA) was formed in 1978 and is the leading renewable energy trade association in the UK, acting as a central information point for its members and as a lobbying group. Its initial focus was the wind industry but has expanded its purview in recent years to include ocean energy. The association hopes to use its experience in championing wind energy to commercial implementation to help ocean energy down the same path.[98]

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[96] OREG, "Welcome to Ocean Renewable Energy Group," OREG website, http://www.oreg.ca, accessed December 2006
[97] OREG, "About," OREG website, http://www.oreg.ca/about.html, accessed December 2006
[98] BWEA, "About BWEA," BWEA website, http://www.bwea.com/about/index.html, accessed December 2006

Sites In British Columbia

In 2002, Triton Consultants completed a study for BC Hydro that identified potential tidal resource sites in BC, the 2006 study built on those results. Triton identified 89 sites on the BC coast with potential tidal resources greater than 1 MW.[99] The great advantage of many of these sites is their relative proximity to the grid, often within a few kilometers – in some cases, the tidal resource is virtually adjacent to a grid connection point.

Marine traffic is a concern along the BC coast and so this has the effect of limiting the feasibility of developing some tidal power resources or limiting the devices that might be used. Heavy marine traffic may prevent the positioning of barges required to install tidal energy generation devices. Large ship traffic requires minimum clearance to turbines below the surface, generally accepted as 15 meters. Some suitable channels may not be of sufficient depth to allow both tidal power generation and ship traffic. Finally, some channels are so deep, with such powerful tidal flows, that installation of tidal power generator(s) is not possible with current technology and available equipment.

Notwithstanding the above noted limitations, the BC coast is richly endowed with tidal resource sites that are suitable for development. The nature of the coastal geography and hydrology means that there are many narrow channels with fast, powerful tidal flows. This creates sites with high power density. In Triton's 2006 report there is a ranking of sites by power density. Sixteen of the top twenty-five sites are in BC, including the top three.[100] These are sites where there is a good opportunity to extract energy from the tidal stream.

Triton's report describes a characteristic of tidal flows in BC that are especially suitable for power generation: "In British Columbia, some of the highest velocity tidal current flows in Canada occur through the passages between Strait of Georgia and Johnstone Strait. The tidal range is moderate (5 m), but the tides from the Pacific through Johnstone Strait are roughly 180 degrees out of phase with the tides in Strait of Georgia entering south of Vancouver Island."[101]

This is the area that includes Stuart Island. Of the top twenty-five power density sites mentioned above, five of those are in the waters surrounding Stuart Island. The picture below illustrates the

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[99] Cornett*, Inventory of Canada's Marine Renewable Energy Resources* p. 83
[100] Tarbotton and Larson, *Canada Ocean Energy Atlas (Phase 1)* p. 16
[101] Ibid. p. 10

narrow channels into which the tidal stream must be compressed, resulting in the powerful currents that create the tidal resources found between Vancouver Island and the mainland of BC.

[102]

[102] Image source: Google Earth, http://earth.google.com/

Appendix I

Stuart Island area

Stuart Island is in a remote location, far from the nearest city. It is a rugged place, with rocky islands poking through the water's surface that only hints of the powerful currents below. The waters of Cardero Channel around Stuart Island are tremendous tidal power resources. These resources, along with the off-grid location, are the reason the Stuart Island area was chosen for this study.

First Nations people have been living in the area for centuries, long before electrical power was invented. The powerful ocean currents that make the waters of Cardero Channel a prime habitat for fish, sea birds and marine mammals make the islands surrounding the channel a prime place for people to live.

Nowadays, electrical power has made life easier in the Stuart Island area – modern conveniences like electric lighting, power for refrigeration, telephone and communications are now available for residents. Resorts have sprouted up around Cardero Channel and there are more visitors each year. Presently, all the electrical power is produced by diesel generators (gensets), so the price paid for these conveniences of modern life are air pollution, noise pollution and the potential for water pollution. Each resort has one or more gensets to provide electricity for their guests and most of the residences have a small generator on their property.

Cardero Channel, in the subject area, is surrounded by Stuart Island to the east, Sonora Island to the southwest, Dent Island to the west and the mainland of BC to the north. Resorts, permanent residences and summer vacation homes dot the shoreline. Most of the residential dwellings are on the west side of Stuart Island. In the past, the community was centred on Big Bay, where there was a public marina, small general store and post office. The marina was purchased by a private company and the public facilities were closed, so the community currently lacks a focal point. Some of the resident's families have lived in the area for generations, after it was first inhabited by white settlers about 80 years ago. At present, Canada Post records show there are twelve permanent residences in the Stuart Island area.

At the time of writing there were ten resorts, some private and some public. They range in size from about twelve guests to more than a hundred. As with the residences, most of the resorts are located on the west side of Stuart Island, but there are a couple on the mainland shore and the largest resort by far is on Sonora Island. Sonora Resort is the largest power user in the area. Most of the visitors to the area come in the summer, when the weather is fairest and the ocean calmest. Often the visitors come in pursuit of trophy Spring Salmon and guided fishing trips are the mainstay of the resorts. However, ecotourism is a growing business in the area. Wilderness areas are a short boat ride away, and ecotourists can go on expeditions in search of eagles, grizzly bears, sea lions and if they are lucky, orcas.

Ecotourism

Ecotourism represents good growth potential for the Stuart Island area, for three main reasons:

- It can generate revenue from non-fishing visitors accompanying fishermen,
- It does not require more infrastructure investment, and
- It can extend the busy season for the resorts, even into winter.

A large proportion of the visitors to Stuart Island come during salmon fishing season, from late June until mid September. Resorts are usually fully booked in the peak of the salmon season, so revenue growth from fishing would require adding capacity (rooms). However, some visitors are accompanying fishermen but have little interest in fishing. For these guests, ecotourism provides an opportunity to enjoy the wilderness setting to a greater extent. Most resorts are offering some ecotours now. Promoting ecotourism can enable resorts to fill more rooms in the off-peak weeks at the beginning and end of the prime fishing season.

The largest opportunity that ecotourism presents to the Stuart Island area is by extending the time the resorts are open each year. Earlier in the summer before the main salmon runs have arrived, and later in the fall when most of the fish have passed through are times when ecotourism could be emphasized. Adding a few weeks to the season would use existing resort infrastructure and provide additional return on investment from assets that are idle for a large part of the year. It is possible that opening during the winter season could be a viable way to maximize the use of these assets. Resorts along the west coast of Vancouver Island have established a seasonal business with visitors who come to witness the power of the Pacific Ocean during storm season. The resorts at Stuart Island could do this too.

Appendix I

Power Situation in the Stuart Island area

It is difficult to accurately determine exactly how much diesel fuel is used at Stuart Island and how much money is spent on diesel fuel for power generation. However, estimates can be prepared using confidential information provided by some resorts. At this time, precise information about the amount of power used is impossible to gather, as the gensets at the resorts run at different outputs depending on the number of guests and the weather conditions. Estimates can be prepared, though, using specifications from genset manufacturers to calculate estimated power generated from the amount of fuel used. The actual power usage, therefore, is a source of uncertainty for this study.

Information was received from 7 of the 10 resorts, representing about 90 % of the total generating capacity in the Stuart Island area. Total estimated generation capacity, total cost of fuel and total amount of diesel fuel used were extrapolated from this information to include all resorts, using resorts of similar size to assemble the information. For full details on the calculations, refer to the Financial Analysis – Diesel Power section.

Cost of Diesel Generation

Based on the data collected, it is estimated that in 2006:

- The cost of diesel fuel for power generation in the Stuart Island area was $ 1,250,000
- About 1,450,000 litres of diesel fuel was used to generate electrical power
- Total generation capacity was approximately 1,950 KW
- Effective generation capacity was about 1,300 KW in summer and 600 KW in winter
- Total power generated was about 4,640,000 KW hours
- 529 KW average power produced in the Stuart island area in 2006.
- The cost of the electricity currently being produced by the diesel generators at Stuart Island is about 29 cents per KWh.

Diesel fuel, along with Propane and Gasoline, is delivered to the resorts and residents of the Stuart Island area on a monthly basis by Inlet Transportation out of Campbell River. This scheduled barge service also brings other supplies to communities along the BC coast, from Vancouver to Prince Rupert.

Non-monetary costs

There are a number of non-monetary costs to the diesel power generation in the Stuart Island area. The most obvious one is the air pollution created by the emissions from the diesel generators' exhaust gases. Diesel exhaust contains a number of different gases: carbon monoxide, oxides of nitrogen, carbon dioxide and water vapour are the main constituents. Other components of diesel exhaust are actually the ones people notice the most – unburnt fuel from incomplete combustion and sulphur compounds from fuel impurities cause most of the odour, and soot particles (carbon) cause most of the visible smoke.

Lately, the world's attention has been focused on greenhouse gases and the effect they are having on global warming. Carbon dioxide (CO2) has been identified as one of the major culprits causing global warming, with atmospheric CO2 levels having risen sharply over the last century. Exactly how much of that CO2 is from human activity is a matter of vigorous debate that will not be discussed here, but there is no doubt that limiting emissions and pollutants makes sense. According to the US Environmental Protection Agency (EPA), the amount of CO2 emissions from a gallon of diesel fuel is 10.1 kg,[103] which converts to 2.67 kg / litre. So the 1,450,000 litres of diesel fuel used for power generation in the Stuart Island area in 2006 contributed about 3,871,500 kg of CO2 emissions.

Another non-monetary effect of diesel power generation is noise pollution. It is ironic that to visit a place as quiet as Stuart Island, people have to listen to the background noise of a genset.

The risk of a diesel spill during transportation or storage is an additional non-monetary aspect of diesel power generation. A serious spill could cause severe environmental damage to the waters of Cardero Channel.

A clean power solution for the Stuart Island area would reduce or eliminate the negative environment effects described above and improve the quality of life for residents and visitors. And it would also create an unprecedented opportunity for promotion and marketing of the resorts in the Stuart Island area. Clean power would enhance the area's reputation as a location for ecotourism and provide an additional impetus to the growth of ecotourism in the area.

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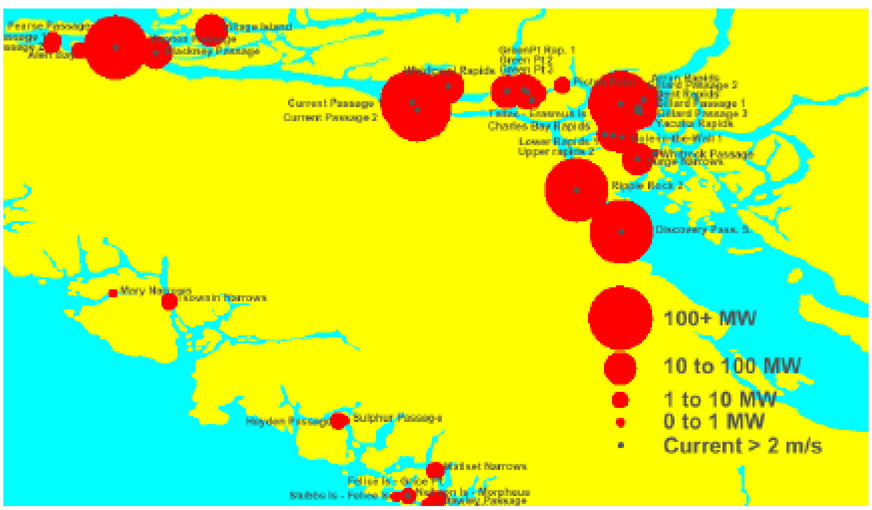
[103] US Environmental Protection Agency, "Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel," EPA website, http://www.epa.gov/otaq/climate/420f05001.htm accessed January 2007

Location Criteria - general

The most important consideration for a tidal power generation site is a suitable tidal power resource. Triton Consultants has identified 89 locations on the BC coast with tidal resources of 1MW or more. The diagram below shows a segment of the BC coast, centred on mid Vancouver Island, including Discovery Passage and Seymour Narrows. The Stuart Island area is in the top right area, with several overlapping red dots indicating the presence of large tidal resources.

Figure 8: Potential Sites – Central Vancouver Island



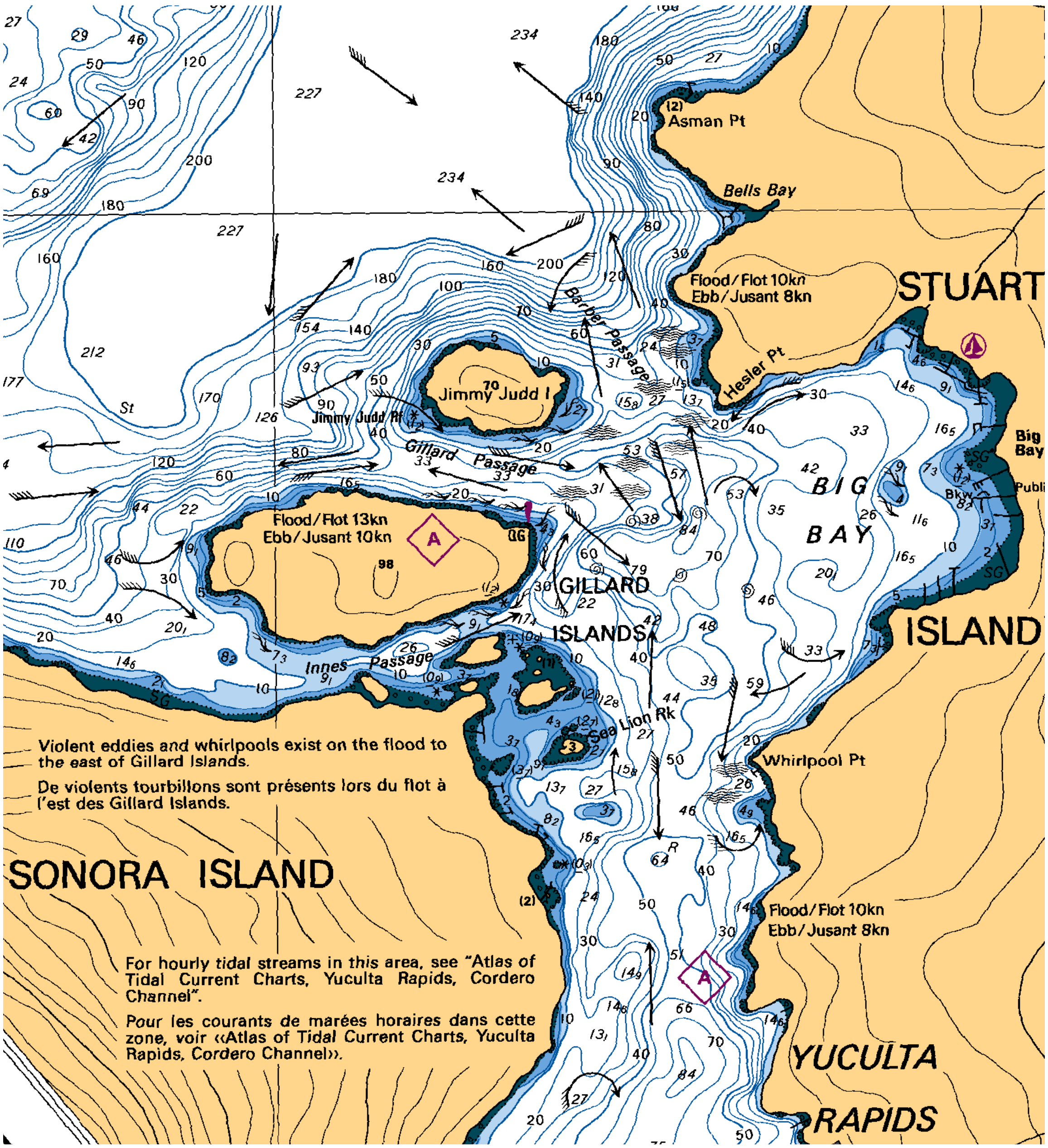
[104]

As previously mentioned, flow rate is a vitally important aspect of tidal power generation – the more current flow, the better. Peak current flows in Cardero Channel near Stuart Island are in the 8 to 14 knot range (4 to 7 m/s) so the channels and rapids certainly have enough current velocity for tidal power generation, in light of Triton Consultants' threshold of 2 m/s. See below for a marine chart of the area showing the tidal currents.

A third consideration for site selection is proximity to the grid, or in the case of an off-grid application, is proximity to the community. The major resorts in the area are centred around Big Bay, on the west side of Stuart Island, and immediately across the channel on Sonora Island. Proximity to four potential tidal power sites is very close, with Big Bay and Sonora Resort virtually adjacent to the resources on opposite sides of the channel.

[104] Triton Consultants, Green Energy Study for British Columbia. p. 19

Water depth requirement is dictated by two factors, the size of the proposed device(s) and the marine traffic. Marine traffic is frequent through the passages of Cardero Channel, but the vessels are not particularly large or with very deep drafts. EPRI studies mentioned a requirement for a minimum of 5 metres clearance between the low water level and the turbine. There are a number of sites in the Stuart Island area that can easily meet this requirement. The marine traffic, however, would eliminate surface piercing devices from use in the area.



[105]

[105] Canadian Hydrographic Service, chart 3543

Appendix I

Location Criteria - Specific

As noted in the previous section, the waters of Cardero Channel around Stuart Island are tremendous tidal power resources. Of particular interest are Gillard Passage (referred to as Gillard 1 by Triton), Barber Passage (Gillard 2), Innes Passage (Gillard 3) and Yaculta Rapids. Refer to the chart on the previous page for locations. These resources, along with the off-grid situation, are the reason the Stuart island area was chosen for this study.

The four locations mentioned were considered for this study; they represent a cross section of tidal resources on the BC coast. Yaculta Rapids is a deep, relatively narrow channel with powerful currents that make it a sizable tidal power resource. Gillard and Barber Passages are smaller, moderately deep channels with higher current velocities. Innes Passage is much smaller and shallower than the others, still with significant current flows and the advantage of no commercial marine traffic.

Data excerpted from Triton Consultants report[106]

Name	Mean maximum depth average current speed	Width	Average Depth	Mean Potential Power
Yaculta Rapids	4.12 m/s	539 m	28 m	78.7 MW
Gillard Passage (Gillard 1)	4.74 m/s	237 m	16 m	43.3 MW
Barber Passage (Gillard 2)	3.71 m/s	393 m	18 m	23.2 MW
Innes Passage (Gillard 3)	3.71 m/s	92 m	5 m	3.2 MW

The average depth figures shown in the table can be misleading; deeper areas exist in the centre of the channel and/or near the channel as can be seen on the chart. Site selection would have to be determined according to the overall height above the seabed for a given device and the anticipated clearance for marine traffic.

[106] Triton Consultants, Green Energy Study for British Columbia p. 21

Seabed conditions are unknown, and this represents considerable uncertainty. The powerful tidal currents in the passages and rapids of Cardero Channel mean that tremendous forces will be brought to bear on any power generation device that might be installed there. The anchoring method will be critical to the success of the endeavor. Seabed conditions will determine both the anchoring method and the manner in which the device will be anchored to the bottom of the channel. For example, if the seabed is granite (as is likely) then holes for anchors will have to be drilled from the surface. What are the limitations and availability of the equipment necessary to hold position accurately and drill holes in solid rock in conditions where the tidal currents are not just strong, but also constantly changing in velocity? At present, there are no answers available to those questions. The recent installation at Race Rocks has shown that a tidal turbine can be successfully installed in BC waters. However, this installation does not shed much light on installation of a turbine in the waters near Stuart Island, where the current velocities are much greater and the channels are narrow.

The rationale for choosing a location from the four channels near Stuart Island must include an examination of marine traffic in the area. It makes sense that Yaculta Rapids and the widest of the channels between Stuart and Sonora Islands (Barber Passage) would not be able to be blocked for a few weeks while a turbine or turbines were installed. A full size turbine is too large for Innes Passage, so Gillard Passage is the best choice for an investigation into the possibility of installing tidal power generation device(s) at Stuart Island. A study would have to be made of the extent and nature of marine traffic through Gillard Passage and the effect that a turbine installation closure would have.

Environmental considerations are an important aspect of site selection, and a full review would need to be done as part of the site selection process. At this time, it is unknown what the effect on the ecosystem would be if a portion of the tidal energy were removed. In its feasibility studies, EPRI has suggested that a maximum of 15% of the total tidal energy from an area is appropriate.[107] A possible effect is a slowing of the tidal flow through the channel, resulting in increased sedimentation. A large change in the speed of volume of water through the channel could cause a correspondingly large change in the channel's ecosystem.

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[107] EPRI, "Instream Tidal Power in North America – Environmental and Permitting Issues," http://www.epri.com/oceanenergy/attachments/streamenergy/reports/007_Env_and_Reg_Issues_Report_060906.pdf accessed February 2007

Appendix I

A wide variety of fish and marine mammals live in or pass through the waters of Cardero Channel. No studies have yet been completed on the effects that tidal turbines have on marine life. Verdant Power, as part of its project in the East River, is conducting a comprehensive study using an array of sensors to determine the effect on fish. The study has not been completed and no data is yet available, but preliminary indications are that fish not adversely affected. In fact, fish and diving birds (cormorants) have been observed simply swimming around the turbine. [108]

Cardero Channel is home to many different marine birds and mammals and there is no available evidence to suggest how a tidal power turbine might affect them. There is a large population of resident seals and sea lions; dolphins and orcas transit the area. Diving birds such as cormorants, grebes, loons and ducks frequent the area. Until more turbines are in the water, information cannot be gathered on how marine birds and mammals might react to a tidal power installation.

[108] Trey Taylor, Verdant Power, telephone interview with author, February 13, 2007

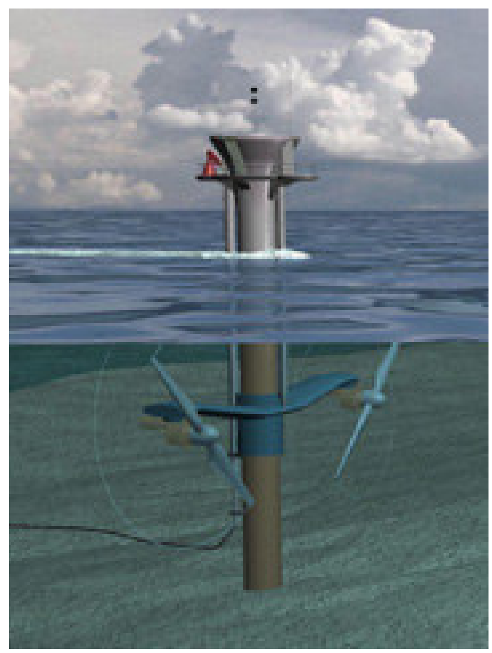
Appendix I

Technology

Tidal power generation technology is in its infancy. There are many developers of tidal power generation equipment and a myriad of designs, limited only by the designers' imaginations. The devices that are progressing fastest toward commercialization are turbines. Even within the confines of the turbine group, though, there are many different devices that are being developed. The following is a review of some of the leading technologies. Images in this section are from company websites.

Marine Current Turbines

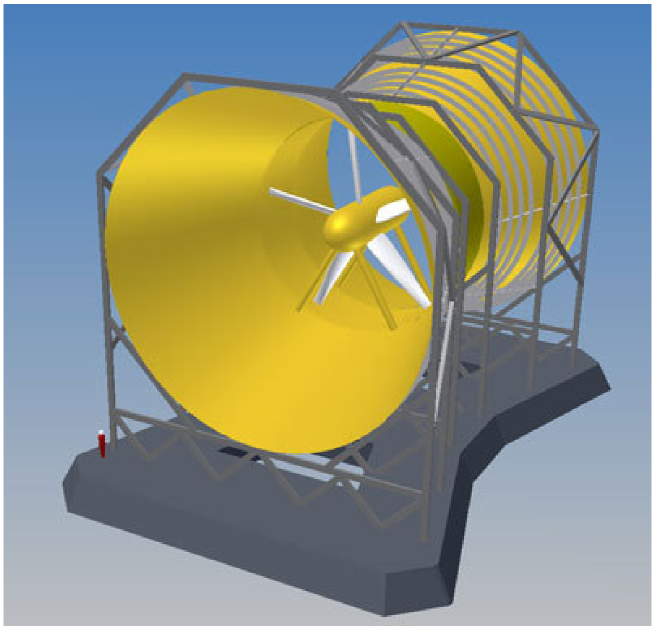
Until very recently, Marine Current Turbines (MCT) held the distinction of being the only company that had produced and installed a near-commercial scale tidal power turbine. The Seaflow project was installed in May 2004 off the coast of Lynmouth, Devon. This 300 KW device has worked very well over the last three years – well enough for MCT to move forward to Seagen, a commercial size unit (1.2 MW) that will be installed near Strangford Narrows in 2007. The Seagen device is completed and sitting on a dock waiting for installation. MCT uses an open axial flow rotor because "it is the most efficient and cost-effective form of kinetic energy converter. If this sounds like a bold statement it should be noted that every conceivable form of rotor, open and shrouded, has been tried for wind turbines and the technology has converged on the most cost-effective technical solution, namely a tubular tower carrying a nacelle with an upwind pitch-regulated axial flow rotor. Although water kinetic energy conversion introduces some different design issues, the basic physical principles are the same as for wind turbines." [109]



[109] Peter Fraenkel, "Marine Current Turbines tidal turbine developments: the development of an entirely new energy conversion system ," paper presented at World Maritime Technology Conference 2006, London, UK, March 6 – 10, 2006

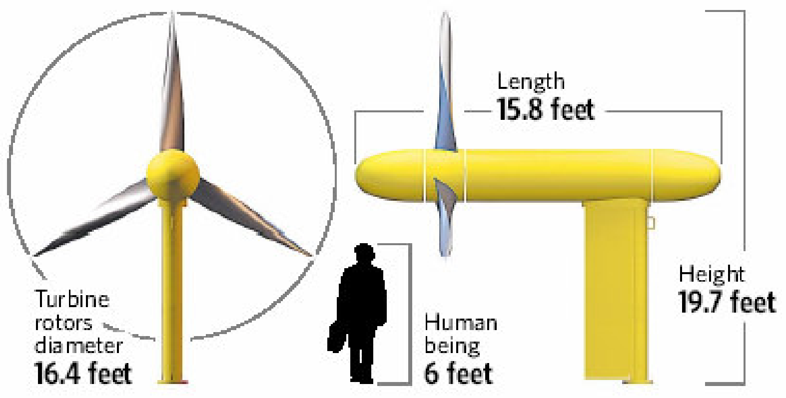
Lunar Energy

Lunar Energy is a UK based tidal energy device developer. Lunar's design features a bidirectional concentrator cone structure with the turbine and power conversion components contained in a removable centre mounted cassette. The picture at right gives a good sense of the size of tidal turbines – note the human figure in the bottom left corner. In 2005, Lunar completed proof of concept testing in the laboratory and is currently in the process of building a full scale 1 MW device that will be installed at the EMEC facility at Orkney in late 2007 or early 2008. When completed, this will be only the second full size, commercial scale tidal energy generator in the world. Lunar Energy is a participant in the BC tidal energy industry as it holds an Investigative Use Permit for an area of Discovery Passage, and forecasts activity at that site near Seymour Narrows to begin in late 2009.



Verdant Power

Verdant Power is a US based company that has developed and tested several tidal stream turbine devices. The company settled on a design that uses a three bladed horizontal axis axial flow turbine.[110] In December 2006 the first turbine was installed in New York's East River. The picture at right shows the nature and scale of the device.[111] It is supplying power to an area of Roosevelt Island now.



[110] Verdant Power, "Background of Verdant Power," http://www.verdantpower.com/aboutus/history.html, accessed January 2007

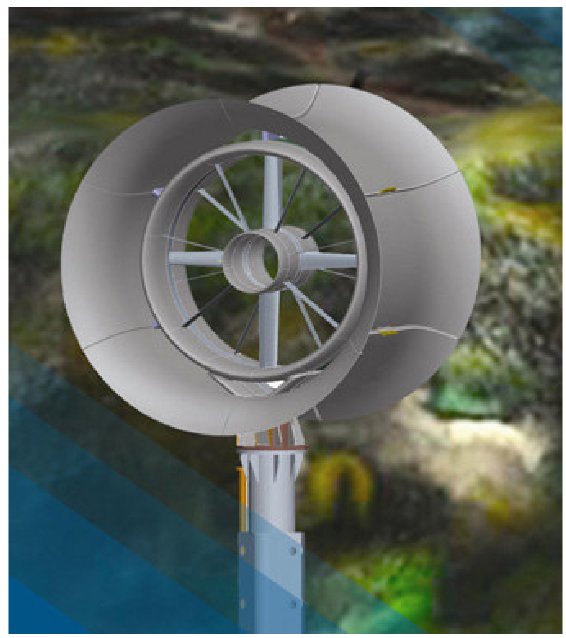
[111] "Planning the next wave," *Newsday* (May 30, 2006): A26 Courtesy of Trey Taylor

Appendix I

If initial success is confirmed a further five turbines will be installed. These turbines are rated at 35 KW, but plans are to scale up the device to units having a capacity up to 250 KW and eventually up to 1 MW. Of particular note is the study Verdant Power is doing with regard to the impact tidal energy turbines have on fish. Verdant Power has spent two million dollars to install an array of sensors to capture evidence of safe fish passage at the East River site. Preliminary observations indicate that fish are swimming around the turbine.[112]

Clean Current

Clean Current's tidal turbine generator is a bi-directional ducted horizontal axis turbine with a direct drive variable speed permanent magnet generator. "This proprietary design delivers better than 50 per cent water-to-wire efficiency, a significant improvement over competing free stream tidal energy technologies. Operability is enhanced by a simple design that has one moving part - the rotor assembly that contains the permanent magnets. There is no drive shaft and no gearbox. The turbine generator has a design life of 10 years (major overhaul every 10 years) and a service life of 25-30 years." [113]



Clean Current entered into a demonstration project with Pearson College at Race Rocks, BC with major funding provided by Encana.[114] A one quarter scale, 65 KW turbine was installed on September 27, 2006 and is now producing power for the lighthouse, weather station and other infrastructure on the island. As this power plant is not connected to the electrical grid, banks of batteries are used to store electricity for times when the tidal stream generator is not producing power, such as slack tide.[115]

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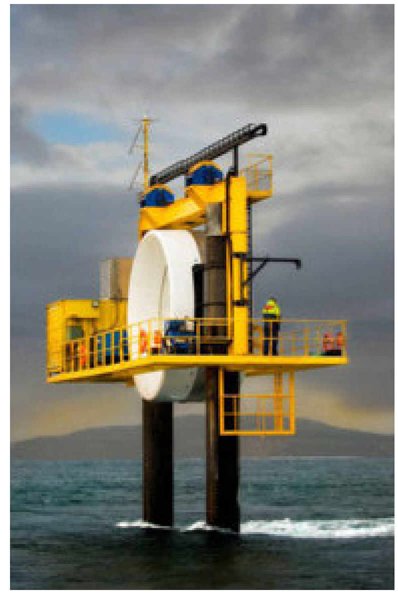
[112] Trey Taylor, Verdant Power, email correspondence with author, January 29, 2007
[113] Natural Resources Canada, "Clean Current Tidal Power Demonstration Project at Race Rocks, BC," Natural Resources Canada website, http://www.cleanenergy.gc.ca/international/project_e.asp?item=61, accessed January 2007
[114] Encana, "Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks," Encana website, http://www.encana.com/responsibility/eif/fundedprojects/P1162484703969.html, accessed January 2007
[115]Russell Strothers, Clean Current, telephone interview with author, January 8, 2007

OpenHydro

OpenHydro is a tidal energy company based in Ireland that uses a unique design called the Open-Centre Turbine. The Open-Centre Turbine, with just one moving part and no seals, is a self-contained rotor with a solid state permanent magnet generator encapsulated within the outer rim, minimising maintenance requirements. Open-Centre Technology is unique and covered by a suite of worldwide patents.[116] In January 2007 was the first developer to install a tidal turbine at the EMEC facility at Orkney. As can be seen at right, the test unit is mounted between two monopiles allowing it to be raised and lowered easily for testing. Commercial installations will be deployed on the seabed using a gravity base, out of sight beneath the surface of the sea.[117]



In January 2007, OpenHydro was selected by Nova Scotia Power to be the provider of the tidal stream power generation device at a new demonstration project in the Bay of Fundy. OpenHydro's technology was chosen because of its proven experience, simple robust design and low impact on the environment. If the demonstration project is successful, Nova Scotia Power plans to develop the largest tidal stream power generation facility in the world.[118]

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[116] OpenHydro, "technology," OpenHydro website, http://www.openhydro.com/technology.html , accessed January 2007

[117] OpenHydro, "technology: installation," OpenHydro website, http://www.openhydro.com/techInstall.html, accessed January 2007

[118] "Nova Scotia Power Takes Another Step Towards Tidal Power Pilot Project," Nova Scotia Power press release (Halifax, NS, January 12, 2007). From Nova Scotia Power website, http://www.nspower.ca/about_nspi/in_the_news/2007/01122007.shtml, accessed January 2007

New Energy

New Energy is a Calgary based developer of tidal energy technology. New Energy's EnCurrent technology builds on work carried out by the National Research Council on a vertical axis hydro turbine. Based on the design of the Darrieus wind turbine, commonly referred to as an egg-beater windmill due to the shape of its blades, the EnCurrent turbine is able to extract 40% to 45% of the energy in the water moving through it. One of the unique properties of the Darrieus Turbine design is that it is able to capture the energy from the water irrespective of the direction of the current. This property enables the EnCurrent turbine to harness the energy contained in both flood and ebb tides.[119] The EnCurrent design allows for various configurations of the turbine including overhung, beam style, center shaft or end plate supported, fixed blade or variable pitch.[120] New Energy has working devices installed in two small scale outflow demonstration projects in Alberta. New Energy is involved in the Canoe Pass demonstration project so it is making an active contribution to the development of the BC tidal power industry.

Underwater Electric Kite

Underwater Electric Kite (UEK) is an American company that is doing development and testing of tidal stream turbines. UEK uses two counter rotating turbines and a patented ducted turbine design that is enhanced by a flared skirt that creates a low pressure zone directly behind the turbine. The company claims this design has the potential to achieve overall efficiency of up to 57%. The company has worked with the University of Manitoba to study the performance of the turbine and is planning to supply turbines for an installation in Africa. A proposed project at Indian River Inlet in Delaware is at the permitting stage.[121]

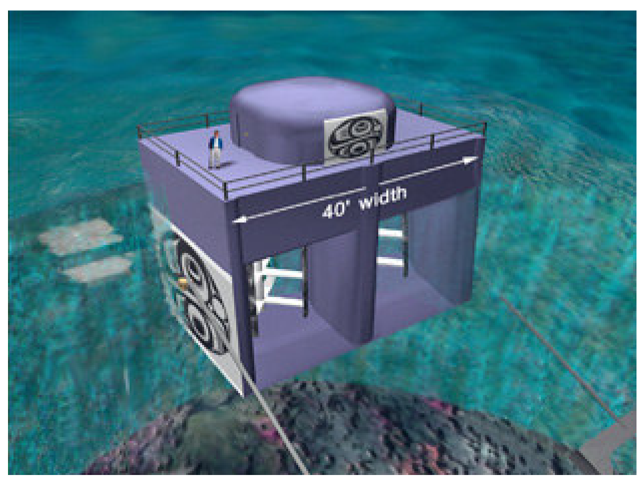
[119] New Energy Corporation, "Technology: Overview," New Energy Corporation website, http://www.newenergycorp.ca/technology_overview.htm, accessed January 2007
[120] New Energy Corporation, "Technology: How It Works," New Energy Corporation website, http://www.newenergycorp.ca/technology_how_it_works.htm, accessed January 2007
[121] Philippe Vauthier, "Kite soars to new depths," *International Water Power and Dam Construction*, March 16, 2006, http://www.waterpowermagazine.com/storyprint.asp?sc=2034904, accessed January 2007

Gorlov Turbine

The rights to the Gorlov turbine are held by GCK Technologies, a US company. The Gorlov Helical Turbine was specifically designed for hydroelectric applications in free flowing low head water courses. Some of the characteristics of the Gorlov turbine are that it rotates in the same direction, independent of water flow direction and can be assembled vertically, horizontally or in any other cross-flow combination using a common shaft and generator for an array of multiple turbines. The modular design offers great flexibility, which can simplify and reduce the construction, expansion and maintenance costs of a power generating facility.[122] A proposal for a floating power plant at Ulmoldok, Korea uses the Gorlov turbine.

Blue Energy

Blue Energy is a Canadian company based in Vancouver. The key component of the Blue Energy Power System is the Davis Hydro Turbine, which is based on the undeveloped 1927 patent on a vertical axis windmill by French inventor Georges Darrieus. Blue Energy's predecessor, Nova Energy Ltd., successfully built and field-tested two experimental test units and three prototype Davis Hydro Turbines through a $1.3 million, 10-year collaborative R&D program with the National Research Council of Canada.[123] The Blue Energy Ocean Turbine acts as a highly efficient underwater vertical-axis windmill.



Four fixed hydrofoil blades of the Blue Energy Ocean Turbine are connected to a rotor that drives an integrated gearbox and electrical generator assembly. The turbine is mounted in a

[122] GCK Technology, “The Gorlov Helical Turbine,” GCK Technology website, http://www.gcktechnology.com/GCK/pg2.html, accessed January 2007
[123] Blue Energy Canada, “Blue Energy Development,” Blue Energy website, http://www.bluenergy.com/davisTurbinesptypes.html, accessed January 2007

durable concrete marine caisson which anchors the unit to the ocean floor, directs flow through the turbine further concentrating the resource supporting the coupler, gearbox, and generator above it.[124]

Water Wall Turbine

Water Wall Turbine is a tidal power turbine developer based in British Columbia. Little information is available about the device, other than it is a horizontal axis turbine. Water Wall Turbine claims that its simple design has over double the energy production per square metre than any of the competing renewable energy generation technologies.[125]

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[124] Blue Energy Canada, "Blue Energy Technology," Blue Energy website, http://www.bluenergy.com/technology.html, accessed January 2007

[125] Marek Sredzki, Water Wall Turbines, email correspondence with author, November 25, 2006.

Device & Installation Details

There are many aspects to a tidal stream power generation deployment, and the device is just one of them. All of these factors must be considered together when determining the suitability for a particular site. The site itself is the most important consideration – the site characteristics will determine what type of device may be considered and what size limitations there may be. Because all tidal energy conversion devices are governed by the same principles of physics, namely area and current velocity, for the same site conditions and rated power the physical size of the units will be similar.

Triton Consultants provide the following formula for calculating the instantaneous power $P_{extractable}$ for a turbine installation[126]

$$P_{extractable} = N_{units}\eta\frac{1}{2}\rho A_{turbine}U^3$$

Where *N* $_{units}$ is the number of installed units, *n* is the turbine/mechanical/electrical efficiency, *p* is the density of water (kg/m^3), *A* $_{turbine}$ is the turbine rotor area (m^2) and *U* is the instantaneous current velocity (m/s). It can be seen that power is proportional to the area swept by the turbine, so at a given site, devices that present a similar area will have similar power potential. The difference between devices, then, is the efficiency *n* with which the device extracts the power from the water flowing through it – this is the battleground for the device developers.

A very significant observation from the formula is the importance of current velocity to power. Because velocity is cubed in the formula, higher velocities confer an ever-greater power advantage, thus the importance of site selection.

Other factors that affect the logistics of a tidal power installation are the subsea cabling, as well as on shore transforming & power conditioning, and on-shore electricity distribution or interconnection to existing distribution.

The installation itself is a source of considerable variation. The seabed composition is an important factor in the method chosen to support or anchor the power generation device.

[126] Triton Consultants, Green Energy Study for British Columbia.

However, this is not the only consideration. The availability of equipment suitable for the installation method chosen may play a major role in determining cost or feasibility of the installation. For example, equipment may have to be brought in from far away parts of the world. The nature of the site conditions, such as current speed, narrowness of channel and marine traffic plays an important part in the determination of the cost, time and practicability of the installation.

Further discussion on costs associated with devices and installation can be found in the Financial Analysis section of this paper.

Appendix I

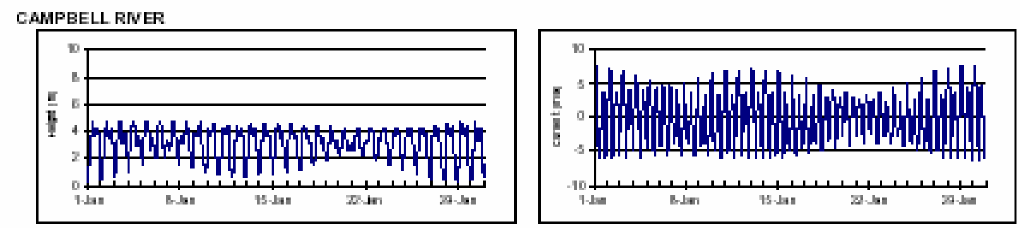
Storage

When this study began, no consideration was given to energy storage. However, as the investigation progressed, the importance of energy storage in off-grid installations became more and more apparent. This is true not just of tidal power generation, but any power being generated in an off-grid situation. Energy storage in tidal power applications, because of the continuously fluctuating power output, is a critical factor and very challenging.

A fundamental characteristic of electrical power is that the power generated must be balanced by the electrical load (power requirement of the system). This can be done by increasing the load or decreasing the power being generated. In a large system, individual increases or decreases in load or power generated can cancel one another out, resulting in a dampening effect. In the case of the North American power grid, computers in control centres strategically located across the continent monitor the grid and make the adjustments necessary to keep the grid stable.

In an off-grid system, balancing of the generation and the load is more immediate. If generated power is not being used by the system, it must be either dumped or stored. Dumped power, as the term suggests, is often wasted power. Power can be dumped into a load bank that will convert the power to heat in a manner similar to an electric baseboard heater. In some cases, this heat may be put to good use, but in other cases that heat will just be allowed to dissipate. Alternatively, generated power can be stored – for example, by charging a bank of batteries or by using excess power to do work.

Off-grid tidal power, by its nature, necessitates an efficient method of power storage. The power from a tidal generator will go to zero from two to four times a day, at slack tide. Obviously, at those times no power will be available to supply electricity to anything that draws power from the system. Conversely, peak current velocity at other times of the day may generate power far in excess of demand. So an efficient storage system that can store power at times of excess production for use during the times of low or zero production is necessary in off-grid applications. The following graphs from Triton Consultants illustrate how the height of the tide (left) and tidal current (right) fluctuate throughout a representative month. As noted in the previous section, current velocity has a major impact on power generated by a tidal stream turbine. Hence, it can be concluded that the fluctuations in current velocity shown in the graph below represent power fluctuations.



127

High school physics taught the Law of Conservation of Energy, which states that energy cannot be created or destroyed, but can change its form. Energy storage in an off-grid tidal application, put simply, is changing the form of the energy from kinetic energy to potential energy. Pumping water to a higher elevation is the most straightforward example – kinetic energy from a tidal stream is used to pump water up to a higher elevation where it is stored as potential energy. Of course, it's not quite that simple; in this example, the tidal stream turbine converts kinetic energy from the water flow to mechanical energy, the generator converts the mechanical energy to electrical energy, which is used to do work to store the energy, such as powering a pump to move the water up to the higher elevation storage reservoir where it is then in the form of potential energy.

The most common type of energy storage is with batteries, a method everyone is familiar with. For example, a large bank of forklift batteries is being used at Race Rocks for energy storage. The batteries are large and heavy, making them impractical for full scale installations. Future advances in battery technology might make this type of energy storage more viable for large installations.

In the search for energy storage methods that are more efficient and less expensive, a few other methods have been proposed for tidal power applications, as follows:

- Ultracapacitors – Large capacitors might prove to be a viable method of energy storage, but at present this technology is not available off the shelf. Capacitors have the advantage of accepting a charge very quickly and are capable of being charged and discharged thousands of times without losing capacity. Advances in technology may make ultracapacitors a possibility in the future.

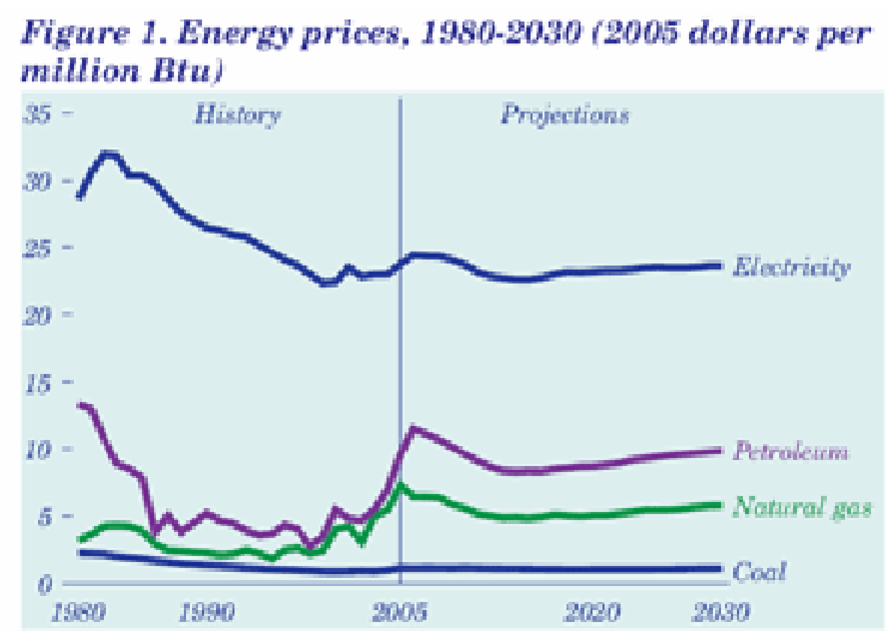
[127] Ibid., p. 13.

- Water pumping – pumping water to a higher elevation is a way to store potential energy. The water stored in a reservoir at the higher elevation can be allowed to return to the base elevation under controlled circumstances, changing the form of the energy from potential to kinetic so as to turn a turbine and generate secondary power.
- Compressed air – excess power can be used to increase air pressure in a vessel (potential energy) then released in a controlled manner when required to turn a turbine.
- Hydrogen – excess power could be used to create hydrogen, which could then be used in a fuel cell to provide power to produce electricity. This system has good future potential, but the efficiency of the system is not yet good enough for it to be viable at present. In BC there is potential for synergy between the tidal energy industry and the fuel cell industry.
- Fresh water – excess power could be used to produce fresh water, by distillation or by reverse osmosis. This would not store energy, but instead would do work to use excess energy to produce another unrelated product (fresh water) to be stored for use when required. There is an opportunity for the development of a package solution for off grid remote communities encompassing power generation and fresh water production.

Appendix I

Financial Analysis - Diesel power calculations

The cost of diesel power generation and future projections can be estimated with a reasonable level of certainty. While the past summer's price spike for petroleum products was an excellent example of the dramatic effect uncertainty can have in the marketplace, the price of oil over the long term is predicted to be quite stable. The US Energy Information Agency published its Annual Energy Outlook 2007 with projections to 2030, which predicts crude oil prices will decline slowly to just below US $50 a barrel in 2014, followed by a gradual rise to US $59 a barrel by 2030 (all figures in 2005 dollars). This is a result of new conventional and unconventional oil supply coming on stream and a prediction that OPEC will adjust production to keep oil prices in the US $50 to $60 range over the next 25 years.[128]



[129]

As a correlation, the World Bank commodity forecast indicates that the price of crude oil will decline though the next several years and in fact is predicting the average price of a barrel of oil will fall to US $35 by 2015.[130]

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[128] Energy Information Administration (EIA), "Annual Energy Outlook 2007 (Early Release)," EIA website, http://www.eia.doe.gov/oiaf/aeo/growth.html, accessed January 2007
[129] Ibid.
[130] World Bank, "Commodity Forecast (Nominal Prices)," World Bank website, http://web.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTDECPROSPECTS/EXTGBLPROSPECTSAPRIL/0,,contentMDK:20423496~menuPK:902607~pagePK:2470434~piPK:2470429~theSitePK:659149,00.html, accessed February 2007

It is reasonable to expect that the price of crude oil derivatives, such as diesel fuel, would roughly track the price of crude oil. Hence, it is reasonable to predict that the supply and price of diesel fuel to the Stuart Island area will be more or less stable over the next ten years or more. Currently, the price for diesel fuel delivered to the Stuart Island area is between 80 and 90 cents per litre, depending on the volume used by each customer.

Based on confidential information received from resort operators, estimates of total diesel power generated in the Stuart Island area can be made. Information on diesel fuels costs from seven resorts, representing about 90% of the area's total power usage, was obtained in the investigation. An estimate of power consumed by the remaining smaller resorts was made by comparison with similar sized operations. This estimate was compared to total fuel delivery approximations that were obtained from the company that delivers diesel fuel to the Stuart Island area. In this way, an estimate of the total amount of diesel fuel used in the Stuart Island area in 2006 can be calculated by two different methods.

1 Calculation based on cost of diesel fuel
$ 1,250,000 at about 85 cents per litre = 1,470,588 litres

2 Calculation based on deliveries

Summer season	140,000 litres X 5 months =	700,000 litres
Winter season	105,000 litres X 7 months =	735,000 litres
Total		1,435,000 litres

Total fuel used in 2006, averaged and rounded **1,450,000 litres**

Correlation between these two totals is good and suggests a variation of only 3%. But since some of the raw data was based on recollections or estimates, it is reasonable to assume an accuracy of +/- 10%.

Power Produced by Diesel Generators

A wide range of gensets are used in the Stuart Island area, each with its own ratio of fuel consumption to power. Some are old, some new. Some are big, some are small. Some are fuel efficient and properly tuned to maximize power output, other less so. Fuel consumption varies with the load on the genset. For the purposes of this estimate, a 50% load factor was used.

Some examples of genset specs follow:

• Cummins 45 KW	3.21 KWh / litre
• Caterpillar 36 KW	3.10 KWh / litre
• SDMO John Deere 55 KW	2.61 KWh / litre
• Cummins 113 KW	2.82 KWh / litre
• Cat 114 KW	2.46 KWh / litre
• SDMO John Deere 91KW	3.50 KWh / litre
• Cummins 250 KW	3.67 KWh / litre
• SDMO Volvo 409 KW	3.76 KWh / litre

Because there is so much variation in the power production of the various gensets, and because of the inherent uncertainty with regard to the load factors and characteristics of the gensets in use, for this estimate a somewhat arbitrary figure of 3.2 KWh / litre will be used.

1,450,000 litres X 3.2 KWh / litre = **4,640,000 KWh** in 2006

Divided by 8760 hours / year = **529 KW average** power produced in the Stuart island area in 2006.

There are other costs that contribute to the total cost of diesel generation, such as the cost of financing and the cost of maintenance. Based on the confidential information obtained from resorts in the course of the investigation the following can be said:

Total generating capacity – just under 2 MW
Effective generating capacity (because some generators are backups) – 1.3 MW
Generator life expectancy - 20 years with one rebuild
Annual maintenance per resort – between $2,000 and $10,000
Cost of a new 100 KW genset - $30,000 everything included

Appendix I

Estimate for all diesel generation in the Stuart Island area

- value existing gensets at 2/3 the replacement cost $ 400,000
- amortized at 5% per year $ 20,000
- maintenance $ 50,000
- financing at 7.5% $ 30,000

$ 100,000

The cost of the electricity currently being produced by the diesel generators at Stuart Island is

Fuel	$ 1,250,000 / = 26.94 cents per KWh.
Generation costs	$ 100,000
	$ 1,350,000

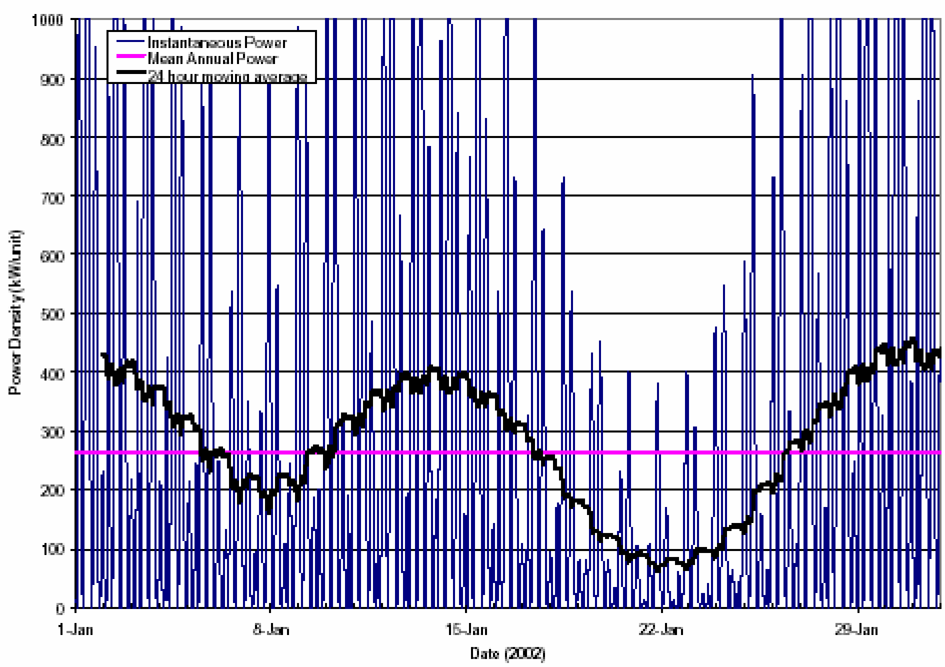
Divided by 4,640,000 KWh

= **29.1 cents per KWh**

Appendix I

Financial Analysis - Tidal power cost calculations

As noted in Triton Consultants reports and in EPRI reports, the average power produced by a tidal power generator on an annual basis is far lower than the rated capacity. According to Betz law, a theoretical maximum of 59% of the kinetic energy in a flow can be converted to mechanical energy using a turbine. Once ecological considerations, power conversion efficiencies and other factors are taken into consideration, only a fraction of the available tidal stream energy resource can be extracted at any site.[131] "In the case of tidal current energy extraction, the resource potential goes to zero two to four times per day and reaches its peak annual value only a few hours per year. For this reason, it is much more informative to speak of mean power in the context of tidal power, as such a definition integrates the effect of the highly variable daily and annual variation of the resource." [132] Triton calculated this factor to be about 26%, and EPRI's Knik Arm study calculated 29%. The following graph from Triton's 2002 Green Energy report clearly illustrates the extreme variability of the output of a tidal power generator.



[133]

So to generate an average of about 569 KW (per the diesel calculation) two 1 MW tidal stream generators would be required.

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[131] Cornett, *Inventory of Canada's Marine Renewable Energy Resources,* p. 46
[132] Triton Consultants Green Energy Study for British Columbia.
[133] Ibid.

Based on confidential information received from equipment developers, compared with EPRI feasibility studies, a very rough estimate of the cost of a tidal power installation can be made. Information obtained in the investigation is summarized below (all figures in US Dollars). This cost comparison includes only available information on the cost of the turbine, support structure and installation and does not include costs specific to a remote, off-grid location.

Company or site	Size	Equipment	Installation	Total	$ per KW
EPRI Knik Arm[134]	760 KW	1,720,670	1,442,000	3,162,670	4161
EPRI Minas Passage[135]	1.1 MW	2,178,000	1,442,000	3,620,000	3258
Company A	1 MW	3,733,000	860,000	4,593,000	4,593
Company B					3,000 *
Company C	500 KW	1,425,000	1,440,000	2,865,000	5,730

* Estimate for a commercial size system

It can be seen that there is a considerable difference in the equipment and installation costs for the feasibility studies or project estimates shown above. None of the locations are as remote as the Stuart Island area and none are in channels where the tidal currents are as strong as at Stuart Island. There are many other costs involved in a tidal power turbine installation at Stuart Island; some can be reasonably estimated – and some cannot. In several cases it is simply not possible to estimate cost without further detailed engineering or hydrographic studies.

Following are additional costs associated with a tidal power facility at Stuart Island, further discussion can be found in the Financial Analysis - Uncertainty section of this paper:

- Approvals and permits are expected to be in the range of $400,000 to $500,000 comparable to the Canoe Pass site,[136] although this cannot be considered to be a certain figure.
- Financing costs are predictable at 7 - 8% per year.
- Annual maintenance costs are estimated to be approximately 4% of the installed cost for a commercial size system. [137]

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[134] EPRI, "TP-006-AK Alaska Tidal Power System Level Design," EPRI website, http://www.epri.com/oceanenergy/attachments/streamenergy/reports/006-AK_06-10-06.pdf, accessed December 2006

[135] EPRI, "TP-006-NS Nova Scotia Tidal Power System Level Design," EPRI website, http://www.epri.com/oceanenergy/attachments/streamenergy/reports/006_NS_RB_06-10-06.pdf, accessed December 2006

[136] Canoe Pass Tidal Energy Consortium, *Canoe Pass Tidal Energy Demonstration Project - Detailed Project Description*

- Storage of excess electricity when power generated exceeds demand represents a significant cost with a great deal of uncertainty. At Stuart Island, when the tidal stream is flowing rapidly, power generators will be producing at full capacity, far in excess of peak demand. Energy storage is a critical factor for an off-grid application, so this is a major uncertainty which can affect project viability.
- Installation of turbines in the deep, fast flowing waters of the passages and rapids near Stuart Island may not be possible with currently available technology. Further detailed study of the seabed would need to be conducted before the anchoring technique could be determined, and equipment sourced to suit. Installation cost cannot be estimated for this study due to these uncertainties.
- Transportation to a site as remote as Stuart Island is likely to be a very large expense which is unknown. If a jack up barge is necessary for the installation, it would have to be brought in from the Gulf of Mexico or even from the North Sea.
- Subsea cables are generally installed in trenches dug into the seabed. In the channels of Stuart Island it is possible that the scouring action of the fast flowing tidal currents has prevented the buildup of sediments that would enable the digging of trenches. However, the EPRI Environmental study states that “Coarse-grained armored bottom sediments typically occur in channels having high current velocities that preclude the deposition of fine-grained sediments.” [138] If that is the case, conventional cable trenching would be possible at Stuart Island. A study of the seabed would be required to estimate the cost of installation or anchoring of such a cable.
- On-shore interconnection costs are dependent on the system design, including the output of the turbine and the energy storage method, and can only be estimated as part of a complete system. On-shore distribution costs can be estimated at approximately $70,000 to $100,000 per kilometre for 25 kV power line in rough terrain,[139] with six to eight kilometres required for the west side of Stuart Island.
- Government participation in the project or grants may be available, but these must be applied for on an individual project basis and are considered on the specific merits of the project.

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[137] EPRI, “TP-006-AK Alaska Tidal Power System Level Design,” EPRI website, http://www.epri.com/oceanenergy/attachments/streamenergy/reports/006-AK_06-10-06.pdf, accessed December 2006

[138] EPRI, “Instream Tidal Power in North America – Environmental and Permitting Issues,” http://www.epri.com/oceanenergy/attachments/streamenergy/reports/007_Env_and_Reg_Issues_Report_060906.pdf p. 2-80, accessed February 2007

[139] Nick Hawley, BC Hydro, telephone interview by author, March 6, 2007

Appendix I

Financial Analysis - Uncertainty

At the present time, a great deal of uncertainty exists in the development and implementation of tidal stream power generation devices. Several technology developers have produced working prototypes, and some smaller scale devices up to 65 KW are in the water now and producing power. However, only one manufacturer has a proven, ocean tested device in the 300 KW range. MCT's Seaflow demonstration project has been in the water for three years and the technology has proven to be reliable. But Seaflow's surface piercing design is not suitable for the Stuart Island area with its frequent large marine traffic and narrow channels. OpenHydro's device currently under test at EMEC shows promise. Other developers' completely submerged devices could be suitable for the area, but the device development cost and time projections are uncertain.

Installation of a tidal turbine in the powerful currents near Stuart Island is another area where questions arise. The narrow, steep sided channels concentrate the power of the water and exactly how a turbine could be installed in these conditions is unknown. In addition, slack tide in the Cardero Channel is typically very short, creating additional installation challenges.

The State of Tidal Stream Power Generation Technology

As described in the Technology section, there are many developers of tidal stream power generation equipment. However, there has been only one demonstration project anywhere in the world that is actually using a device that approaches commercial size – MCT's Seaflow project off the English coast. MCT has a second generation project, Seagen, set to go into the water in 2007 which will have a capacity of 1.2 MW. Lunar Energy has plans to start testing a 1 MW device in the latter part of 2007. However, as none of these devices in the water yet, availability and performance characteristics are uncertain. One thing that is certain is that these are very large devices, with turbines or inlets between 15 and 20 metres in diameter.

All of the other device developers have been working with much smaller models, most in the range of 25 KW or less. Scaling up the device ten times or more cannot be expected to happen without challenges, and so this adds considerable uncertainty to the contemplation of a tidal power project.

Power Generation in Very Powerful Tidal Currents

According to Triton Consultants, "At some of these sites, such as Seymour Narrows, the current is too strong for a tidal current power installation using present techniques. However there is good reason to believe that advances in technology and construction techniques will make high current sites exploitable in the future."[140] The current velocities in the Stuart Island area are comparable to those at Seymour Narrows, although the magnitude of the resources is smaller. Maximum current flows at Stuart Island are up to 14 knots or almost 7 metres per second. Contrast this with mean maximum tidal current of 2.5 m/s at the Seaflow site.[141] Tidal power generation devices have not been proven in high current locations and this adds a tremendous amount of fundamental uncertainty.

Installation of Tidal Power Turbines in Very Powerful Currents

In its 2002 study, Triton Consultants has the following comment about installing tidal power devices in narrows with high current velocities: "Although these currents carry enormous quantities of energy, marine construction in such conditions would be extremely difficult and the cost and feasibility of constructing/maintaining infrastructure in these currents may be prohibitive."[142] As previously mentioned, only one tidal power turbine of significant size has been installed anywhere in the world. Much is unknown about installation of these devices in areas with moderate currents. Nothing at all is known about turbine installation in areas with high current velocities. Further, the availability or even the existence of the equipment that could do the installation is undefined and unknown.

Unknown Seabed Conditions in the Waters near Stuart Island

Little is known about the seabed in the passages and rapids of Cardero Channel near Stuart Island. A detailed study of the seabed composition and structure to determine the nature of the overburden and the rock beneath it would need to be conducted before turbine installation and subsea cable anchoring methods could be selected.

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[140] Triton Consultants, Green Energy Study for British Columbia.
[141] Fraenkel, Marine Current Turbines tidal turbine developments
[142] Triton Consultants, Green Energy Study for British Columbia.

Marine Traffic

There is frequent large marine traffic in the subject area – every week sees the transit of huge log booms through the area, some more than a thousand feet long. Towing a log boom through the narrow passages of Cardero Channel and the Yaculta Rapids requires precision timing, down to the minute.[143] An investigation would have to be conducted into the impact that an installation barge anchored in one of the passages would have on marine traffic. Innes Passage, closest to Sonora Island, has the advantage of little marine traffic, but the disadvantage of a shallow depth unsuitable for large turbines.

Debris

The amount of submerged debris of significant size, such as logs, that pass through the subject channels is unknown. A submerged log would cause catastrophic damage to a turbine and kelp suspended in the water column presents a risk of entanglement in the turbine. Further study into the amount and nature of the suspended debris is necessary. Steps that might need to be taken to protect tidal turbines are unknown.

[143] Martin Beaulieu, telephone interview with author, January 20, 2007

Appendix I

Feasibility

Determining the feasibility of a tidal power installation in the Stuart island area requires more than just looking at the financial bottom line. Consideration must also be given to the environmental and social aspects of such an important project. This is the Triple Bottom Line. After thorough investigation, and taking into account the aspects of the triple bottom line and other considerations, it has been determined that the installation of a tidal power generation plant at Stuart Island to replace the existing diesel gensets is not feasible at this time due to an excessive amount of uncertainty. A discussion of the elements of the triple bottom line plus aspects of the state of the technology follows.

Social

The importance of environment stewardship and sustainability has skyrocketed in Canadian public opinion over the last year. Much more attention is being paid to energy conservation and alternative energy. The time is right to advance new energy technologies, as the public is more and more willing to support the cost of development and demonstration. North America has lagged behind Europe in this regard, as several European countries have for several years offerred incentives to produce clean energy. For example, Germany's Renewable Energy Sources Act sets tariff rates for the supply of renewable energy to the power grid, on a sliding scale based on the energy source and the size of the operation. A small geothermal plant (up to 5 MW) can get 15 eurocents per kilowatt hour, and the basic rate for solar generated electricity is 45.7 eurocents per kilowatt hour.[144] This premium pricing provides an incentive for smaller renewable energy producers to bring these projects on line.

Governments in North America are finding that they must take action on environmental issues or risk defeat in the polls at the next election – a powerful incentive indeed. The Government of Canada has announced two new programs in 2007 – the ecoEnergy Renewable Initiative in January and the ecoTrust program in February 2007.[145] The Government of BC, in the Throne Speech on February 13, 2007 announced new measures to ensure that greenhouse gas

[144] The Green Power Group, "Government Incentives for Renewable Energy in Europe," The Green Power Group website, http://www.thegreenpowergroup.org/pdf/renewable_policy_Germany.pdf, accessed February, 2007
[145] Government of Canada, "Prime Minister unveils new Canada ecoTrust," Office of the Prime Minster website, http://www.pm.gc.ca/eng/media.asp?id=1532, accessed February, 2007

emissions are reduced and that ninety percent of electricity will be from clean, renewable resources.[146]

Often people will support an idea as long as it doesn't affect them directly - the "not in my backyard" (NIMBY) syndrome. But that is not the case with the people who live and work in the Stuart Island area. Without exception, the people from the area interviewed for this study were favourable to the concept of tidal power generation, both in general and in their own local waters.

Environment

The environmental benefits of replacing diesel generators with clean, quiet tidal power are readily apparent. The diesel generators presently in use in the Stuart Island area pump about 3872 tonnes of carbon dioxide into the atmosphere annually - more than 700 cars.[147] Diesel exhaust contains other pollutants, including carbon monoxide, oxides of nitrogen, unburnt fuel and soot. Replacement of diesel power with ocean energy would be consistent with government objectives for clean power generation.

In addition to the air pollution, gensets contribute to noise pollution – ironic for a quiet wilderness like Stuart Island.

Transportation of one and a half million litres of diesel fuel to the area every year poses another risk to the environment – the risk of spills. A major spill could involve up to 80,000 litres of diesel fuel washing up on the rocks surrounding Cardero Channel.

Financial

The high cost of diesel power generation in the Stuart Island area means that there are good possibilities for an alternate source of electricity to be viable. Residents and resorts are paying a lot to provide heat and light for their homes and businesses. Resorts in particular are willing to look at whatever alternatives there may be, as there is considerable money involved. Business

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[146] Government of British Columbia, "Throne Speech," Government of British Columbia website, http://www.gov.bc.ca/bvprd/bc/content.do?brwId=%402Uq1U%7C0YQtuW&navId=NAV_ID_province&crumb=B.C.+Home&crumburl=%2Fhome.do, accessed February, 2007
[147] Energy Star, "Useful Facts and Figures," Energy Star website, http://www.energystar.gov/index.cfm?c=energy_awareness.bus_energy_use, accessed February, 2007

sustainability includes financial strength, and tidal power could provide valuable growth opportunities for the area if ecotourism could extend the tourist season.

Unfortunately, there is too much uncertainty in the various elements of costing to make a reliable financial determination. The tidal power turbines are in a very early stage of development, making costing uncertain. Installation of a tidal power generator in powerful currents like those that occur in the narrow passages near Stuart Island is questionable, as it has not yet been done anywhere in the world. Exactly what equipment could do the job, and where in the world it might be located, is a source of uncertainty without even considering the cost. Extensive (and likely expensive) investigation into the seabed conditions and the amount of debris carried by the current are necessary before a serious attempt at costing could be made.

Technology

In this case, there is another aspect to be considered in determining feasibility besides the Triple Bottom Line. Tidal power technology is in its infancy, and several aspects are not far enough advanced to recommend a tidal power generation facility at Stuart Island. First, the turbines themselves have not developed yet into full scale, commercial ready units of the size that would be required to replace the diesel generators in the Stuart Island area. While recent events show promise, such as the OpenHydro installation at EMEC, MCT's Seagen project set to go in the water at Strangford Narrows this spring and Lunar Energy's full size unit targeted to go in the water at EMEC late this year, the technology has not yet advanced to the point where a device can be recommended.

Deployment of the tidal stream power generation devices in very strong currents such as those found at Stuart Island has not yet been attempted, nor has the development of the anchoring techniques that may be required. It is likely that the ship or barge required for the installation would have to be tested in a narrow channel / powerful current environment before such techniques could be developed. Such a vessel may have to come all the way from the North Sea, which would be a large expense with no guarantee of success.

Storage of a large amount of energy in an off-grid situation is a very significant unknown. The situation at Stuart Island could result in excess power production at peak times of more than one megawatt. Engineering a system that could capture that much power and store it for a relatively short time, then make it available to draw from would be challenging and very site specific. The entire system would have to be designed together, from the output of the tidal generator, to the cable length, to the voltage for transmission to shore, to the power conversion and finally to the storage device.

Appendix I

Marketability of tidal power solutions

One of the objectives of the Alternative Energy Task Force is to market BC solutions to the high-growth areas of the world to help create export opportunities.[148] There is a very real opportunity for Canadian and BC companies to develop and market tidal power solutions worldwide. As previously mentioned, the industry is in its infancy. Companies from the UK would have to be considered to be in the lead, but Canadian companies are not far behind and could make up ground quickly. Resource opportunities abound in Canada, notably Minas Basin on the east coast and several potential locations on the west coast such as Discovery Passage. Moreover, there are opportunities for projects in BC that would develop unique capabilities, like expertise in high velocity current deployments.

Off-grid tidal power generation, as this study has shown, comes with its own set of challenges. However, as the technology advances, some of these challenges could be turned into opportunities. Developing package systems including the turbine, power conditioning and storage may be an excellent opportunity. This kind of package could be developed to provide solutions to remote communities here in BC, and then sold to countries around the world. Production of fresh water is another way to add value to a package solution that would be especially useful in island applications where natural fresh water is scarce.

Services are an ever-increasing part of the global economy. Companies and individuals can develop expertise in construction, deployment and installation of tidal power systems and market these skills internationally. Some of the conditions on the BC coast that are the challenges of today could represent the valuable, exportable service of tomorrow. “Contrary to popular belief, large tidal currents do not necessarily require a large tidal range. Some of the largest tidal flows in the world occur between the islands on the east side of the Philippines where the tidal range is small but the tide is high in the Pacific at the same time that the tide is low within the Philippine Islands. In technical terms, this is described as the two tides being 180 degrees (or half a cycle) out of phase; the result is very large tidal currents. Another factor that

[148] BC Ministry of Energy, Mines and Petroleum Resources, “Alternative Energy and Power Technology: A Strategy for BC,” BC Ministry of Energy, Mines and Petroleum Resources website, http://www.gov.bc.ca/empr/down/alternative_energy_task_force_strategy_final_april_5_05.pdf, accessed January 2007

impacts the magnitude of tidal currents is the presence of narrow passages; these passages result in a narrowing and concentration of tidal flow."[149]

The very powerful tidal currents and narrow channels of BC waters could prove to be the laboratory for developing skills that could be used to harness the power of the tides in other challenging sites around the world. Thus there are opportunities for British Columbians to develop exportable skills that would be unique in the world market. Consulting expertise can be developed in the following areas:

- Environmental impact and permitting
- Installation
- Site selection
- Project management
- Project design, tying all aspects together.

[149] Tarbotton and Larson, *Canada Ocean Energy Atlas (Phase 1)*

Appendix I

Recommendations

Arising from this study are six recommendations for the BC Ministry of Energy, Mines and Petroleum Resources (MEMPR). These recommendations are intended as concrete steps that can be taken to further the growth and development of the tidal power industry in BC, and to help guide future policy and programs.

Continue to support the industry

MEMPR has been an active supporter of tidal power though its assistance in establishing the Ocean Renewable Energy Group and its active participation in events and symposia. This support has been very valuable to the industry and the companies within it. With new initiatives recently announced by both the federal and provincial governments, continued strong involvement by MEMPR is vital to the growth and prosperity of the industry in BC.

Get the general public involved

In Alberta, individuals can choose to get involved in alternative energy by paying a premium for wind power. The wind power goes on to the grid, of course, but by “buying” more expensive wind power, these consumers are helping to fund the development of alternative energy capacity voluntarily. BC Hydro already has green power certificates available for purchase by its corporate customers. MEMPR can work with BC Hydro to extend the program so that the general public can participate in it.

Resolve Uncertainties

This study has identified a great deal of uncertainty that exists in the development of tidal energy technology and installations. The MEMPR could take a leading role in identifying these uncertainties and taking steps towards their resolution. Because many of these uncertainties are quite specific to the BC coast, resolving them would tend to confer the benefits on companies working in BC waters. This would enhance the development of a technology cluster of tidal energy expertise in BC.

Appendix I

Advocate for streamlined approval process

Work with relevant agencies and departments to establish a permitting and approvals policy to streamline the procedures of obtaining the necessary permits and navigating the environmental review process. This would involve coordination with the appropriate federal department(s) and could involve sponsoring fish or marine mammal impact studies, or studies on the effect of reducing tidal flows.

Clean power for remote communities

Continue the work being done to bring clean electricity to remote communities, and work with BC Hydro on the Remote Community Electrification program. Act as a conduit between technology developers working in complementary areas. For example, fuel cells could be an answer to the energy storage situation for a small off-grid tidal power generation installation. MEMPR could act as an intermediary to bring those technology developers together.

Continue to encourage private sector investment

Private sector investment is critical to the success of the tidal energy industry in BC. The BC Government, through MEMPR, should create incentives to encourage entrepreneurial activity in the development of tidal power devices and installations. As noted earlier in the German example, rates paid to Independent Power Producers (IPPs) can be structured to encourage the development of targeted technologies. MEMPR can act as a resource for tidal power technology developers to make them aware of programs offered by other branches of the BC government, such as the tax credits available to investors in eligible projects through the Venture Capital Program under the auspices of the Ministry of Economic Development.

Appendix I

Conclusion

Tidal power holds great promise for providing clean power to remote, off-grid communities. But not right now.

At this point in time, tidal power technology is not far enough advanced for it to be feasible for installation at Stuart Island to replace the existing diesel generators. However, it won't be long until commercial size devices have been built and tested. There are a handful of Canadian manufacturers of tidal turbines that have working small scale devices that will soon be scaled up for use in commercial applications. The world leaders in the field are in the UK, but Canadian developers are not far behind.

Canada is rich in potential tidal resources. Minas Basin, on the east coast is a tremendous resource, both in terms of magnitude and proximity to the electricity market. The BC coast has 89 potential development sites, and perhaps more importantly, resources unlike any that are been developed in the world right now. So an opportunity exists for Canadian and BC device manufacturers and site developers to become world leaders in tidal power generation.

Even though a tidal power project for the Stuart Island is not feasible at this time, great potential exists for tidal power generation in BC.

The time for action is now. A focus on ocean energy can firmly establish the path to BC's future prosperity.

Appendix I

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Appendix I

Glossary

Alternative energy	Power produced by methods other than conventional
Clean energy	Power produced using non-polluting technologies
Conventional energy	Power produced by large hydro, nuclear or hydrocarbon fueled plants
Genset	Common name for a diesel generator assembly
Green energy	Power produced using non-polluting technologies
Grid	Power grid, as the North American electrical power grid
Knot	Nautical mile per hour 1 knot = 1.15 miles per hour = 0.51 m/s
KW	Kilowatt, one thousand Watts
KWh	Kilowatt hours, kilowatts produced or consumed in one hour
m/s	Metres per second 1 m/s = 1.94 knots
MW	Megawatt, one million Watts
NGO	Non Governmental Organization
Off-grid	An area or system that is not connected to the electrical power grid

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Tidal current energy assessment for Johnstone Strait, Vancouver Island

G Sutherland[1]*, **M Foreman**[2], and **C Garrett**[1]

[1]Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada

[2]Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, British Columbia, Canada

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Abstract: The maximum tidal power potential of Johnstone Strait, BC, Canada is evaluated using a two-dimensional finite element model (TIDE2D) with turbines simulated in certain regions by increasing the drag. Initially, side channels are closed off so that the flow is forced through one channel to test the validity of a general analytic theory [**1**] with numerical results. In this case, the modelled power potential of 886 MW agrees reasonably well with the analytic estimate of 826 MW. In reality, two main channels, Discovery Passage and Cordero Channel, connect the Pacific Ocean to the Strait of Georgia. Turbines are simulated in Johnstone Strait, northwest of the two main channels, and separately for Discovery Passage and Cordero Channel. Northwestern Johnstone Strait is similar to the one channel case as the flow must go through this channel, but Discovery Passage and Cordero Channel are different as the flow can be diverted away from the channel with the turbines and into the other channel. The maximum extractable power in northwestern Johnstone Strait is found to be 1335 MW, which agrees well with the theoretical estimate of 1320 MW. In Discovery Passage and Cordero Channel, the maximum extractable power is modelled to be 401 and 277 MW, respectively, due to the flow being partly diverted into the other channel. In all cases, the current is reduced to between 57 and 58 per cent of the undisturbed flow, close to the 56 per cent predicted by the analytic theory. All power calculations are for the M2 constituent alone, as this is the largest current in the region. The total power from the eight major constituents (M2, S2, N2, K2, K1, 01, P1, and Q1) can be obtained by multiplying the power estimates for M2 by 1.12.

Keywords: tidal power, alternative energy, renewable energy, energy assessment

1 INTRODUCTION

Traditionally, tidal energy is extracted by blocking the entrance of a small bay with a barrier containing numerous sluices and turbines. The sluices allow the water to enter the bay on the flood tide but are closed at high tide. The water is then released through turbines when there is a large enough head difference due to the ebbing tide outside the barrage. A tidal power plant of this nature is located in the Bay of Fundy at Annapolis Royal with an installed capacity of 18 MW. A more complex scheme can generate electricity on both the flood and the ebb tide though this operates with a smaller head. The world's largest two-way generation tidal power plant is at La Rance, France, with an installed capacity of 240 MW and an average production of about 100 MW [**2**].

Although tidal power barrages produce zero emissions while operating, there are still many other environmental concerns [**3**], mostly due to a prolonged high tide inside the basin and a decrease in the tidal current speed. These concerns are reduced slightly with two-way generation, which more closely mimics the real tide, but there are still ecological impacts which will vary widely from site to site depending on the local tidal regime [**2**]. There may also be impacts on the tidal regime on the seaward side of the barrage [**4**], which could have serious implications for the neighbouring coastline.

In response to some of the environmental and ecological concerns with tidal barrages, there has

*Corresponding author: Department of Physics and Astronomy, P.O. Box 3055, STN CSC, Victoria, V8W 3P6, Canada. email: graig.sutherland@gmail.com

been a strong interest in harnessing power from tidal currents in a similar fashion to wind power generation [5]. This is seen as both a cheaper and more ecologically sound alternative to building a large tidal barrage. In 2002, Marine Current Turbines Ltd. (http://www.marineturbines.com) installed a single turbine with a rated capacity of 300 kW off Lynmouth, Devon, UK. This turbine only generates electricity for the tidal current moving one way, but there are proposals for a two-way rotor with a 1 MW rated capacity off the coast of Northern Ireland. Small tidal current projects are also underway at Race Rocks, BC, Canada (http://www.racerocks.com/racerock/energy/tidalenergy/tidalenergy.htm) and in the East River, New York City (http://www.verdantpower.com) with plans to install only one or two turbines. The majority of these projects are small scale (i.e. <1 MW) and will have little impact on the tidal currents at the site. However, for larger projects the turbines will tend to block the flow, thus reducing the power generated. Studies on how much energy can be extracted and the impacts on the tidal regime vary widely [**1**, **5**–**8**].

A common approach for evaluating tidal current potential is to assume that some percentage of the kinetic energy flux of the tidal flow (i.e. $(1/2)\rho u^3 \times$ the cross-sectional area) can be extracted for commercial use. An often quoted limit is the Betz limit [**9**], which claims that a maximum of 59 per cent of this kinetic power is available for extraction. However, this may be unrealistic because of the various assumptions made by Betz [**9**]. For example, Gorban *et. al.* [**10**] argued that only 35 per cent of the power may be extracted if one allows for the curvature of streamlines around the turbine. Regardless of what efficiency factor is used, the u^3 dependence (and a linear dependence on cross-sectional area) suggests that placing the turbines in the narrowest part of a confined stream will produce the most power. This may be true for an isolated turbine, or even a few turbines, as long as there is little change to the existing flow. However, it cannot apply to larger scale projects where there may be an appreciable change to the underlying flow because of the extra drag from the turbines. As more turbines are added, the flow is reduced, ultimately to the point at which the power produced decreases.

This article estimates the maximum power potential of the Johnstone Strait region (Fig. 1) in British Columbia, Canada. This region has very high tidal currents and has been proposed as an excellent site for harnessing tidal current energy [**5**]. First, theoretical calculations concerning the extraction of energy from the tidal currents are reviewed. The theory will then be applied to Johnstone Strait and compared with results from a numerical tidal model of the region.

2 A THEORETICAL APPROACH

For a single channel between two large basins, a general analytic theory to estimate the maximum extractable tidal power has been developed [**1**]. Turbines are simulated by increasing the friction across the entire cross-section of the channel. Assuming the wavelength of the tide is much longer than the channel length, so that the volume flux is constant along the entire channel, and the height difference between the ends of the channel does not vary with the addition of extra friction, the estimated maximum extractable power for a single tidal constituent was shown by Garrett and Cummins [**1**] to be given by

$$P_{\max} = \gamma \rho g a Q_{\max} \qquad (1)$$

Here ρ is the density of seawater, g is the acceleration due to gravity, a is the amplitude of the sinusoidal height difference between the ends of the channel, and $Q_{\max}$ is the maximum volume flux in the natural tidal regime. All calculations assume the constant values for ρ and g of 1025 kg/m^3 and 9.81 m/s^2, respectively. The coefficient γ only varies over the small range between 0.20 and 0.24 and is determined by whether the forcing is balanced by acceleration or friction in the natural state without added drag from turbines.

The appropriate value of γ in a given situation may be determined by examining the phase lag of the current behind the maximum elevation difference in the natural state. If the forcing is balanced by acceleration, the phase lag is 90° and $\gamma = 0.24$, whereas if the forcing is balanced by friction and/or the effect of flow separation, and the response thus quasi-steady, the phase lag is zero and $\gamma = 0.21$. There is a small dip to a minimum $\gamma = 0.196$ for intermediate situations (see Fig. 4 of Garrett and Cummins [**1**]). For Johnstone Strait, the along-strait average phase lag is 35°, which is in between the two limits but closer to the quasi-steady case. A value of 0.20 is appropriate for γ and is used in this article.

Garrett and Cummins [**1**] showed how the quasi-steady limit can be examined analytically. In this case, the potential power P as a function of the peak flow rate, Q, with added turbines may be written

$$P/P_{\max} = \left(\frac{3^{3/2}}{2}\right)\left(\frac{Q}{Q_{\max}}\right)\left[1 - \left(\frac{Q}{Q_{\max}}\right)^2\right] \qquad (2)$$

where $P_{\max}$ is the maximum power given by equation (1) and, as already defined, $Q_{\max}$ is the maximum volume flux in the natural tidal regime. The essential physics of the situation is

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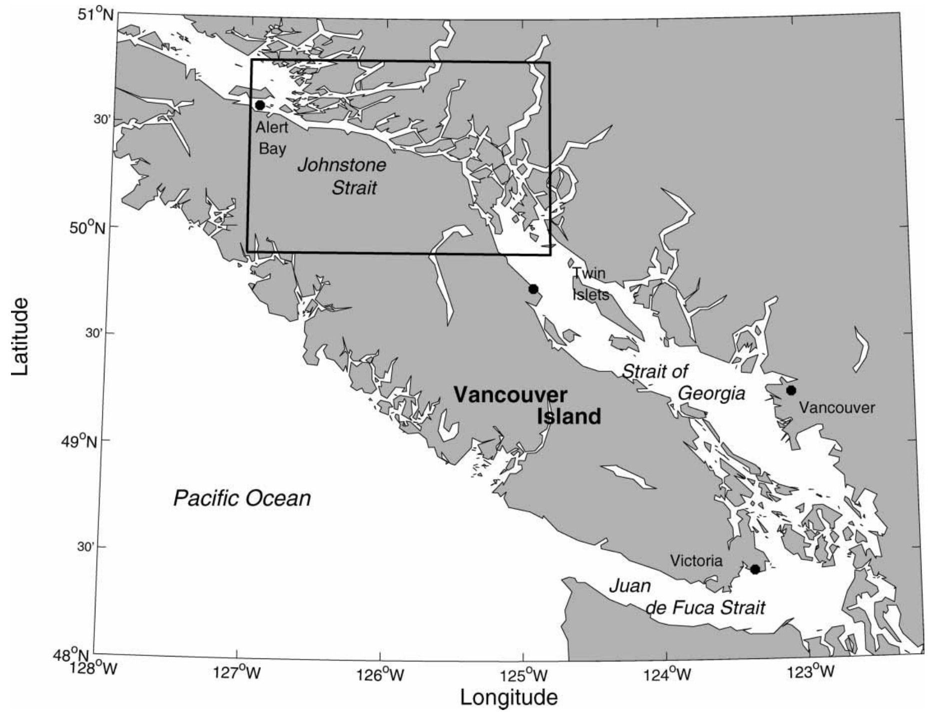

Fig. 1 Map of Vancouver Island. The location of the inset map (Fig. 3) is shown with the solid black line

well illustrated by equation (2). The term inside the square brackets is a non-dimensional form of the head loss across the fence of turbines, or an array of fences, and is zero when there are no turbines so that $Q = Q_{\max}$. As the number of turbines increases, this head loss increases as Q decreases. The power is given by the head times the volume flux. Ultimately, when so many turbines have been added that the flow is completely blocked, all the head loss originally associated with the natural state is transferred to the turbine array but the power produced is zero as there is no flow! Figure 2 is a graph of equation (2) illustrating this increase and then decrease of P as Q decreases from $Q_{\max}$ to zero. At maximum power extraction, the volume flux drops to 58 per cent of that in the natural regime and 2/3 of the original head along the whole channel has been transferred to the turbine array. For a 10 per cent reduction in the current, which might be more acceptable for environmental reasons than the 42 per cent decrease at the maximum, the available power is still 44 per cent of equation (1) with $\gamma = 0.21$. A very minor point worth mentioning is that the current referred to here is the current averaged over some suitable time. For low energy extraction, the reduction in this average current may be less than the magnitude of turbulent current fluctuations.

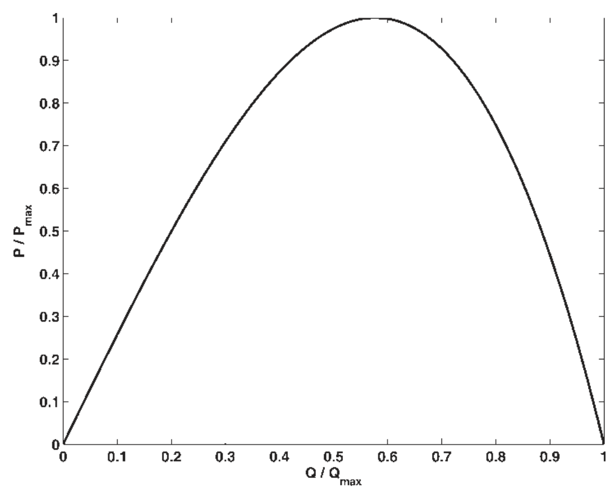

Fig. 2 The variation in the extractable power as a function of the reduced volume flux due to the presence of turbines for the situation in which there is a quasi-steady force balance in the natural state between pressure head and friction [**1**]. The volume flux is expressed as a fraction of the peak volume flux in the natural state and the power as a fraction of the maximum that can be extracted

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These simple results are for the situation in which the natural state has a balance between forcing and friction. Numerical results (P. Cummins, 2006, personal communication) show that in the other limit with the basic balance between forcing and acceleration, the current at maximum power is 70 per cent of that in the natural state. For our intermediate situation, this fraction is 56 per cent, close to the 58 per cent for the quasi-steady limit.

3 JOHNSTONE STRAIT REGION

Much of Johnstone Strait (Figs 1 and 3) has a typical width of 4 km and mid-channel depths up to 400 m, while Seymour Narrows and Cordero Channel have minimum widths of 0.8 and 0.5 km, respectively, and mid-channel depths as little as 50 m. These constrictions and the near 180° phase difference between tidal elevations in the northern Strait of Georgia and Queen Charlotte Strait create some of the largest tidal currents in the world. Current speeds in Seymour Narrows can reach 7.7 m/s [**11**], with the along-channel M2 current amplitude being 4.7 m/s [**12**]. Gillard Passage and Arran Rapids, at the southern end of Cordero Channel, have maximum current speeds of 5.7 and 6.7 m/s, respectively [**11**]. Although there are also substantial estuarine flows in the region because of the runoff of several rivers, of which the Fraser is the largest [**13**, **14**], these flow values will not be included in this study. Likewise, important baroclinic features associated with the tides [**13**] will be neglected by assuming a homogeneous density for all model simulations and power potential calculations.

4 A NUMERICAL APPROACH

Tidal heights and currents are calculated with the TIDE2D finite element model, which solves the two-dimensional shallow water equations with conventional hydrostatic and Boussinesq assumptions. Particulars of the numerical scheme are described in detail by Walters [**15**]. The model application uses the same triangular grid, encircling Vancouver Island, that was employed in Foreman *et al.* [**12**]. The model grid was created using the software package TRIGRID [**16**] and digital coastline and bathymetric data obtained from the Canadian Hydrographic Service and the National Oceanic and Atmospheric Administration. Grid element sizes were chosen to preserve important coastline and bathymetric features such as the numerous narrow channels in the Johnstone Strait region. Triangle sides range from 12 km in the ocean west of Vancouver Island to 130 m in Seymour Narrows. In order to ensure that volume transports within channels are accurate, the depths assigned to each node represent an average of nearby soundings.

Although many tidal constituents can be investigated, only M2 was employed here to speed up computation and to more easily relate the work to the theoretical results of Garrett and Cummins [**1**]. Moreover, the tidal currents for the region are predominantly semi-diurnal, so the M2 constituent will be the major contributor of extractable current energy.

For the natural tidal regime, a bottom friction coefficient of 0.007 was assumed everywhere except for eastern Juan de Fuca Strait and Discovery Passage, where the values were assumed to be 0.02 and 0.013, respectively. All coefficients are larger than normal to compensate for the inability of the model to represent correctly all the dissipation mechanisms, such as unresolved flow separation, with a conventional coefficient of 0.003 [**12**], and to allow for M2 being the only modelled constituent when in reality, the other constituents make significant contributions to the non-linear bottom friction. The values of the friction coefficients were chosen to obtain a good agreement between the modelled and observed tidal elevations since, for tidal power calculations, an important aspect of the tidal height field is the sinusoidal height difference, between the ends of the channel, which is forcing the current. The height difference is calculated between Alert Bay and Twin Islets (Fig. 1) where the observed M2 elevations are obtained from a harmonic analysis [**17**] of the recorded time series [**11**] at each location. The modelled value of 2.11 m is nearly identical to the observed value of 2.12 m.

4.1 Energy dissipation rate

One way to compute the dissipation is to take the difference between the energy flux into and out of a section of the channel. However, this can lead to a large relative error when the difference is small compared to the incoming and outgoing energy fluxes. Also, it has been shown [**18**] that, since TIDE2D employs a wave-equation formulation, volume is not always conserved locally. This leads to a continuity equation residual that contributes to the energy budget and remains a matter of concern with the finite element approach. Nonetheless, the success of the model in reproducing the natural tidal regime accurately in a number of regions [**19**, **20**] suggests that it is still reliable for estimates of the current and hence for direct calculations of the energy dissipation rate.

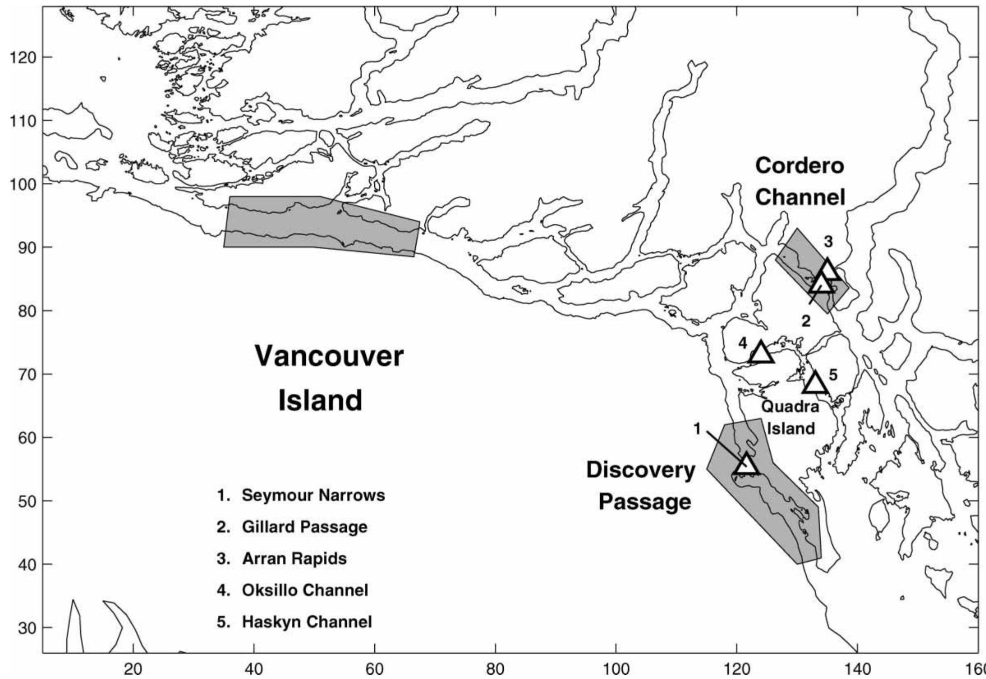

Fig. 3 Transect locations for the addition of synthetic turbines in Johnstone Strait. The shaded areas are the locations where turbines were simulated. The axes give the horizontal distances in kilometres

The rate at which energy is dissipated for a section of the seabed is calculated by integrating the bottom friction, that is,

$$P = \int\int_A \rho C_d \overline{|u^3|}\ \mathrm{d}A \tag{3}$$

where C_d is the quadratic bottom friction coefficient, u is the tidal current speed, and dA is an element of the area of the seabed.

5 TURBINE SIMULATIONS

The additional dissipation associated with the presence of turbines is simulated by increasing the bottom friction coefficient over a region of model nodes to represent a 'farm' of turbines. The bottom friction coefficient is increased to $C_d = k_0 + k_t$ where k_0 is the natural bottom friction coefficient and k_t is that associated with the added turbines. The energy dissipated solely by the turbines is

$$P_t = \frac{k_t}{k_0 + k_t} P \tag{4}$$

Figure 3 shows the areas of the simulated turbine farms. Using a two-dimensional numerical model it can be shown that these turbines extract energy from the entire cross-section of the tidal current flowing through a particular channel. This is similar to proposals for one or more tidal fences across the whole channel.

5.1 One Channel Open

To mimic the single channel case of Garrett and Cummins [**1**], we first close off the Cordero Channel and the Oksillo and Haskyn Channels on the eastern side of Quadra Island (Fig. 3) by disconnecting the nodes there. Although the system is still not exactly a single channel, because of some flow splitting in the central part of the strait, all the water entering into the Strait of Georgia must now pass through Discovery Passage and thus cannot be diverted away from the channel with the turbines. In this case, the height difference between Twin Islets and Alert Bay is 2.27 m.

Figure 4 shows the maximum M2 tidal volume flux for certain transects through Johnstone Strait before turbines are added. Along-channel variations in the volume flux are partly due to the limited accuracy of interpolating the volume flux to the transect location and partly due to the local accumulation or loss of water as the sea level changes with time.

The bottom friction coefficient is steadily increased in Discovery Passage until the extracted

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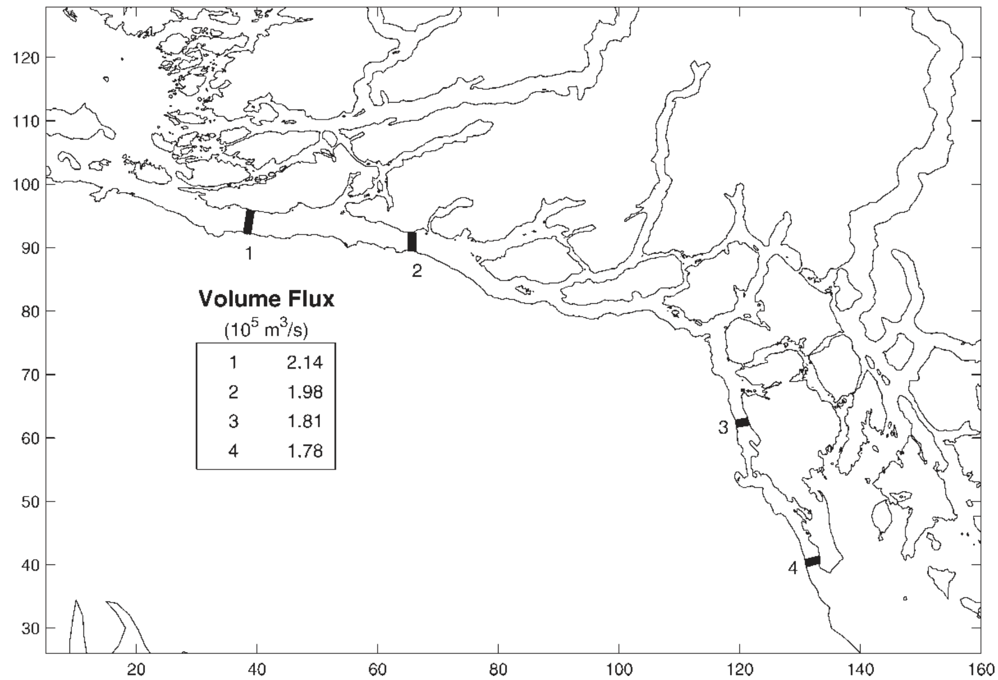

Fig. 4 Maximum volume flux with Cordero Channel effectively blocked and no turbines in Discovery Passage or Johnstone Strait. The axes give the horizontal distances in kilometres

energy, calculated using equation (4), peaks, as shown in Fig. 5. At peak power, the extracted energy is 886 MW with a corresponding drop in the maximum volume flux to 58 per cent of $Q_{\max}$, close to the theoretical expectation of 56 per cent cited earlier. The modelled power of 886 MW agrees reasonably well with the analytic value of 826 MW from equation (1) using $1.81 \times 10^5\,\mathrm{m^3/s}$ for the maximum volume flux, 2.27 m for a, and $\gamma = 0.20$. At peak power, a increases to 2.35 m, which is only a 3.5 per cent increase from the natural regime. This increase in the head would add, at the most, 3.5 per cent to the peak power obtained from equation (1), bringing 826 MW up to 855 MW, closer to the value from the numerical model.

5.2 All channels open

For the true tidal regime, we consider three separate scenarios. In the first, turbines are simulated in the northwestern region of Johnstone Strait, leaving open the two main channels, Discovery Passage and Cordero Channel, that connect to the Strait of Georgia. This region of Johnstone Strait is located in series with the major branching of the flow into Discovery Passage and Cordero Channel and thus should give results similar to those for the one channel case. In the second scenario, we leave northwestern Johnstone Strait and Cordero Channel unmodified and simulate the presence of turbines in Discovery Passage, which has some of the largest tidal currents in the world [**14**] and is, therefore, a prime candidate for any future tidal current projects [**15**]. However, this channel not only has heavy

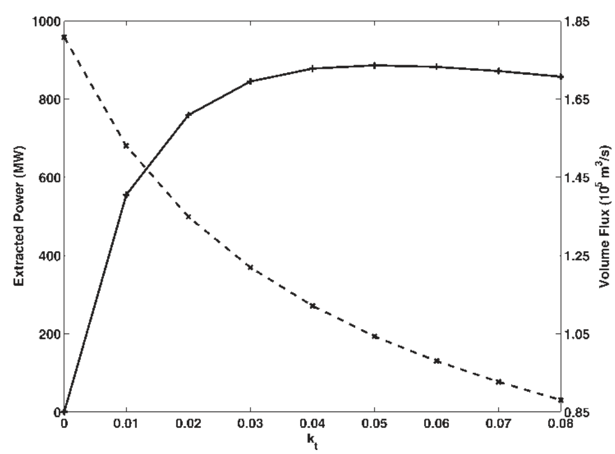

Fig. 5 Power dissipated by the addition of turbines in Discovery Passage, with Cordero Channel closed, as a function of increased friction coefficient. The solid line denotes the power dissipated (scale on left) and the dotted line denotes the change in volume flux through the channel (scale on right)

shipping traffic, but is also a major migration corridor for salmon returning to the Fraser River. Therefore, it would seem unrealistic to be able to extract the maximum possible tidal energy as part of the channel would need to be kept open. Hence, in a third scenario, we simulate turbines in Cordero Channel, which has relatively high currents in addition to being out of the way of major shipping traffic, while leaving northwestern Johnstone Strait and Discovery Passage unmodified. As shown in Fig. 6, Cordero Channel and Discovery Passage (i.e. transects 9 and 10, respectively) have comparable volume fluxes in the natural state, thus rendering previous single-channel theoretical assumptions invalid in our second and third scenarios.

For turbines simulated in northwestern Johnstone Strait (Fig. 3), our first scenario, the modelled peak power is 1335 MW (Fig. 7). This is in good agreement with equation (1), which predicts a maximum extractable power of 1320 MW using 3.11×10^5 m^3/s for $Q_{\max}$, 2.11 m for a, and $\gamma = 0.20$. In this section of Johnstone Strait, the volume flux varies between 3.00×10^5 and 3.21×10^5 m^3/s so 3.11×10^5 m^3/s is chosen as the mean maximum flux. The peak volume flux falls to 58 per cent of the value in the natural regime at maximum power extraction, again close to the expected 56 per cent. At maximum power, the height difference, a, increased to 2.18 m, which would increase the theoretical peak power, at the most, to 1363 MW.

Next, the bottom friction coefficient is slowly increased in Discovery Passage with Cordero Channel left unchanged, and the extracted power is shown in Fig. 8. The peak extractable power here is 401 MW. The same is then done for Cordero Channel with Discovery passage left unchanged, and the maximum extractable power is 277 MW as shown in Fig. 9. The peak volume flux drops to 57 and 58 per cent of the value in the natural state for Discovery Passage and Cordero Channel, respectively.

Using 2.11 m for a in equation (1), along with $\gamma = 0.20$ and 1.35×10^5 and 1.41×10^5 m^3/s for the peak volume fluxes in Discovery Passage and Cordero Channel, gives an estimated power potential of 573 and 598 MW, respectively. The single channel analytical model is inappropriate for these situations involving turbines in either Discovery Passage or Cordero Channel, however, due to the flow diverting into the channel without the turbines. This necessitates the need for a numerical model to accurately estimate the power potential, though it is possible that the single channel analytical model could be extended. In both of the cases evaluated above, at maximum power extraction the volume flux increases by 14 per cent in the channel without the

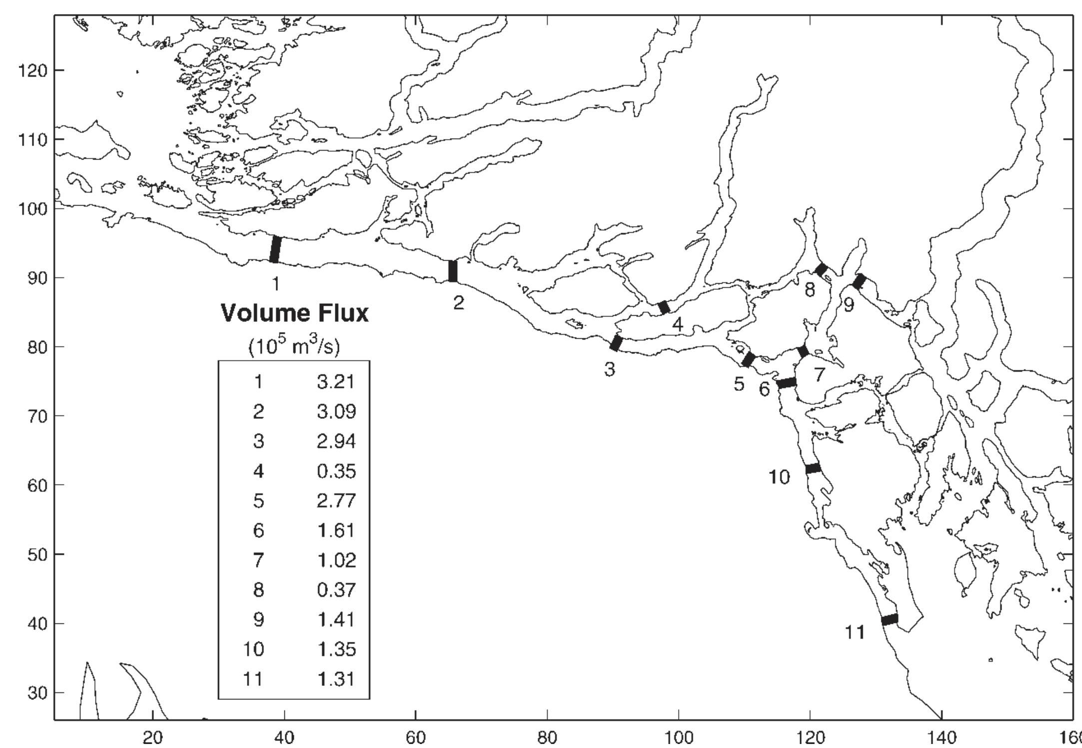

Fig. 6 Volume flux through Johnstone Strait with no channels blocked. The axes give the horizontal distances in kilometres

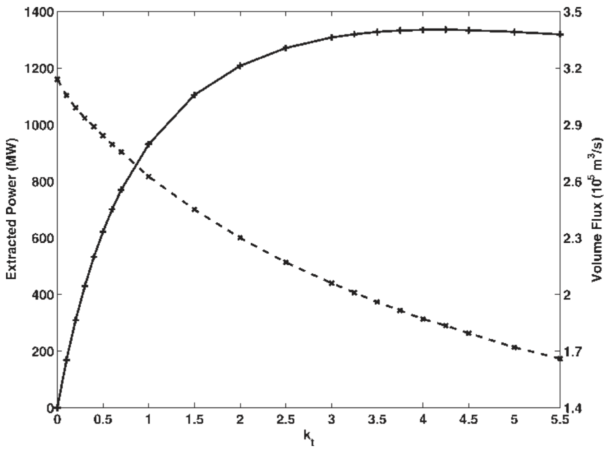

Fig. 7 Power extracted by the turbines in northwestern Johnstone Strait as a function of the extra friction coefficient. The solid line denotes the energy dissipation rate associated with the turbines (scale on left) and the dotted line denotes the change in peak volume flux through the channel (scale on right)

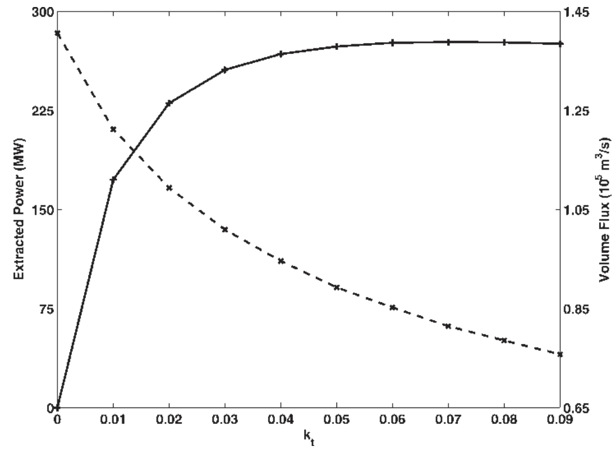

Fig. 9 Power extracted by the turbines in Cordero Channel as a function of the extra friction coefficient. The solid line denotes the energy dissipation rate associated with the turbines (scale on left) and the dotted line denotes the change in peak volume flux through the channel (scale on right)

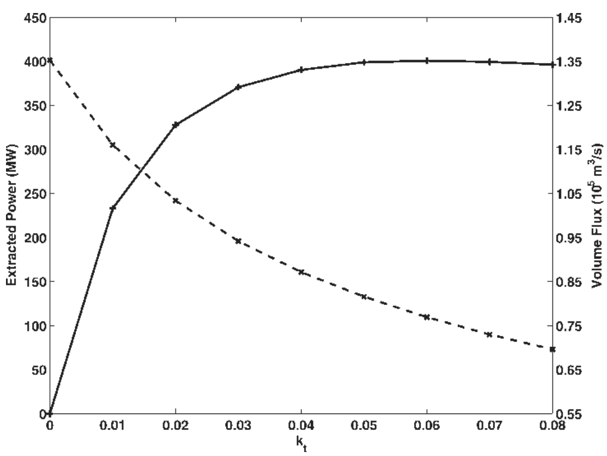

Fig. 8 Power extracted by the turbines in Discovery Passage as a function of the extra friction coefficient. The solid line denotes the energy dissipation rate associated with the turbines (scale on left) and the dotted line denotes the change in peak volume flux through the channel (scale on right)

turbines and the change in the height difference, a, is negligible.

5.3 Summary of results

The results of the turbine simulations along with the theoretical estimates for the maximum energy dissipation from equation (1) are shown in Table 1. For

Table 1 Results from simulating turbines in certain regions of Johnstone Strait

Location	Theoretical dissipation (MW)	Modelled dissipation (MW)	Percent vol. flux at max dissipation
Discovery Passage w/ Cordero closed	826	886	58
Johnstone Strait	1320	1335	58
Discovery Passage	573*	401	57
Cordero Channel	598*	277	58

Asterisks denote power estimates for channels where the water can be diverted and equation (1) is no longer valid.

the two cases with all the tidal flow going through the turbines there is good agreement between power estimates from equation (1) and numerical simulations. However, for the two cases where the flow can be diverted to a channel without turbines the theory is no longer valid and estimates cannot be made using equation (1). It is unclear why Cordero Channel, which has the greater volume flux in the natural regime, has a smaller power potential than Discovery Passage, even though both have roughly the same drop in volume flux, and the same increase in volume flux for the neighbouring channel, at peak power. Further study is required to discover the nature of this discrepancy.

5.4 Adding other constituents

These results for M2 can be extrapolated to account for the entire tide [1]. For a multi-frequency tide, e.g. $\zeta_0 = a\cos\omega t + a_1\cos\omega_1 t + a_2\cos\omega_2 t\cdots$, the extractable power is multiplied in the quasi-steady limit by $1 + \frac{9}{16}(r_1^2 + r_2^2\cdots)$, where $r_1 = a_1/a$, $r_2 = a_2/a$, ... and a is the M2 sinusoidal height difference between Alert Bay and Twin Islets. The factor 9/16 is replaced by 1 if the basic state is dominated by acceleration rather than friction [1], but we retain it, as the basic state here is closer to the quasi-steady, frictionally dominated limit. The scaling factor was computed using the harmonic constants for the eight major tidal constituents: M2, S2, N2, K2, K1, O1, P1, and Q1 were calculated through a harmonic analysis [17] of the observed time series [11] at these two locations. Accounting for these eight major constituents instead of just M2 will only increase the total power potential by a factor of 1.12.

6 FAR FIELD EFFECTS

To determine the far field effects, the tidal height amplitudes were compared between the natural regime and the regime at maximum power extraction for the three cases with the real geometry (i.e. excluding the first case where the side channels are blocked). The one channel case is not analysed here as it seems unlikely that Cordero Channel, Oksillo Channel, and Haskyn Channel would all be blocked off to force the flow through Discovery Passage.

We are assuming here that the prescribed tidal elevation at the open boundary, which generally lies beyond the edge of the continental shelf, is unchanged. This is likely to be a good assumption because any significant changes in deep water would lead to large transport changes which would be incompatible with the rest of the ocean. Further discussion of this issue is given by Garrett and Greenberg [21].

The variation in the phase lag of the tidal elevation is negligible outside Johnstone Strait. The maximum change is an increase in the phase lag of 10° in the area where the turbines are added. The currents also vary little outside Johnstone Strait with the maximum deviation being a decrease of 2 cm/s in Juan de Fuca Strait. In the Strait of Georgia, the currents slightly increase between 0 and 1 cm/s.

Extracting 1335 MW from Johnstone Strait has an appreciable impact on the far field tidal elevations. In the Strait of Georgia, there is a near uniform decrease in the M2 amplitude of 15 cm. In Juan de Fuca Strait, the M2 amplitude increases in the western end and decreases eastward. A lot of this change is due to the degenerate M2 amphidrome near Victoria [22] moving towards the Strait of Georgia.

Similar patterns arise when extracting 401 and 277 MW from Discovery Passage and Cordero Channel, respectively, but the magnitude of the changes is smaller. In fact, the magnitude appears to vary linearly with the amount of energy extracted, i.e. the far field effects, away from Johnstone Strait have the same shape as for extracting 1335 MW out of Johnstone Strait, but the tidal height amplitude variation is scaled down by 30 per cent (401/1335) and 20 per cent (277/1335) for turbines in Discovery Passage and Cordero Channel, respectively.

The effects of blocking Johnstone Strait completely are very similar to extracting 1335 MW out of Johnstone Strait with a slightly greater decrease in the M2 amplitude in the Strait of Georgia and Juan de Fuca Strait. At peak extraction, which has maximized the balance between the dissipative force and the flow through the turbines, the far field effects are similar to blocking off the channel completely so no water flows through.

Estimates of the far field effects using only M2 will be inaccurate if Johnstone Strait has an appreciable effect on the other constituents. The diurnal tidal amplitude is comparable to the semi-diurnal tide in most of the Strait of Georgia (the K1 amplitude is in fact larger than the M2 amplitude at Victoria). There may be significant changes in the diurnal tides as the resonant period is closer to the diurnal band than the semi-diurnal band [23]. As a result, estimating far field effects using only M2 is insufficient. Further work on this may be desirable.

7 DISCUSSION

We have shown that, when the flow cannot be diverted away from the channel with the turbines, the numerical results for the tidal power potential agree well with the analytic theory of Garrett and Cummins [1]. For these two scenarios, the estimates using equation (1) are both within 10 per cent of the numerical results. Small variations in the volume flux along the channel and the slight increase in the head with added friction will cause small discrepancies in the calculated power potential, but variations in the volume flux and head difference appear to be either negligible or cancel each other out. Thus the assumptions made by Garrett and Cummins [1] appear reasonable and their model useful.

If the flow can be diverted away from the turbines, the analytic theory [1] is no longer directly

Appendix J

applicable. This is apparent for turbines added in Discovery Passage and Cordero Channel where the power potential is not predicted by equation (1) as it does not account for this diversion of the flow. These more complex channels can be addressed using a numerical model to estimate the maximum extractable power, though a semi-analytic extension of the basic theory could be undertaken. With flow diversion, equation (1) still gives an upper bound on the power potential, though this may not be very useful.

Given the support for the basic theory of Garrett and Cummins [**1**], it is clear that results rely on the model providing a good representation of the volume flux as well as the tidal elevation in the natural regime. Measurements of the M2 barotropic volume flux are available from current meter measurements in Johnstone Strait [**13**]. The peak volume flux was measured to be $2.6 \times 10^5\,\mathrm{m^3/s}$ from five current meters along a transect at roughly the same location as transect 2 in Fig. 6. This, along with 2.12 m for a and 0.20 for γ, would result in equation (1) estimating the maximum power potential to be 1108 MW for the entire channel. This is less than from the model which has a larger volume flux of roughly $3.1 \times 10^5\,\mathrm{m^3/s}$. Both observations and the model have uncertainties, so further work is needed to establish the correct volume flux. In particular, a more intensive current measurement program, using Acoustic Doppler Current Profilers instead of single current meters, could provide more accurate data on the tidal volume flux in the natural state. We emphasize that this would remove the sensitivity to the uncertainty of friction coefficients in the numerical model; as long as these are chosen so that the computed flux matches the observed value, they need not be accurate in every location.

In a study for BC HYDRO [**5**], the tidal current power potential was assessed for multiple sites along the BC coast, with the majority of these located in Johnstone Strait. The power potential at each site was estimated from the kinetic energy flux $(1/2)\rho u^3$ multiplied by the cross-sectional area. Only sites with current speeds greater than 2.4 m/s were chosen, excluding Seymour Narrows as the currents were deemed too high for present technology, and their estimated total power potential from 12 sites in Johnstone Strait was found to be 767 MW. This assessment looked at each site separately and assumed that extraction from one site will not affect extraction at another site, though this has been shown by Garrett and Cummins [**1**] and this study to be false. Also, in using the kinetic energy flux of the undisturbed flow as a metric for the maximum potential, changes to the flow due to the increased drag from energy extraction are neglected, quite apart from the fact that the kinetic energy flux varies from cross-section to cross-section.

Large current speeds are desirable for efficient turbine operation, and, for an isolated turbine, the extractable power is proportional to the kinetic energy flux of the basic flow through the area presented by the turbine. However, when turbines are present in the entire cross-section of a channel as a tidal fence, the maximum extractable energy is not proportional to the natural kinetic energy flux in any general way. The general analytic theory of Garrett and Cummins [**1**] has been shown here to be accurate in both predicting the change in the current from power extraction and determining the maximum power potential for a single channel where the water cannot be diverted away from the turbines. Specifically, the assumptions made in the analytical theory seem to be adequately valid when compared with the results from a numerical model.

Both the analytical model and the numerical model used here do use particular representations of the turbines. Future work will include investigating different ways to add friction to simulate turbines. One method would be to scale the turbine friction coefficient linearly with water depth so the body force will be constant for the whole turbine farm, i.e. $k_t = \alpha H$ where α is a constant and H is the water depth. This method has been applied to northwestern Johnstone Strait with nearly identical results to those obtained with the uniform friction coefficient increase.

Another important extension will be to increase the friction for only part of the channel in order to leave a portion open for shipping. In that case, of course, water can flow around the turbines rather than through them. Such an extension could be carried out using a two-dimensional model if the partial tidal fence occupies the whole water column in the vertical but is limited laterally, but a three-dimensional model is required if the turbines are confined near the sea floor. Preliminary investigations show that, in either of these scenarios, a turbine farm which is extensive in the along-channel direction is ineffective as the water will tend to avoid it and flow through the unrestricted part of the cross-section. Turbine fences would then need to be well spaced in the along-channel direction, allowing turbulent mixing to cause a recovery of the flow profile between fences. In this case, however, a loss of head is associated with the merging of flows that have, and have not, passed through a particular fence, giving less power than if the tidal fences occupy the entire channel [**24**].

Finally, we stress that the maximum extractable power predicted by Garrett and Cummins [**1**] and computed in this article would have to be reduced to allow for losses to drag on turbine support structures and to allow for the internal efficiency of the turbines themselves.

ACKNOWLEDGMENTS

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Executive Summary

This book describes 207 ways in which the size of "electrical resources"—devices that make, save, or store electricity—affects their economic value. It finds that properly considering the economic benefits of "distributed" (decentralized) electrical resources typically raises their value by a large factor, often approximately tenfold, by improving system planning, utility construction and operation (especially of the grid), and service quality, and by avoiding societal costs.

The *actual* increase in value, of course, depends strongly on the case-by-case technology, site, and timing. These factors are so complex that the distribution of value increases across the universe of potential applications is unknown. However, in many if not most cases, the increase in value should change investment decisions. For example, it should normally far exceed the cost differences between, say, modern natural-gas-fired power plants and windfarms. In many applications it could even make grid-interactive photovoltaics (solar cells) cost-effective today. It should therefore change how distributed resources are marketed and used, and it reveals policy and business opportunities to make these huge benefits explicit in the marketplace.

The electricity industry is in the midst of profound and comprehensive change, including a return to the local and neighborhood scale in which the industry's early history is rooted. Through the twentieth century, thermal (steam-raising) power stations evolved from local combined-heat-and-power plants serving neighborhoods to huge, remote, electricity-only generators serving whole regions. Elaborate technical and social systems commanded the flow of electrons from central stations to dispersed users and the reverse flow of money to pay for power stations, fuel, and grid. This architecture made sense in the early twentieth century when power stations were more expensive and less reliable than the grid, so they had to be combined via the grid to ensure reliable and economical supply. The grid also melded the diverse loads of many customers, shared the costly generating capacity, and made big and urban customers subsidize extension of electric service to rural customers.

By the start of the twenty-first century, however, virtually everyone in industrialized countries had electric service, and the basic assumptions underpinning the big-station logic had reversed. Central thermal power plants could no longer deliver competitively cheap and reliable electricity through the grid, because the plants had come to cost *less* than the grid and had become so reliable that nearly all power failures originated *in* the grid. Thus the grid linking central stations to remote customers had become the main driver of those customers' power costs and power-quality problems—which became more acute as digital equipment required extremely reliable electricity. The cheapest, most reliable power, therefore, was that which was produced at or near the customers.

Utilities' traditional focus on a few genuine economies of scale (the bigger, the less investment per kW) overlooked larger *dis*economies of scale in the power stations, the grid, the way both are run, and the architecture of the entire system. The narrow vision that bigger is better ended up raising the costs and financial risks that it was meant to reduce. The resulting disadvantages are rooted in an enormous difference of scale between most needs and most supplies. Three-fourths of U.S. residential and commercial customers use electricity at an average rate that does not exceed 1.5 and 12 kilowatts respectively, whereas a single conventional central power plant produces about a million kilowatts. Resources better matched to the kilowatt scale of most customers' needs, or to the tens-of-thousands-of-kilowatts scale of typical distribution substations, or to an intermediate "microgrid" scale, thus became able to offer important but little-known economic advantages over the giant plants.

The capital markets have gradually come to realize this. Central thermal power plants stopped getting more efficient in the 1960s, bigger in the '70s, cheaper in the '80s, and bought in the '90s. Smaller units offered greater economies from mass-production than big ones could gain through unit size. In the '90s, the cost differences between giant nuclear plants—the last gasp of '70s and '80s gigantism—and railcar-deliverable combined-cycle gas-fired plants, derived from mass-produced aircraft engines, created political stresses that drove the restructuring of the industry. At the same time, new kinds of "micropower" generators thousands or tens of thousands of times smaller—microturbines, solar cells, fuel cells, wind turbines—started to become serious competitors, often enabled by information and telecommunications technologies. The restructured industry exposed the previously sheltered power-plant builders to brutal market discipline. Competition from micropower, uncertain demand, and the inflexibility of big, slow-to-build plants created financial risk well beyond the capital markets' appetite. Then in 2001, longstanding concerns about the inherent vulnerability of giant plants and the far-flung grid were reinforced by the 9/11 terrorist attacks.

The disappointing cost, efficiency, financial risk, and reliability of large thermal stations (and their associated grid investments) were leading their orders to collapse even before the cost difference between nuclear and combined-cycle costs stimulated restructuring that began to delaminate utilities. That restructuring created new market entrants, unbundled prices, and increased opportunities for competition at all scales—and thus launched the revolution in which swarms of microgenerators began to displace the behemoths. Already, distributed resources and the markets that let them compete have shifted most new generating units in competitive market economies from the million-kilowatt scale of the 1980s to the hundredfold-smaller scale that prevailed in the 1940s. Even more radical decentralization, all the way to customers' kilowatt scale (prevalent in and before the 1920s), is rapidly emerging and may prove even more beneficial, especially if it comes to rely on widely distributed microelectronic intelligence. Distributed generators do not require restructured electricity markets, and do not imply any particular scale for electricity business enterprises, but they are starting to drive the evolution of both.

Appendix K

Some distributed technologies like solar cells and fuel cells are still made in low volume and can therefore cost more than competing sources. But such distributed sources' increased *value*—due to improvements in financial risk, engineering flexibility, security, environmental quality, and other important attributes—can often more than offset their apparent cost disadvantage. This book introduces engineering and financial practitioners, business managers and strategists, public policymakers, designers, and interested citizens to those new value opportunities. It also provides a basic introduction to key concepts from such disciplines as electrical engineering, power system planning, and financial economics. Its examples are mainly U.S.-based, but its scope is global.

A handful of pioneering utilities and industries confirmed in the 1990s that distributed benefits are commercially valuable—so valuable that since the mid-'90s, most of the best conceptual analyses and field data have become proprietary, and government efforts to publish methods and examples of distributed-benefit valuation have been largely disbanded. Most published analyses and models, too, cover only small subsets of the issues. This study therefore seeks to provide the first full and systematic, if preliminary, public synthesis of how making electrical resources the right size can minimize their costs and risks. Its main findings are:

- The most valuable distributed benefits typically flow from financial economics—the lower risk of smaller modules with shorter lead times, portability, and low or no fuel-price volatility. These benefits often raise value by most of an order of magnitude (factor of ten) for renewables, and by about 3–5-fold for nonrenewables.
- Electrical-engineering benefits—lower grid costs and losses, better fault management, reactive support, etc.—usually provide another ~2–3-fold value gain, but more if the distribution grid is congested or if premium power quality or reliability are required.
- Many miscellaneous benefits may together increase value by another ~2-fold—more where waste heat can be reused.
- Externalities, though hard to quantify, may be politically decisive, and some are monetized.
- Capturing distributed benefits requires astute business strategy and reformed public policy.

Emerging electricity market structures can now provide the incentives, the measurement and validation, and the disciplinary perspectives needed to give distributed benefits a market voice. Successful competitors will reflect those benefits in investment decisions and prices. Nearly a dozen other technological, conceptual, and institutional forces are also driving a rapid shift toward the "distributed utility," where power generation migrates from remote plants to customers' back yards, basements, rooftops, and driveways. This transformation promises a vibrantly competitive, resilient, and lucrative electricity sector, at less cost to customers and to the earth—thus fulfilling Thomas Edison's original decentralized vision, just a century late.

207 Benefits of Distributed Resources

1 Distributed resources' generally shorter construction period leaves less time for reality to diverge from expectations, thus reducing the probability and hence the financial risk of under- or overbuilding.

2 Distributed resources' smaller unit size also reduces the consequences of such divergence and hence reduces its financial risk.

3 The frequent correlation between distributed resources' shorter lead time and smaller unit size can create a multiplicative, not merely an additive, risk reduction.

4 Shorter lead time further reduces forecasting errors and associated financial risks by reducing errors' amplification with the passage of time.

5 Even if short-lead-time units have lower thermal efficiency, their lower capital and interest costs can often offset the excess carrying charges on idle centralized capacity whose better thermal efficiency is more than offset by high capital cost.

6 Smaller, faster modules can be built on a "pay-as-you-go" basis with less financial strain, reducing the builder's financial risk and hence cost of capital.

7 Centralized capacity additions overshoot demand (absent gross underforecasting or exactly predictable step-function increments of demand) because their inherent "lumpiness" leaves substantial increments of capacity idle until demand can "grow into it." In contrast, smaller units can more exactly match gradual changes in demand without building unnecessary slack capacity ("build-as-you-need"), so their capacity additions are employed incrementally and immediately.

8 Smaller, more modular capacity not only ties up less idle capital (#7), but also does so for a shorter time (because the demand can "grow into" the added capacity sooner), thus reducing the cost of capital per unit of revenue.

9 If distributed resources are becoming cheaper with time, as most are, their small units and short lead times permit those cost reductions to be almost fully captured. This is the inverse of #8: revenue increases there, and cost reductions here, are captured incrementally and immediately by following the demand or cost curves nearly exactly.

10 Using short-lead-time plants reduces the risk of a "death spiral" of rising tariffs and stagnating demand.

11 Shorter lead time and smaller unit size both reduce the accumulation of interest during construction—an important benefit in both accounting and cashflow terms.

12 Where the multiplicative effect of faster-and-smaller units reduces financial risk (#3) and hence the cost of project capital, the correlated effects—of that cheaper capital, less of it (#11), and needing it over a shorter construction period (#11)—can be triply multiplicative. This can in turn improve the enterprise's financial performance, gaining it access to still cheaper capital. This is the opposite of the effect often observed with large-scale, long-lead-time projects, whose enhanced financial risks not only raise the cost of project capital but may cause general deterioration of the developer's financial indicators, raising its cost of capital and making it even less competitive.

13 For utilities that use such accrual accounting mechanisms as AFUDC (Allowance for Funds Used During Construction), shorter lead time's reduced absolute and fractional interest burden can improve the quality of earnings, hence investors' perceptions and willingness to invest.

14 Distributed resources' modularity increases the developer's financial freedom by tying up only enough working capital to complete one segment at a time.

15 Shorter lead time and smaller unit size both decrease construction's burden on the developer's cashflow, improving financial indicators and hence reducing the cost of capital.

16 Shorter-lead-time plants can also improve cashflow by starting to earn revenue sooner—through operational revenue-earning or regulatory rate-basing as soon as each module is built—rather than waiting for the entire total capacity to be completed.

17 The high velocity of capital (#16) may permit self-financing of subsequent units from early operating revenues.

18 Where external finance is required, early operation of an initial unit gives investors an early demonstration of the developer's capability, reducing the perceived risk of subsequent units and hence the cost of capital to build them.

19 Short lead time allows companies a longer "breathing spell" after the startup of each generating unit, so that they can better recover from the financial strain of construction.

20 Shorter lead time and smaller unit size may decrease the incentive, and the bargaining power, of some workers or unions whose critical skills may otherwise give them the leverage to demand extremely high wages or to stretch out construction still further on large, lumpy, long-lead-time projects that can yield no revenue until completed.

21 Smaller plants' lower local impacts may qualify them for regulatory exemptions or streamlined approvals processes, further reducing construction time and hence financing costs.

22 Where smaller plants' lower local impacts qualify them for regulatory exemptions or streamlined approvals processes, the risk of project failure and lost investment due to regulatory rejection or onerous condition decreases, so investors may demand a smaller risk premium.

23 Smaller plants have less obtrusive siting impacts, avoiding the risk of a vicious circle of public response that makes siting ever more difficult.

24 Small units with short lead times reduce the risk of buying a technology that is or becomes obsolete even before it's installed, or soon thereafter.

25 Smaller units with short development and production times and quick installation can better exploit rapid learning: many generations of product development can be compressed into the time it would take simply to build a single giant unit, let alone operate it and gain experience with it.

26 Lessons learned during that rapid evolution can be applied incrementally and immediately in current production, not filed away for the next huge plant a decade or two later.

27 Distributed resources move labor from field worksites, where productivity gains are sparse, to the factory, where they're huge.

28 Distributed resources' construction tends to be far simpler, not requiring an expensively scarce level of construction management talent.

29 Faster construction means less workforce turnover, less retraining, and more craft and management continuity than would be possible on a decade-long project.

30 Distributed resources exploit modern and agile manufacturing techniques, highly competitive innovation, standardized parts, and commonly available production equipment shared with many other industries. All of these tend to reduce costs and delays.

31 Shorter lead time reduces exposure to changes in regulatory rules during construction.

32 Technologies that can be built quickly before the rules change and are modular so they can "learn faster" and embody continuous improvement are less exposed to regulatory risks.

33 Distributed technologies that are inherently benign (renewables) are less likely to suffer from regulatory restrictions.

34 Distributed resources may be small enough per unit to be considered *de minimis* and avoid certain kinds of regulation.

35 Smaller, faster modules offer some risk-reducing degree of protection from interest-rate fluctuations, which could be considered a regulatory risk if attributed to the Federal Reserve or similar national monetary authorities.

36 The flexibility of distributed resources allows managers to adjust capital investments continuously and incrementally, more exactly tracking the unfolding future, with continuously available options for modification or exit to avoid trapped equity.

37 Small, short-lead-time resources incur less carrying-charge penalty if suspended to await better information, or even if abandoned.

38 Distributed resources typically offer greater flexibility in accelerating completion if this becomes a valuable outcome.

39 Distributed resources allow capacity expansion decisions to become more routine and hence lower in transaction costs and overheads.

40 Distributed generation allows more learning before deciding, and makes learning a continuous process as experience expands rather than episodic with each lumpy, all-or-nothing decision.

41 Smaller, shorter-lead-time, more modular units tend to offer cheaper and more flexible options to planners seeking to minimize regret, because such resources can better adapt to and more cheaply guard against uncertainty about how the future will unfold.

42 Modular plants have off-ramps so that stopping the project is not a total loss: value can still be recovered from whatever modules were completed before the stop.

43 Distributed resources' physical portability will typically achieve a higher expected value than an otherwise comparable non-portable resource, because if circumstances change, a portable resource can be physically redeployed to a more advantageous location.

44 Portability also merits a more favorable discount rate because it is less likely that the anticipated value will not be realized—even though it may be realized in a different location than originally expected.

45 A service provider or third-party contractor whose market reflects a diverse range of temporary or uncertain-duration service needs can maintain a "lending library" of portable distributed resources that can achieve high collective utilization, yet at each deployment avoid inflexible fixed investments that lack assurance of long-term revenue.

46 Modular, standardized, distributed, portable units can more readily be resold as commodities in a secondary market, so they have a higher residual or salvage value than corresponding monolithic, specialized, centralized, nonportable units that have mainly a demolition cost at the end of their useful lives.

47 The value of the resale option for distributed resources is further enhanced by their divisibility into modules, of which as many as desired may be resold and the rest retained to a degree closely matched to new needs.

48 Distributed resources typically do little or no damage to their sites, and hence minimize or avoid site remediation costs if redeployed, salvaged, or decommissioned.

49 Volatile fuel prices set by fluctuating market conditions represent a financial risk. Many distributed resources do not use fuels and thus avoid that costly risk.

50 Even distributed resources that do use fuels, but use them more efficiently or dilute their cost impact by a higher ratio of fixed to variable costs, can reduce the financial risk of volatile fuel prices.

51 Resources with a low ratio of variable to fixed costs, such as renewables and end-use efficiency, incur less cost volatility and hence merit more favorable discount rates.

52 Fewer staff may be needed to manage and maintain distributed generation plants: contrary to the widespread assumption of higher per-capita overheads, the small organizations required can actually be leaner than large ones.

53 Meter-reading and other operational overheads may be quite different for renewable and distributed resources than for classical power plants.

54 Distributed resources tend to have lower administrative overheads than centralized ones because they do not require the same large organizations with broad capabilities nor, perhaps, more complex legally mandated administrative and reporting requirements.

55 Compared with central power stations, mass-produced modular resources should have lower maintenance equipment and training costs, lower carrying charges on spare-parts inventories, and much lower unit costs for spare parts made in higher production runs.

56 Unlike different fossil fuels, whose prices are highly correlated with each other, non-fueled resources (efficiency and renewables) have constant, uncorrelated prices that reduce the financial risk of an energy supply portfolio.

57 Efficiency and cogeneration can provide insurance against uncertainties in load growth because their output increases with electricity demand, providing extra capacity in exactly the conditions in which it is most valuable, both to the customer and to the electric service provider.

58 Distributed resources are typically sited at the downstream (customer) end of the traditional distribution system, where they can most directly improve the system's lowest load factors, worst losses, and highest marginal grid capital costs—thus creating the greatest value.

59 The more fine-grained the distributed resource—the closer it is in location and scale to customer load—the more exactly it can match the temporal and spatial pattern of the load, thus maximizing the avoidance of costs, losses, and idle capacity.

60 Distributed resources matched to customer loads can displace the least utilized grid assets.

61 Distributed resource matched to customer loads can displace the part of the grid that has the highest losses.

62 Distributed resources matched to customer loads can displace the part of the grid that typically has the biggest and costliest requirements for reactive power control.

63 Distributed resources matched to customer loads can displace the part of the grid that has the highest capital costs.

64 Many renewable resources closely fit traditional utility seasonal and daily loadshapes, maximizing their "capacity credit"—the extent to which each kW of renewable resource can reliably displace dispatchable generating resources and their associated grid capacity.

65 The same loadshape-matching enables certain renewable sources (such as photovoltaics in hot, sunny climates) to produce the most energy at the times when it is most valuable—an attribute that can be enhanced by design.

66 Reversible-fuel-cell storage of photovoltaic electricity can not only make the PVs a dispatchable electrical resource, but can also yield useful fuel-cell byproduct heat at night when it is most useful and when solar heat is least available.

67 Combinations of various renewable resources can complement each other under various weather conditions, increasing their collective reliability.

68 Distributed resources such as photovoltaics that are well matched to substation peak load can precool the transfomer—even if peak load lasts longer than peak PV output—thus boosting substation capacity, reducing losses, and extending equipment life.

69 In general, interruptions of renewable energy flows due to weather can be predicted earlier and with higher confidence than interruptions of fossil-fueled or nuclear energy flows due to malfunction or other mishap.

70 Such weather-related interruptions of renewable sources also generally last for a much shorter time than major failures of central thermal stations.

71 Some distributed resources are the most reliable known sources of electricity, and in general, their technical availability is improving more and faster than that of centralized resources. (End-use efficiency resources are by definition 100% available—effectively, even more.)

72 Certain distributed generators' high technical availability is an inherent per-unit attribute—not achieved through the extra system costs of reserve margin, interconnection, dispersion, and unit and technological diversity required for less reliable central units to achieve the equivalent supply reliability.

73 In general, given reasonably reliable units, a large number of small units will have greater collective reliability than a small number of large units, thus favoring distributed resources.

74 Modular distributed generators have not only a higher collective availability but also a narrower potential range of availability than large, non-modular units, so there is less uncertainty in relying on their availability for planning purposes.

75 Most distributed resources, especially renewables, tend not only to fail less than centralized plants, but also to be easier and faster to fix when they do fail.

76 Repairs of distributed resources tend to require less exotic skills, unique parts, special equipment, difficult access, and awkward delivery logistics than repairs of centralized resources.

77 Repairs of distributed resources do not require costly, hard-to-find large blocks of replacement power, nor require them for long periods.

78 When a failed individual module, tracker, inverter, or turbine is being fixed, all the rest in the array continue to operate.

79 Distributed generation resources are quick and safe to work with: no post-shutdown thermal cooling of a huge thermal mass, let alone radioactive decay, need be waited out before repairs can begin.

80 Many distributed resources operate at low or ambient temperatures, fundamentally increasing safety and simplicity of repair.

81 A small amount of energy storage, or simple changes in design, can disproportionately increase the capacity credit due to intermittent renewable resources.

82 Distributed resources have an exceptionally high grid reliability value if they can be sited at or near the customer's premises, thus risking less "electron haul length" where supply could be interrupted.

83 Distributed resources tend to avoid the high voltages and currents and the complex delivery systems that are conducive to grid failures.

84 Deliberate disruptions of supply can be made local, brief, and unlikely if electric systems are carefully designed to be more efficient, diverse, dispersed, and renewable.

85 By blunting the effect of deliberate disruptions, distributed resources reduce the motivation to cause such disruptions in the first place.

86 Distributed generation in a large, far-flung grid may change its fundamental transient-response dynamics from unstable to stable—especially as the distributed resources become smaller, more widespread, faster-responding, and more intelligently controlled.

87 Modular, short-lead-time technologies valuably temporize: they buy time, in a self-reinforcing fashion, to develop and deploy better technologies, learn more, avoid more decisions, and make better decisions. The faster the technological and institutional change, and the greater the turbulence, the more valuable this time-buying ability becomes. The more the bought time is used to do things that buy still more time, the greater the leverage in avoided regret.

88 Smaller units, which are often distributed, tend to have a lower forced outage rate and a higher equivalent availability factor than larger units, thus decreasing reserve margin and spinning reserve requirements.

89 Multiple small units are far less likely to fail simultaneously than a single large unit.

90 The consequences of failure are far smaller for a small than for a large unit.

91 Smaller generating units have fewer and generally briefer scheduled or forced maintenance intervals, further reducing reserve requirements.

92 Distributed generators tend to have less extreme technical conditions (temperature, pressure, chemistry, etc.) than giant plants, so they tend not to incur the inherent reliability problems of more exotic materials pushed closer to their limits—thus increasing availability.

93 Smaller units tend to require less stringent technical reliability performance (*e.g.*, failures per meter of boiler tubing per year) than very large units in order to achieve the same reliability (in this instance, because each small unit has fewer meters of boiler tubing)—thus again increasing unit availability and reducing reserves.

94 "Virtual spinning reserve" provided by distributed resources can replace traditional central-station spinning reserve at far lower cost.

95 Distributed substitutes for traditional spinning reserve capacity can reduce its operating hours —hence the mechanical wear, thermal stress, corrosion, and other gradual processes that shorten the life of expensive, slow-to-build, and hard-to-repair central generating equipment.

96 When distributed resources provide "virtual spinning reserve," they can reduce cycling, turn-on/shutdown, and low-load "idling" operation of central generating units, thereby increasing their lifetime.

97 Such life extension generally incurs a lower risk than supply expansion, and hence merits a more favorable risk-adjusted discount rate, further increasing its economic advantage.

98 Distributed resources can help reduce the reliability and capacity problems to which an aging or overstressed grid is liable.

99 Distributed resources offer greater business opportunities for profiting from hot spots and price spikes, because time and location-specific costs are typically more variable within the distribution system than in bulk generation.

100 Strategically, distributed resources make it possible to position and dispatch generating and demand-side resources optimally so as to maximize the entire range of distributed benefits.

101 Distributed resources (always on the demand side and often on the supply side) can largely or wholly avoid every category of grid costs on the margin by being already at or near the customer and hence requiring no further delivery.

102 Distributed resources have a shorter haul length from the more localized (less remote) source to the load, hence less electric resistance in the grid.

103 Distributed resources reduce required net inflow from the grid, reducing grid current and hence grid losses.

104 Distributed resources cause effective increases in conductor cross-section per unit of current (thereby decreasing resistance) if an unchanged conductor is carrying less current.

105 Distributed resources result in less conductor and transformer heating, hence less resistance.

106 Distributed resources' ability to decrease grid losses is increased because they are close to customers, maximizing the sequential compounding of the different losses that they avoid.

107 Distributed photovoltaics particularly reduce grid loss load because their output is greatest at peak hours (in a summer-peaking system), disproportionately reducing the heating of grid equipment.

108 Such onpeak generation also reduces losses precisely when the reductions are most valuable.

109 Since grid losses avoided by distributed resources are worth the product of the number times the value of each avoided kWh of losses, their value can multiply rapidly when using area- and time-specific costs.

110 Distributed resources can reduce reactive power consumption by shortening the electron haul length through lines and by not going through as many transformers—both major sources of inductive reactance.

111 Distributed resources can reduce current flows through inductive grid elements by meeting nearby loads directly rather than by bringing current through lines and transformers.

112 Some end-use-efficiency resources can provide reactive power as a free byproduct of their more efficient design.

113 Distributed generators that feed the grid through appropriately designed DC-to-AC inverters can provide the desired real-time mixture of real and reactive power to maximize value.

114 Reduced reactive current improves distribution voltage stability, thus improving end-use device reliability and lifetime, and enhancing customer satisfaction, at lower cost than for voltage-regulating equipment and its operation.

115 Reduced reactive current reduces conductor and transformer heating, improving grid components' lifetime.

116 Reduced reactive current, by cooling grid components, also makes them less likely to fail, improving the quality of customer service.

117 Reduced reactive current, by cooling grid components, also reduces conductor and transformer resistivity, thereby reducing real-power losses, hence reducing heating, hence further improving component lifetime and reliability.

118 Reduced reactive current increases available grid and generating capacity, adding to the capacity displacement achieved by distributed resources' supply of real current.

119 Distributed resources, by reducing line current, can help avoid voltage drop and associated costs by reducing the need for installing equipment to provide equivalent voltage support or step-up.

120 Distributed resources that operate in the daytime, when sunlight heats conductors or transformers, help to avoid costly increases in circuit voltage, reconductoring (replacing a conductor with one of higher ampacity), adding extra circuits, or, if available, transferring load to other circuits with spare ampacity.

121 Substation-sited photovoltaics can shade transformers, thereby improving their efficiency, capacity, lifetime, and reliability.

122 Distributed resources most readily replace distribution transformers at the smaller transformer sizes that have higher unit costs.

123 Distributed resources defer or avoid adding grid capacity.

124 Distributed resources, by reducing the current on transmission and distribution lines, free up grid capacity to provide service to other customers.

125 Distributed resources help "decongest" the grid so that existing but encumbered capacity can be freed up for other economic transactions.

126 Distributed resources avoid the siting problems that can occur when building new transmission lines.

127 These siting problems tend to be correlated with the presence of people, but people tend to correlate with both loads and opportunities for distributed resources.

128 Distributed resources' unloading, hence cooling, of grid components can disproportionately increase their operating life because most of the life-shortening effects are caused by the highest temperatures, which occur only during a small number of hours.

129 More reliable operation of distribution equipment can also decrease periodic maintenance costs and outage costs.

130 Distributed resources' reactive current, by improving voltage stability, can reduce tapchanger operation on transformers, increasing their lifetime.

131 Since distributed resources are nearer to the load, they increase reliability by reducing the length the power must travel and the number of components it must traverse.

132 Carefully sited distributed resources can substantially increase the distribution system operator's flexibility in rerouting power to isolate and bypass distribution faults and to maintain service to more customers during repairs.

133 That increased delivery flexibility reduces both the number of interrupted customers and the duration of their outage.

134 Distributed generators can be designed to operate properly when islanded, giving local distribution systems and customers the ability to ride out major or widespread outages.

135 Distributed resources require less equipment and fewer procedures to repair and maintain the generators.

136 Stand-alone distributed resources not connected to the grid avoid the cost (and potential ugliness) of extending and connecting a line to a customer's site.

137 Distributed resources can improve utility system reliability by powering vital protective functions of the grid even if its own power supply fails.

138 The modularity of many distributed resources enables them to scale down advantageously to small loads that would be uneconomic to serve with grid power because its fixed connection costs could not be amortized from electricity revenues.

139 Many distributed resources, notably photovoltaics, have costs that scale far more closely to their loads than do the costs of distribution systems.

140 Distributed generators provide electric energy that would otherwise have to be generated by a centralized plant, backed up by its spinning reserve, and delivered through grid losses to the same location.

141 Distributed resources available on peak can reduce the need for the costlier to-keep-warm centralized units.

142 Distributed resources very slightly reduce spinning reserves' operational cost.

143 Distributed resources can reduce power stations' startup cycles, thus improving their efficiency, lifetime, and reliability.

144 Inverter-driven distributed resources can provide extremely fast ramping to follow sudden increases or decreases in load, improving system stability and component lifetimes.

145 By combining fast ramping with flexible location, often in the distribution system, distributed resources may provide special benefits in correcting transients locally before they propagate upstream to affect more widespread transmission and generating resources.

146 Distributed resources allow for net metering, which in general is economically beneficial to the distribution utility (albeit at the expense of the incumbent generator).

147 Distributed resources may reduce utilities' avoided marginal cost and hence enable them to pay lower buyback prices to Qualifying Facilities.

148 Distributed resources' ability to provide power of the desired level of quality and reliability to particular customers—rather than just a homogeneous commodity via the grid—permits providers to match their offers with customers' diverse needs and to be paid for that close fit.

149 Distributed resources can avoid harmonic distortion in the locations where it is both more prevalent (*e.g.*, at the end of long rural feeders) and more costly to correct.

150 Certain distributed resources can actively cancel harmonic distortion in real time, at or near the customer level.

151 Whether provided passively or actively, reduced harmonics means lower grid losses, equipment heating (which reduces life and reliability), interference with end-user and grid-control equipment, and cost of special harmonic-control equipment.

152 Appropriately designed distributed inverters can actively cancel or mitigate transients in real time at or near the customer level, improving grid stability.

153 Many distributed resources are renewable, and many customers are willing to pay a premium for electricity produced from a non-polluting generator.

154 Distributed resources allow for local control of generation, providing both economic-development and political benefits.

155 Certain distributed nonelectric supply-side resources such as daylighting and passive ventilation can valuably improve non-energy attributes (such as thermal, visual, and acoustic comfort), hence human and market performance.

156 Bundling distributed supply- with demand-side resources increases many of distributed generation's distributed benefits per kW, *e.g.*, by improving match to loadshape, contribution to system reliability, or flexibility of dispatching real and reactive power.

157 Bundling distributed supply- with demand-side resources means less supply, improving the marketability of both by providing more benefits (such as security of supply) per unit of cost.

158 Bundling distributed supply- with demand-side resources increases the provider's profit or price flexibility by melding lower supply-side with higher demand-side margins.

159 Certain distributed resources can valuably burn local fuels that would otherwise be discarded, often at a financial and environmental cost.

160 Distributed resources provide a useful amount and temperature of waste heat conveniently close to the end-use.

161 Photovoltaic (or solar-thermal) panels on a building's roof can reduce the air conditioning load by shading the roof—thus avoiding air-conditioner and air-handling capacity, electricity, and the capacity to generate and deliver it, while extending roof life.

162 Some distributed resources like microturbines produce carbon dioxide, which can be used as an input to greenhouses or aquaculture farms.

163 Some types of distributed resources like photovoltaic tiles integrated into a roof can displace elements of the building's structure and hence of its construction cost.

164 Distributed resources make possible homes and other buildings with no infrastructure in the ground—no pipes or wires coming out—thus saving costs for society and possibly for the developer.

165 Because it lacks electricity, undeveloped land may be discounted in market value by more than the cost of installing distributed renewable generation—making that power source better than free.

166 Since certain distributed resources don't pollute and are often silent and inconspicuous, they usually don't reduce, and may enhance, the value of surrounding land—contrary to the effects of central power plants.

167 Some distributed resources can be installed on parcels of land that are too small, steep, rocky, odd-shaped, or constrained to be valuable for real-estate development.

168 Some distributed resources can be double-decked over other uses, reducing or eliminating net land costs. (Double-decking over utility substations, etc., can also yield valuable shading benefits that reduce losses (# 168) and extend equipment life.)

169 The shading achieved by double-decking PVs above parked cars or livestock can yield numerous private and public side-benefits.

170 Distributed resources may reduce society's subsidy payments compared with centralized resources.

171 Distributed resources can significantly—and when deployed on a large scale can comprehensively and profoundly—improve the resilience of electricity supply, thus reducing many kinds of social costs, risks, and anxieties, including military costs and vulnerabilities.

172 Technologies perceived as benign in their local impacts make siting approvals more likely, reducing the risk of project failure and lost investment and hence reducing the risk premium demanded by investors.

173 Technologies perceived as benign or de minimis in their local impacts can often also receive siting approvals faster, or can even be exempted from approvals processes, further shortening construction time and hence reducing financial cost and risk.

174 Technologies perceived as benign in their local impacts have wide flexibility in siting, making it possible to shop for lower-cost sites.

175 Technologies perceived as benign in their local impacts have wide flexibility in siting, making it easier to locate them in the positions that will maximize system benefits.

176 Siting flexibility is further increased where the technology, due to its small scale, cogeneration potential, and perhaps nonthermal nature, requires little or no heat sink.

177 Distributed resources' local siting and implementation tend to increase their local economic multiplier and thereby further enhance local acceptance.

178 Distributed resources can often be locally made, creating a concentration of new skills, industrial capabilities, and potential to exploit markets elsewhere.

179 Most well-designed distributed resources reduce acoustic and aesthetic impacts.

180 Distributed resources can reduce irreversible resource commitments and their inflexibility.

181 Distributed resources facilitate local stakeholder engagements and increase the community's sense of accountability, reducing potential conflict.

182 Distributed resources generally reduce and simplify public health and safety impacts, especially of the more opaque and lasting kinds.

183 Distributed resources are less liable to the regulatory "ratcheting" feedback that tends to raise unit costs as more plants are built and as they stimulate more public unease.

184 Distributed resources are fairer, and seen to be fairer, than centralized resources because their costs and benefits tend to go to the same people at the same time.

185 Distributed resources have less demanding institutional requirements, and tend to offer the political transparency and attractiveness of the vernacular.

186 Distributed resources lend themselves to local decisions, enhancing public comprehension and legitimacy.

187 Distributed resources are more likely than centralized ones to respect and fit community and jurisdictional boundaries, simplifying communications and decision-making.

188 Distributed resources better fit the scale of communities' needs and ability to address them.

189 Distributed resources foster institutional structure that is more weblike, learns faster, and is more adaptive, making the inevitable mistakes less likely, consequential, and lasting.

190 Distributed resources' smaller, more agile, less bureaucratized institutional framework is more permeable and friendly to information flows inward and outward, further speeding learning.

191 Distributed resources' low cost and short lead time for experimental improvement encourages and rewards more of it and hence accelerates it.

192 Distributed resources' size and technology (frequently well correlated) generally merit and enjoy a favorable public image that developers, in turn, are generally both eager and able to uphold and enhance, aligning their goals with the public's.

193 With some notable exceptions such as dirty engine generators, distributed resources tend to reduce total air emissions per unit of energy services delivered.

194 Since distributed resources' air emissions are directly experienced by the neighbors with the greatest influence on local acceptance and siting, political feedback is short and quick, yielding strong pressure for clean operations and continuous improvement.

195 Due to scale, technology, and local accountability informed by direct perception, the rules governing distributed resources are less likely to be distorted by special-interest lobbying than those governing centralized resources.

196 Distributed utilities tend to require less, and often require no, land for fuel extraction, processing, and transportation.

197 Distributed resources' land-use tends to be temporary rather than permanent.

198 Distributed resources tend to reduce harm to fish and wildlife by inherently lower impacts and more confined range of effects (so that organisms can more easily avoid or escape them).

199 Some distributed resources reduce and others altogether avoid harmful discharges of heat to the environment.

200 Some hydroelectric resources may be less harmful to fish at small than at large scale.

201 The greater operational flexibility of some distributed resources, and their ability to serve multiple roles or users, may create new opportunities for power exchange benefiting anadromous fish.

202 Well-designed distributed resources are often less materials- and energy-intensive than their centralized counterparts, comparing whole systems for equal delivered production.

203 Distributed resources' often lower materials and energy intensity reduces their indirect or embodied pollution from materials production and manufacturing.

204 Many distributed resources' reduced materials intensity reduces their indirect consumption of depletable mineral resources.

205 The small scale, standardization, and simplicity of most distributed resources simplifies their repair and may improve the likelihood of their remanufacture or recycling, further conserving materials.

206 Many distributed resources withdraw and consume little or no water.

207 Many distributed resources offer psychological or social benefits of almost infinite variety to users whose unique prerogative it is to value them however they choose.

Site Map

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Appendix K

Appendix K

Distributed Generation in Canada -
Maximizing the benefits of renewable resources

August 2006

This paper is one of eight background reports on the Canadian Renewable Energy Alliance's model framework and recommendations for a comprehensive Canadian renewable energy strategy. This paper includes recommendations for provincial energy efficiency and conservation policies and for actions backed up by national enabling measures and international participation.

For information on the recommendations contained in this paper, contact **Alex Doukas** at **the Ontario Sustainable Energy Asssociation**: alex@ontario-sea.org

The Canadian Renewable Energy Alliance (CanREA) is an alliance of Canadian civil society organizations from the non-profit or voluntary sector that share an interest in maximizing energy efficiency and conservation and promoting a global transition to low-impact renewable energy. Members of CanREA believe that this transition is needed to address global climate change, pollution, global energy supply, human security, poverty eradication and economic sustainability. CanREA recognizes that our window of opportunity is limited and that this global transition must begin now through individual country action, international co-operation and a range of innovative market instruments, regulatory measures, public education efforts and voluntary actions.

The organizations actively involved in the formation of CanREA include:
- Canadian Association for Renewable Energies
- BC Sustainable Energy Association
- The David Suzuki Foundation
- Falls Brook Centre
- The Halifax Initiative
- One Sky—The Canadian Institute for Sustainable Living
- The Ontario Sustainable Energy Association
- The Pembina Institute
- Pollution Probe
- The Saskatchewan Environmental Society
- The Sierra Youth Coalition
- STORM Coalition

For more information on CanREA and its members, visit our website at **www.canrea.ca**

Appendix L

Distributed Generation in Canada - Maximizing the benefits of renewable resources

1. Distributed Generation in Canada

Renewable energy sources are rapidly becoming a key contributor to Canada's electricity supply mix. As the nation's energy infrastructure ages, moving towards clean and inexhaustible sources of electricity is becoming a precondition of Canada's continued economic success in a competitive global market. Social, health and environmental constraints are fuelling a shift in national and regional energy policy, not only in Canada, but around the world.

Historically, energy policy in Canada has emphasized large centralized electricity generation and long-distance, high-voltage transmission from centralized sources such as large-scale hydro, coal, natural gas and nuclear power plants. Canada's aging centralized energy infrastructure is becoming more problematic as demand for clean, reliable and affordable electricity generation grows. North America's centralized grid system, stressed to its limits,[1] has become vulnerable, increasingly brittle,[2] and inefficient. Over-reliance on large, polluting and expensive generation and transmission is no longer an option that Canadians will endorse. More and more frequently, centralized generation is being supplemented or replaced by distributed generation (DG), a new way of thinking about electricity generation, transmission and distribution. The market share of renewable DG continues to grow, and shows no signs of slowing.

Over the past 15 years, a number of factors have helped to push DG to the fore of electricity generation: new innovations in DG technologies, the liberalization of electricity markets generally allowing for the participation of more generators, growing concern around climate change and increasing consumer demand coupled with environmental and social constraints on the construction of new transmission infrastructure have all combined to make renewable DG an appealing option.[3] As of 2005, fully 25% of new electricity generation installed came from distributed resources, compared to only 13% in 2002.[4] To be on the leading edge of this growth trend, all levels of government, along with several other actors, must adapt to a rapidly changing electricity market.

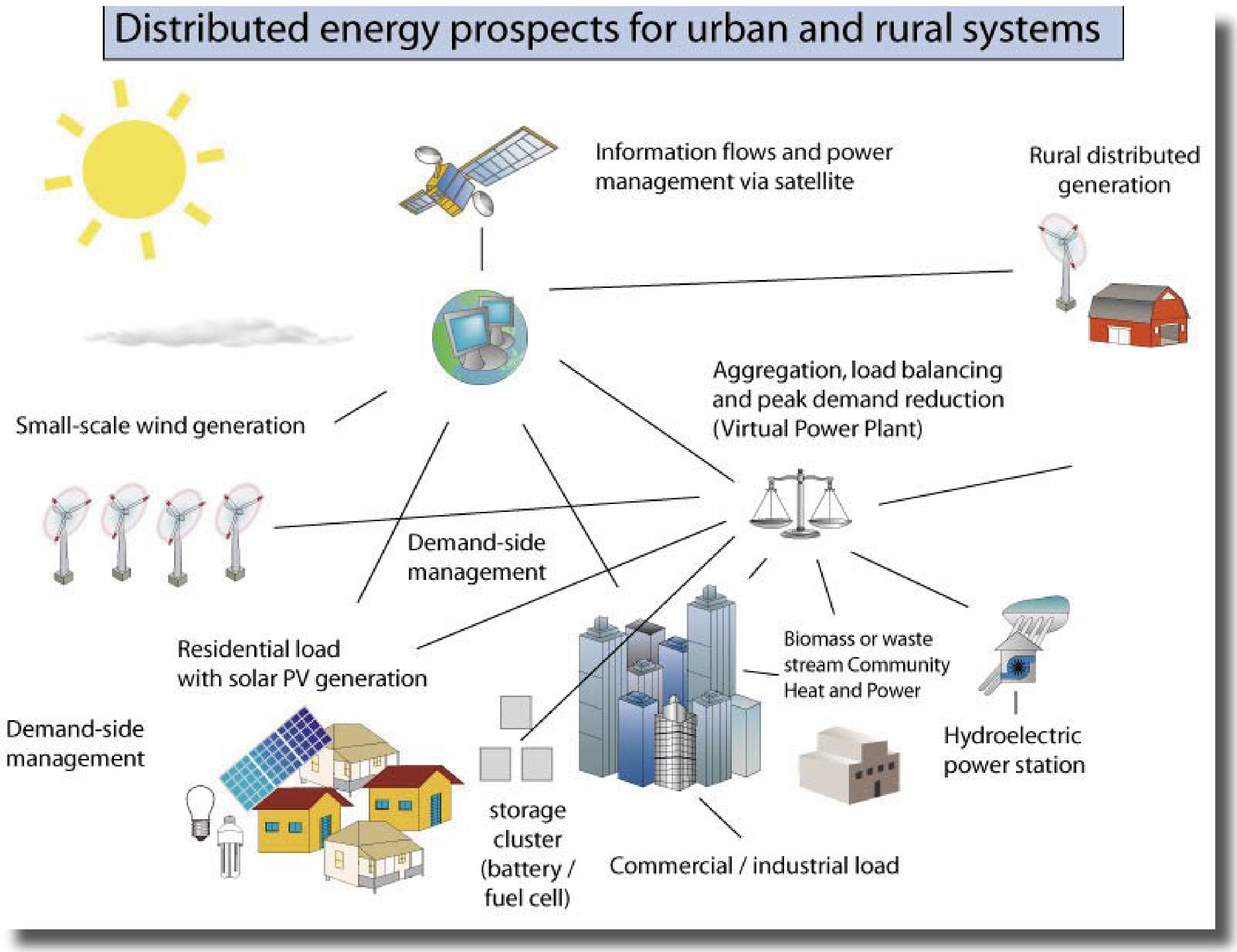
Several provinces, including Ontario, Quebec, Nova Scotia, P.E.I. and B.C., are either currently undergoing or have recently undergone reviews of their long-term energy strategies. The opportunity for these provinces and for Canada to take advantage of distributed electricity generation is considerable, and while the provincial strategies are diverse, each expects that renewable technologies will play a significant role in electricity generation. At the federal level, Canada has made a commitment to reduce carbon dioxide emissions by 6% below 1990 levels between 2008-2012 as a party to the Kyoto Protocol.[5] This commitment will require a major overhaul of electricity generation in Canada; in 2005, Environment Canada reported that electricity and heat generation were responsible for emitting 133 000 kilotonnes of carbon dioxide, a number which increased to 202 000 kilotonnes, or more than a third of Canada's total emissions in 2003 when all energy use and energy industries are considered.[6] To achieve Canada's climate change goal, it is clear that we need to embark on a sustainable energy path that includes policies promoting low-impact renewable technologies.[7]

To realize the potential benefits of distributed generation and renewable energy fully requires not only a new way of thinking about electricity generation, but a new way of thinking about electricity transmission and distribution. An economically, environmentally and socially sustainable energy future will require aggressive adoption of DG technologies and planning practices. DG is a model of electricity generation that allows for thousands of decentralized, small-scale generators. The World Alliance for Decentralized Energy describes DG as "electricity production at or near the point of use".[8] Renewable energy technologies, one of the critical elements of a sustainable future for Canada, are typically modular and are better suited to less environmentally damaging,

Appendix L

distributed applications than larger conventional methods of electricity generation.[9] DG and renewable energy are closely linked, as the transition to renewable energy sources will result in a shift towards less centralized generation and grids as has been the case in Europe due to the nature of renewable technologies. By promoting an integrated approach to innovation in electricity generation as well as grid infrastructure and design, the benefits of renewable energy and DG can both be synergistically maximized. Figure 1, below, illustrates how a grid adapted to DG might appear.

Figure 1
Symbols for diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science.



The benefits offered by DG can be grouped into three closely linked and often overlapping categories: economic benefits, environmental benefits, and social benefits. Below, some of these benefits are described, with a particular focus on the economic impacts of DG.

2. Economic benefits

There is a strong economic case that supports the rapid deployment of DG technologies; indeed, there are many reasons that DG has grown to represent 25% of all new generation in 2005.[10] At the forefront are the technical and electrical engineering-related savings that can be achieved through DG: according to the International Energy Agency, broad deployment of DG could result in cost savings of nearly 30% of total electricity costs by mitigating transmission and distribution losses and displacing expensive infrastructure.[11] translating to hundreds of billions of dollars worldwide, and tens of billions of dollars in Canada alone. One of the economic benefits of DG is reduced transmission loss, or a significant reduction of the electricity wasted in the transmission of electric power over long distances. In 1995, transmission and distribution losses were estimated at 7.2% of total electricity generation in the United States.[12] Canada's grid architecture and infrastructure is similar to that of the United States, and it would not be unreasonable to speculate that a similar figure would apply in Canada, although precise data on this element of grid efficiency is lacking. It is important to note that grid-connected DG will still have losses associated with distribution; however, these costs are significantly lower than in a centralized, long-distance grid system, as emphasized by the IEA's estimate cited above of 30% lower total costs through DG as opposed to centralized generation.

Recently, increasing congestion on transmission lines that have been stretched to their maximum carrying capacity has resulted in even greater transmission losses as electricity demand grows.[13] North America's aging power grids are rapidly becoming more susceptible to congestion along transmission lines. The case of PJM Interconnection provides a pertinent illustration of this issue. PJM, the regional transmission organization largely responsible for the transmission of electricity throughout the Eastern U.S., estimated the costs associated with transmission congestion to be approximately U.S. $65 million in 1999. By 2004, congestion costs had risen to nearly U.S. $800 million, with 2005 costs estimated to be over U.S. $1 billion.[14] To relieve congestion, American Electric Power plans to build a new 765 kV transmission line for almost $3 billion.[15] Typically, DG is sited near end-users, where they can closely mirror customer loads and limit line losses while mitigating grid capital costs related to transmission.

Another constraint of long-distance transmission that can have adverse economic impacts is the reliability of electricity distribution in North America. When demand increases during hot weather, power lines heat up and sag, not only from the increased electricity flowing through the lines, but also from the warmer ambient temperatures and from solar thermal energy heating the black-sheathed transmission cables. This problem can pose a serious threat to system security; two of North America's more recent major blackouts, those in 1996 and 2003, were caused by overloaded lines sagging into trees, resulting in short circuits that precipitated a larger collapse of the electrical grid. [16] Just as electricity is needed most to provide relief for vulnerable individuals during periods of extreme temperatures, it is least available due to the constraints of the existing transmission system and centralized grid configuration. The costs of the 2003 North American blackout alone have been estimated variously to be between $4 billion and $10 billion. [17], [18]

Certain centralized generators are also more vulnerable to failure during extreme conditions due to technical constraints; during the European heat waves, centralized nuclear reactors must limit their output because of high temperatures.[19] Just when their electricity is in high demand, the large, centralized reactors were least able to respond to demand and had to decrease energy production to avoid collapse from overheating. Extraordinary measures were employed to avoid shutdowns, including the spraying of concrete buildings that housed reactors with water to cool them. Even this was not enough, and one of the reactors at the Fessenheim nuclear plant in Germany had to be shut down over concerns surrounding its stability.[20] Reactors also received special governmental permission to discharge water used as a reactor coolant into rivers at temperatures beyond an acceptable threshold established to ensure the safety of aquatic life, endangering fish populations. [21]
Because of its susceptibility to such failures, critics have often described North America's power grid as a "brittle" grid. The Electricity Consumers Resource Council was critical of the tenuous reliability of the grid that the 2003 blackout brought to light: "from a public policy perspective—in the U.S. or Canada—it really does not matter if the total economic damages are $4 billion, $6 or $10 billion, or anywhere in between. The point is that this type of event is unconscionable to the extent that a single utility's failure to properly trim trees is deemed the 'root cause' of the August 14 Blackout."

Such criticisms are not isolated, nor are they novel. As far back as 1981, in *Brittle Power*, an examination of energy security in the United States and North America, experts noted that the North American power grid "interconnects the units rather sparsely, with heavy dependence on a few critical links and nodes;" and that the grid tends to "knit the interconnected units into a synchronous system in such a way that it is difficult for a section to continue to operate if it becomes isolated—that is, since each unit's operation depends significantly on the synchronous operation of other units, failures tend to be systemwide." [22] The decentralization of electricity generation can greatly reduce the damage and disturbance caused by systemwide grid failure and catastrophic power interruptions through the implementation of microgrid systems (described briefly in the "best practices" section of this paper) which can safely provide power from DG to nearby loads during periods of general system failure. When centralized failures do occur, DG can also make positive contributions to restarting the power system, reducing downtime; as modular units, they tend to be far easier to restart that centralized units that rely on energy-intensive startup procedures. These benefits of DG are very valuable, but their degree of efficacy can vary significantly depending on how DG is deployed. Models already exist that can aid planners in quantifying the benefits of DG in particular applications to thereby improve grid planning and electricity supply decisions. [23]

DG offers numerous economic benefits beyond simply reducing line losses and improving system reliability or security. While certain applications of small-scale DG can result in diseconomies of scale, other applications may be far more economically efficient than centralized generation. Additionally, by being situated closer to loads, DG also extends the lifetime of both distribution / transmission and end-use devices, the former through reduced reactive current that helps to keep grid components cool and the latter through improving distribution voltage stability, which can very depending on the DG technologies used. [24]

In addition, DG can be implemented much faster to match generation and demand better than new centralized generation due to its modular nature. Unlike centralized generation plants, DG systems can closely match changes in projected demand achieved through conservation and efficiency strategies. Modular DG also has lower lead-times than most centralized generation, which translates to less financial risk from burgeoning cost overruns, reduced financial risk of under- or over-building in a volatile electricity market, and therefore leads to less financial exposure. It also results in less capital being tied up at any given time prior to a plant generating revenue. This means that costs can be recouped more quickly and debt can be repaid earlier, increasing the value of projects to investors. The smaller scale of DG power plants can also encourage streamlined permitting and planning processes, which means fewer project failures, and less risk to capital investors. Because the flexibility in siting DG is also greater than centralized generators, DG can service areas where a connection to transmission may be entirely uneconomical, eliminating the need for a costly interconnection or uneconomical expansion of transmission lines. [25]

The figures below illustrate some of the economic benefits of infrastructure deferral afforded by certain DG applications. Figure 2 shows a typical response to increasing load: constructing new centralized generation and expanding the transmission and distribution infrastructure. Figure 3 illustrates the costs avoided by scaling DG to meet the growing load.

Figure 2
Typical response to electricity demand growth

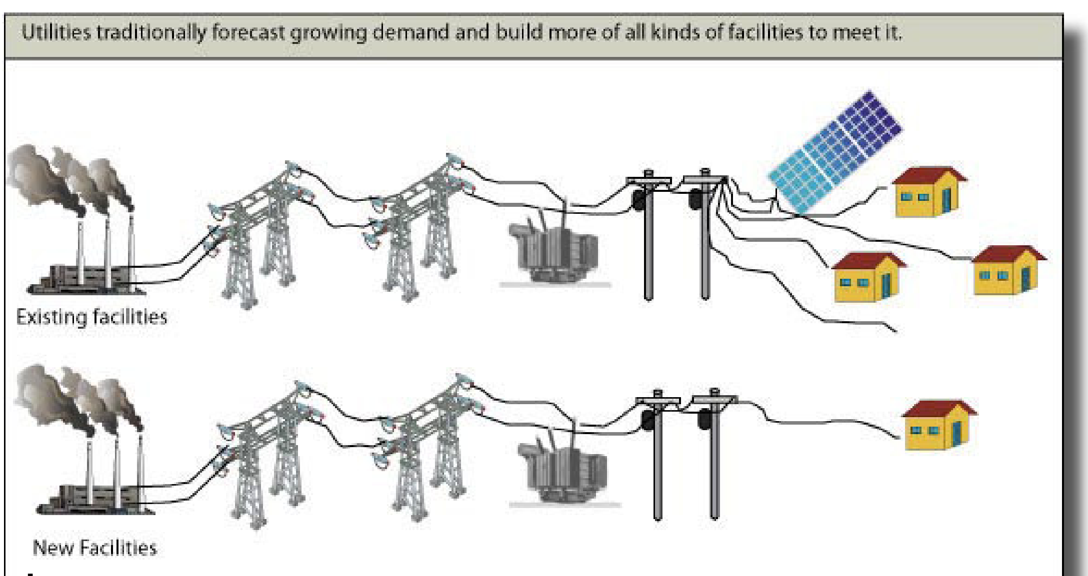
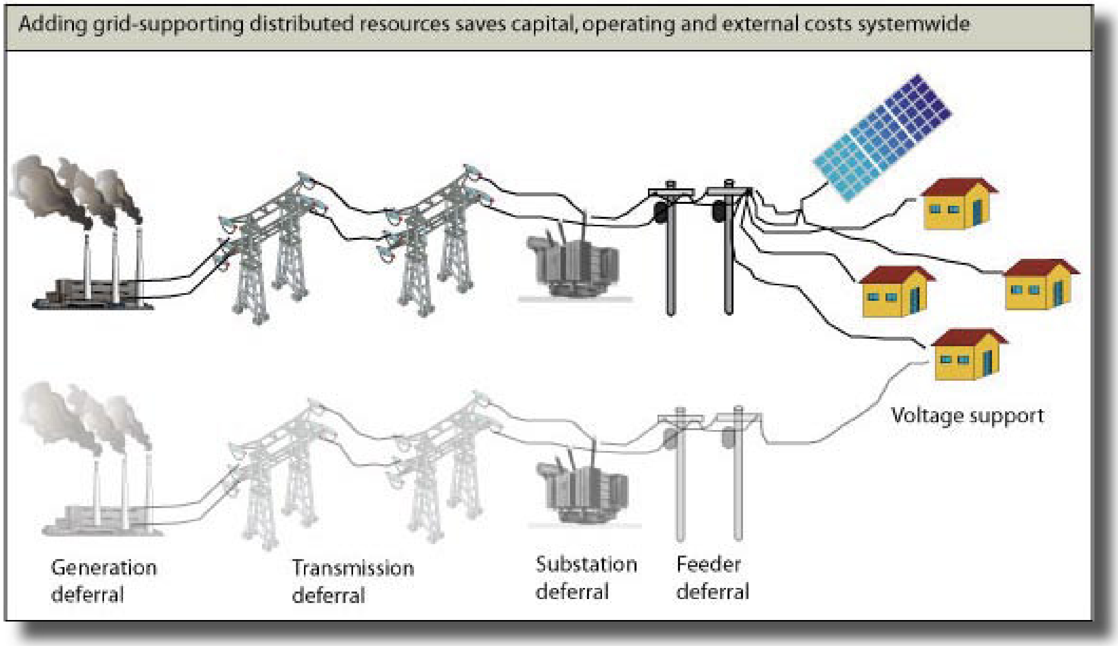


Figure 3
Transmission and infrastructure deferment as a result of DG deployment
Figures 2 and 3 adapted from: Lovins, A. et al. *Small is profitable: The hidden economic benefits of making electric resources the right size*. Snowmass: Rocky Mountain Institute. 2002.



Another major benefit of DG is the opportunity it presents for community economic development. DG allows communities to participate in electricity generation, creating jobs and stimulating local economies. Community-owned renewable energy can generate many times the economic activity of commercial development, keeping more energy dollars in communities. It can also provide significant alternative revenue streams for farmers and rural landowners. For more information in the economic impacts of DG in the context of community-based power projects, see the CanREA paper on community power in this series.

Combined heat and power (CHP) systems can also become even more financially attractive than they already are as the challenges facing DG are addressed. In CHP plants that use renewable fuel sources, biomass from crop residues, livestock byproducts, and other waste streams can be used to generate both electricity and heat. Not only does this increase generation capacity, but it also can assist in the management of crop residues that might normally be considered waste and have an associated disposal cost. Both the heat and the electricity generated by CHP systems are distributed to nearby end-users. When considering CHP applications for DG, it is important to carefully assess the environmental impacts of available technologies. Natural gas, for example, is not a renewable source of energy, and its combustion results in significant carbon dioxide releases.

When the multitude of economic advantages DG enjoys over centralized generation are viewed in their entirety, it should be unsurprising that the benefits of DG can increase the value of renewable energy resources by nearly a factor of ten. [26] While the economic argument for the rapid and extensive deployment of DG is strong enough to stand on its own merits, environmental and social benefits can also add significant value to renewable energy projects.

3. Environmental benefits

DG has the potential to greatly benefit the environment by reducing the need for ecologically disruptive centralized generation. The implications of DG deployment for renewable energy may well be the most significant environmental benefit conferred by DG. If changes to the generation, transmission and distribution system are made that facilitate DG, more renewable generators in more areas are sure to follow. From an ecological standpoint, it is critical that DG take the form of clean renewable energy that is minimally polluting. The electrical engineering and transmission and distribution benefits that accrue from DG are extremely valuable, but could be quickly negated by increased environmental impacts from diesel and natural gas generators that either release carbon dioxide, nitrous oxides, and sulphur dioxide or contribute those emissions during fuel processing. To be sustainable, DG must come in the form of renewable and clean sources, including wind, solar, and low-impact hydropower, along with sustainable biomass combustion. The environmental benefits of renewable energy are described in depth in the paper in this series that discusses Green Power, available through the Canadian Renewable Energy Alliance.

Additionally, smaller generation units in general tend to meet with more support than larger centralized generators. [27] Small clusters of two or three megawatt-scale wind turbines distributed in hundreds of locations tend to meet with a more favourable reaction from local residents than projects at scales of hundreds of megawatts. An increased acceptance of renewable technologies by local people will result in fewer barriers to the growth of renewables, increasing their positive impact on emissions profiles and their mitigation of extractive resource exploitation. Further, smaller-scale projects, when properly sited, tend to have less severe environmental impacts than fewer scaled-up projects using the same technology. Small run-of-the-river hydro projects tend to be less harmful to aquatic life, particularly fish populations, than larger scale hydroelectric generation. Embedded generation, such as the installation of solar photovoltaics on a roof, will minimize the environmental impacts of electricity generation by utilizing existing building envelopes efficiently.

By increasing the efficiency of energy transmission, DG can also reduce the overall demand for electricity, reducing not only the number of new generators but also the transmission and distribution infrastructure required for the delivery of electricity. Eliminating these structures also eliminates their potential environmental impacts, further increasing the attractiveness of DG from an environmental perspective. Offsetting the impacts of siting new transmission and distribution infrastructure is a significant opportunity presented by increasing the percentage of DG relative to centralized generation.

4. Social benefits

Due to the centralized nature of North American power grids, electricity sources “tend to lack the qualities of user controllability, comprehensibility, and user-independence”. [28] Essentially, this means that individuals and communities are unable to participate in electricity generation, resulting in a process that seems almost mystical to those who rely on electricity. Because DG allows for the rapid expansion of community-based electricity generation, many of the social benefits arising from community power are also a function of DG. Community power promotes awareness of the source of electricity generation, and encourages community participation in electricity generation; this in turn facilitates a more profound understanding of the impacts of electricity use and consumption. It has been demonstrated in the case of biomass plants that bottom-up decision-making that consults the public extensively can help to increase acceptance of new generation through the integration of their input during the project development phase. [29] Community-owned and controlled DG also tends to be more acceptable to local people from a siting perspective than large, centralized power plants.

Through community power, DG can help Canadians to better understand the value of renewable energy in reducing environmental impacts, stimulating community economic development, and forging stronger community ties. DG facilitates community economic development spurred by new renewable generation capacity at the community scale, and subsequently it encourages sustainable local development, allowing communities to retain more of their energy dollars.

The smaller components and human-scale nature of DG can also help people relate to electricity generation better than with centralized generators which may be incomprehensible and difficult to interact with in a meaningful way due to their complexity. Subsequently, rules and regulations governing not less susceptible to cooption by special interest groups than those elected to govern. [30] This can help lead to a more equitable model of electricity generation, where the benefits are dispersed as widely as the generators and end-users, directly

Appendix L

benefiting more Canadians.

DG's many diverse benefits make it an attractive option for the incremental replacement of a significant portion of centralized generation as aging power plants are taken offline. There are a number of considerations that play an important role in the effectiveness of DG applications, from grid design to city planning. In Canada, several barriers that prevent or disencentivize the deployment of renewable DG remain in place

5. Challenges to DG

Even for appropriate and sustainable applications of DG, barriers to development remain. For decades, centralized generation has been the dominant standard in North America and throughout the world. Tens of billions of dollars of cumulative investment has been poured into Canada's centralized infrastructure; as a result of this massive-scale investment, existing infrastructure and institutions are focused on the heavily centralized model of generation despite the advances in DG that have made it a financially, socially and environmentally attractive alternative. Because of the accumulated investment in the existing power system, DG often must adapt to existing systems in order to connect to the grid. While this is quite possible within the constraints of the centralized power system, DG may face unnecessarily burdensome requirements in their siting, interconnection to the grid, and their operation. Currently, grid-connected generators must be able to determine when the system as a whole is failing, and be able to disconnect at a moment's notice to allow utilities to resolve problems along the line and carry out necessary repairs. [31]

The primary concern that arises during a system failure that requires repairs relates to "islanding", where a generator will continue to produce power, electrifying an area of the distribution system even after other generators have taken their supply off-line. This situation can endanger not only generators and the distribution system, but can also imperil utility workers performing repairs to bring a system back online. [32] There are some answers to the grid conundrum that can hep to can be largely addressed through the implementation of microgrids. To the centralized grid, microgrids appear as any other customer. They can change between operating on or off of the central grid, and easily isolate themselves in the event of a systemwide failure to avoid islanding issues and to continue to provide power to the microgrid-serviced load. Microgrids can also shed nonessential load during periods of system strain or power shortage to avoid brownouts or blackouts and declines in power quality, while impacting the end-user only minimally. This can protect critical systems like computers systems and communications equipment that have become crucial to the functioning of our economy. [33]

Another concern that applies only to certain distributed renewable technologies is their variability. Wind turbines in particular are susceptible to high degrees of variability; they do not produce electricity when the wind does not blow. This is not so much a problem for DG, however, as it is an opportunity. As the British Wind Energy Association points out, **"**there is little overall impact if the wind stops blowing somewhere – it is always blowing somewhere else," and also that "[t]he more wind farms that are built over a wider geographical location, the more reliable wind energy is". [34] A 2005 study carried out by dena, the German Energy Agency, found that the wind capacity in Germany could be expanded up to as much as 36 000 MW by 2015 "without the addition of new plants to provide operational reserve." [35] Other options are available to mitigate potential problems include 'virtual utilities', describe in the "Best practices and future considerations" section below, that are capable of aggregating and dispatching distributed loads and generation may also play a role in mitigating the variability of wind in areas where variability has more sever impacts on the power system as a whole.

In order to deploy DG rapidly and constructively, Canada must overcome these challenges by utilizing technologies and management strategies that have already been developed. To ease the transition to DG in Canada, practitioners and policymakers can consider the adoption of several beneficial practices that have already been demonstrated successfully worldwide.

6. Best practices and future considerations

Several regions of the world have already begun a shift in earnest away from centralized generation toward DG. In much of Western Europe, extensive deployment of DG is already underway. To facilitate the shift toward renewable DG technologies and to promote their further growth, several European nations are working collaboratively through the EU to transform existing infrastructure into a system that captures all of the benefits of renewable DG. The SmartGrid Technology Platform involves research on technical and regulatory issues surrounding Europe's power system. In Europe, the integration of distributed resources with the power system is becoming increasingly important as the proportion of small generating systems increases, a multi-stakeholder effort to develop a new vision for electricity distribution and transmission networks. Participants include industry representatives, transmission and distribution system operators, research bodies and regulators. [36]

A major component of the smart grid vision is a fully computer-integrated power system, one that is responsive both to consumer and generator demands. Smart digital micromanagement of the power system allows for much more flexibility in both load and generation control, increasing the overall efficiency of grid operations while allowing for a far larger penetration of distributed resources than a brittle centralized system might be able to withstand. The SmartGrid vision intends to develop a toolkit of technical solutions that will address barriers to DG that can be applied in a cost-effective way, while helping to establish a uniform regulatory and standard technical climate for renewables throughout Europe to enable the transfer of electricity across borders. Ultimately, the Platform aims to integrate the emerging model of DG and the existing model of centralized generation through the deployment of new grid equipment that will help to ensure system reliability while streamlining control arrangements.

The SmartGrid Platform attempts to address a problem common to transmission and distribution networks. Because they tend to be so large-scale and expensive, transmission and distribution networks are often extremely limited by regulation, or their controlling interests have a natural monopoly with little or no viable competition, resulting in a disincentive to innovation. Even in a liberalized energy market, electricity distribution networks tend to act as natural monopolies due to their massive scale in a system that emphasizes centralized generation, and are thus regulated by an independent systems operator or through some other centralized institution.

LDCs and utilities, the groups that largely determine the practical shape of the power system, almost always act to maximize profits, and are hesitant to take risks in an environment where a natural monopoly exists. Despite these circumstances, the rapid growth of DG will require system operators to manage networks to actively moderate the grid rather than merely responding to situations when difficulties arise. To achieve a degree of precision may require the deployment of distributed computing, virtual utilities, and microgrids. To encourage these endeavours, regulatory bodies should provide incentives for grid innovation. Through their Innovation Funding Incentive, Britain's gas and electricity regulator already provides incentives for operators of distributed networks who innovate through applied research, development and deployment of new network technologies that facilitate DG.

To properly implement Smart Grids, Canada will have to capitalize on advancements in both distributed computing and power electronics. For example, in a Smart Grid system, the degree of micromanagement of both loads and generators will likely require sophisticated balancing systems capable of a high level of responsiveness. This is likely to result in the development of a concept often described as the 'virtual utility' or 'virtual power plant'. The virtual power plant is not a power plant in the traditional sense; it does not generate electricity, but instead acts as a hub that aggregates loads and generators, controlling dispatch and demand-side management in a decentralized fashion. Smart Grids can capitalize on advances in communications technology, utilizing internets in particular to synchronize operations, develop demand-side control at the micro- level, control generation response to strain on the centralized grid system, and enable new opportunities for novel ancillary services. These operations could be performed through a 'virtual utility' or 'virtual power plant', "a multi-fuel, multi-location and multi-owned power station" that can supply energy as necessary with the ability to change both generation and demand rapidly to correct system imbalances. [37]

The European Commission's introduction to DG highlights that the virtual power plant "is not itself a new technology but a method of organising decentralised generation and storage in a way that maximises the value of the generated electricity to the utility." [38], [39] While the technical and economic feasibility of virtual power plants depends largely on particular logistical and situational circumstances, the exploration of new options for maximizing the efficiency and capacity of DG resources will require incentives for distribution and transmission innovation.

Although incentivizing innovation within the transmission and distribution system is important in providing DG with access to the grid, establishing a fair market for renewable DG is perhaps the most critical factor in determining its success. There are several different ways to level the playing field for renewable DG that competes with heavily subsidized centralized, non-renewable generation: tax incentives, the establishment of a market for emissions certificates, and a number of other policy toolkits are available to regulators that can help to put renewable DG on fair footing with other sources of energy. Historically, however, the most successful policy mechanism in the promotion of distributed renewable energy has proven to be the Advanced Renewable Tariff (ART), known in Ontario as the Standard Offer Contract, and in many parts of Europe as the electricity feed-in law.

ARTs guarantee access to the grid for renewable generators, and offer a standardized price for the electricity they generate. In Europe, this policy mechanism has lead to more renewable capacity than any other policy. Germany, an early adopter of feed-in laws, is now one of the foremost producers of renewable energy, with well over 18 500 MW of installed capacity in wind generation alone, and approaching 1 000 MW of solar photovoltaic capacity. [40], [41] For both technologies, a considerable segment of new installations in Germany are under 10 MW. ARTs are also an equitable method in determining who will own what generation capacity, where it will be sited, and how it's controlled. Structured properly, ARTs can promote renewable DG while boosting community economic development.

ARTs have been utilized in 41 jurisdictions, including Germany, France, Spain, and the Netherlands, along with several other countries, and are being implemented or considered in Ontario, California, Italy, China, India and a number of other regions. In Europe, the ARTs used in Denmark, Germany, and Spain has helped to propel them to the forefront of renewable generation. The success of an ART is contingent on many factors. The policy must specify a contract length that is sufficient to provide a reasonable amount of stability and certainty to investors, often as long as 20 to 25 years. Prices must also be properly determined to allow smaller investors to invest with confidence without undue risk. Additionally, prices offered must be sufficient to encourage new investment in renewable energy, while remaining in line with the benefits that renewable DG provides. Sites with moderate resources must also be provided a sufficient price to ensure some profitability, a consideration of particular importance to DG. Yield-based pricing has worked particularly well in the case of Germany. [42] Finally, for ARTs to be approached by potential generators, both the contracts and the interconnection process must be streamlined[43] to ensure a minimum of difficulty in project development.[44]

With many jurisdictions now exploring and implementing DG options worldwide, Canada has several models from which an effective approach to the deployment of DG can by synthesized.

7. Recommendations

1. Recommendations for federal and provincial collaborations:

<u>Facilitate the rapid deployment of distributed generation:</u>

1.1 Provide access to development capital and adequate financing through innovative loan, grant and tax-based incentive programs: An integrated financial program, including zero- or low-interest loans, grants and progressive policy mechanisms will enable the participation of individuals and communities in DG, improve loan repayment and project success rates, and tap into community capital for energy infrastructure.

1.2 Implement effective renewable energy policy mechanisms, with particular consideration given to Advanced Renewable Tariffs (ARTs): In conjunction with the provision of start-up capital and adequate financing, provincial and territorial governments should adopt policy approaches that promote the growth of renewable DG. Advanced Renewable Tariffs (ARTs), such as the recently-announced Standard Offer Contract program in Ontario, are a proven mechanism of support for renewable DG. **The federal government has an opportunity to ensure that ARTs will work in jurisdictions across Canada by uniting the policy efforts of the provinces and territories,** while maintaining the WPPI as a complimentary support to ARTs across Canada. While ARTs can take different forms, their basic function is to provide a fixed price per kilowatt-hour of generation to community-scale generators of renewable energy for an extended contract term, typically from 15 to 20 years. These policies provide the stability To be effective drivers of DG, ART policies must have a few critical components. They must:

- streamline interconnection to the grid, allowing small-scale generators of renewable energy to sell their energy ;
- offer a reasonable fixed price to producers of renewable energy, preferably through a tiered pricing model based on site-specific resources to encourage the broad distribution of renewable generation capacity rather than concentrations of generation far from electricity loads;
- incorporate fair compensation for transmission loss reduction and avoided transmission costs in the contract pricing models;
- offer that fixed price over a sufficient contract duration to provide a degree of security and certainty for investors, banks, and other financiers, which enables the rapid growth of renewable electricity generation;
- allow for broad participation in electricity generation. Federal support for such policies will help harmonize regional approaches and speed implementation of progressive policy;

1.3 Invest in public and technical education on renewable energy, distributed generation and new technologies: Education programs give individuals and groups the confidence to invest in distributed renewable energy projects. Federal and provincial governments need to *provide funds for universities, colleges and civil society actors to implement and deploy DG* and educate the public, tradespeople and professionals. Provinces and territories must develop and implement practical strategies to train and educate a skilled technician base capable of supporting integrated power systems and distributed technologies through post-secondary and certificate-based training programs, utilizing existing programs like the Association of Canadian Community Colleges renewable energy program. The coordination of broad deployment and support strategies for DG could be carried out through a national renewable energy secretariat, as recommended by the Canadian Renewable Energy Association.

1.4 Provide technical support, educational resources and secondment opportunities for utilities and local distribution companies:
Historically, one of the most immediate barriers to DG in North America has been unfamiliarity with the technology involved or an unwillingness to participate in novel procedures and project types on the part of utilities and local distribution companies. This typically stems from a lack of resources that LDCs are able to dedicate to a particular type of generation, like DG. Because of the prevalence of centralized generation, not all LDCs have staff capable of dealing with DG in an equitable and informed manner, and so it may be necessary to build that capacity within LDCs. Through training programs and through the establishment of liaisons or technical assistance teams that can ensure the least-hassle solutions to DG-related issues are adopted and implemented widely, cutting down on the number of disputes between LDCs and potential generators. The implementation of recommendation 3.3 in this paper would also further the goal of involving LDCs considerably. Federal and

provincial governments need to facilitate staff secondments and professional development placements to increase local capacity.

2. Recommended actions for the federal government:
To continue to develop a distributed grid that makes sense for the future:

2.1 Implement a collaborative multi-stakeholder consortium to research and implement best practices for a secure, sustainable distributed grid: In the U.S., the GridWise Alliance is helping to form "an electric system that will employ new distributed 'plug and play' technologies using advanced telecommunications and information and control approaches" to create an internet-like power grid. In Europe, the SmartGrids Technology Platform[45] is coordinating the development of a grid that is flexible, accessible, reliable and economical. The federal government should coordinate a similar approach to reap the benefits of DG and to maintain Canada's competitiveness in the global market. The federal government should develop a new initiative, involving Natural Resources Canada, Industry Canada, Human Resources and Social Development Canada and provincial bodies to guide this process. [46]

2.2 Invest in innovative DG technologies: Maximizing the benefits of renewable energy and DG will require aggressive deployment and commercialization of existing energy storage technologies, power electronics and other mature technologies, such as the virtual power plant concept. By encouraging further growth in these industries, Canadian industries can capitalize on the global transition to a new era of DG.

3. Recommended actions for provincial and territorial governments
To facilitate the rapid deployment of distributed generation:

3.1 Remove barriers to grid interconnection for small-scale renewable generators: Many interconnection requirements designed for large, centralized generators are unnecessary for smaller generators. Developing safe and reasonable standards for interconnection will maximize the contributions of renewable energy and ensure the protection of grid operators and maintenance personnel. Many safety and system stability concerns surrounding DG relate to "islanding", a phenomenon that occurs when a section of a distribution system becomes electrically isolated from the rest of the system, while still being energized by DG that is connected to that section of the distribution system. [47] Using current anti-islanding methods could prove costly as the penetration of DG increases[48]. New grid and distribution system management techniques must be assessed and adopted where appropriate to facilitate the rapid growth of DG. The implementation of a SmartGrid style plan would include the establishment of microgrids, more isolated, localized distribution systems that present a potential solution to the islanding problem and can also improve localized system reliability. [49]

Many of these solutions, though achievable, challenge the status quo and will require the cooperation of local distribution companies, also known as LDCs. In order to make the prospect of DG favourable to LDCs, it is imperative that LDC / utility revenues do not remain a direct function of the number of kilowatt-hours of electricity they sell. Instead, analyses of utility effectiveness that take into account other metrics focusing on end-user satisfaction and benefits should be practiced to determine the level of service being provided by an LDC / utility. In this way, the participation of LDCs in a sustainable energy future with a strong commitment to renewable DG can be assured through the provision of meaningful incentives that will lead to a willingness to participate in and recognize the benefits of DG on the part of LDCs.

3.2 Standby Charges: In many provinces, LDCs can charge standby fees to load displacing generation. For small generators of electricity, such fees are administratively expensive and largely unwarranted. Small-scale generators should be exempted from standby charges wherever possible.

3.3 Streamline planning and permitting processes through the development of standards for embedded generation technologies in regional building codes, reasonable electrical standards, and streamlined siting procedures. Building codes should specify considerations that allow for future embedded solar generation where possible. For homeowners wishing to install embedded generation, permitting should be made as simple as possible. In the UK, new proposals have been tabled to limit planning restrictions on embedded and microgeneration, allowing homeowners to install solar panels and small-scale wind projects without having to endure a lengthy permitting process. [50]

3.4 Provide incentives for generators and utilities to move away from the traditional motivation of selling more electricity: The dissociation of revenue streams away from the total kilowatt hours of electricity sold by utilities is critical to the development of an energy efficient culture focused on conservation. In particular, "utilities should be rewarded not for selling more kWh, but for helping customers get desired end-use services," [51] an approach that has met with success in Oregon, [52] and one that is practicable in a Canadian context. Provincial governments, with the support of federal resources, can adopt a performance-based approach when evaluating the effectiveness of utilities and when considering who to provide incentives. By providing incentives or regulation that focuses utilities on providing the best possible service to the end customer rather than privileging those who sell the most electricity, significant demand reductions can be achieved as distribution companies and / or utilities bring their resources to bear on demand-side management issues, including conservation and energy efficiency.

4. Recommended actions for municipal and local governments

Advance local solutions to multiply the benefits of DG

4.1 Develop community energy plans and land-use policies that support distributed generation: Municipalities must develop policies and strategies that encourage the siting of DG technologies [53] to provide opportunities for improved energy security and to benefit from the revenue streams provided by distributed technologies. Rapidly growing areas, such as Ontario's York Region, must plan ahead to take advantage of the shift toward distributed and embedded generation.

4.2 Promote innovative, local solutions to growing energy demand: Local governments should look to local solutions for growing energy demand by engaging community members through partnerships in community / municipally-owned renewables.

Inspire and educate at the community level

4.3 Lead by example: Local governments can partner with community groups to create demonstration projects that educate community members and encourage the deployment of DG technologies [54] outside of the demonstration project.

4.4 Promote awareness and an understanding of energy issues: Public awareness campaigns to reduce electricity use and encourage smart energy choices are a key component of a DG vision, and can make local economies more attractive to businesses. Establishing and maintaining municipal or regional commitments to the mitigation of greenhouse gas emissions allows for an even greater role for DG in the near term than might otherwise develop.

Additional resources

SmartGrids Technology Platform: Vision and Strategy for Europe's Electricity Networks for the Future

http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf

GridWise Alliance

http://www.gridwise.org/

"A consortium of public and private stakeholders who have joined together in a collaborative effort to provide real-world technology solutions to support the U.S. Department of Energy's vision of a transformed national electric system. An electric system that will employ new distributed 'plug and play' technologies using advanced telecommunications, information and control approaches to create a society of devices that functions as an integrated transactive system."

Small is Profitable
http://www.smallisprofitable.org/
"Small is Profitable describes 207 ways in which the size of "electrical resources"-devices that make, save, or store electricity - affects their economic value. It finds that properly considering the economic benefits of 'distributed' (decentralized) electrical resources typically raises their value by a large factor, often approximately tenfold, by improving system planning, utility construction and operation, and service quality, and by avoiding societal costs. Small Is Profitable introduces engineering and financial practitioners, business managers and strategists, public policymakers, designers, and interested citizens to the new value opportunities presented by considering these economic benefits. It also provides a basic introduction to key concepts from such disciplines as electrical engineering, power system planning, and financial economics."

Endnotes

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