# Solar Photovoltaics in British Columbia

## A Scoping Review of Residential, Grid-Connected Systems


by

SEAN TYNAN


A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS (PLANNING)

in

THE FACULTY OF GRADUATE STUDIES

School of Community and Regional Planning

We accept this project as conforming to the required standard

………………………………………………………...

………………………………………………………...

………………………………………………………...

THE UNIVERSITY OF BRITISH COLUMBIA
Vancouver
April, 2010

## Abstract

This document provides information regarding recent developments in small-scale residential, grid-connected photovoltaic systems. The purpose of the document is three-fold: to explore the current status and potential of these systems within the Province of British Columbia, to identify the major barriers to PV systems, and to examine the key policy interventions that would be required to bring about widespread uptake of these systems.

Research was conducted primarily through a review of the literature. This information was supplemented through a market survey and interviews with key informants from both the public and private sector.

The document contains two substantive findings. Firstly, there are environmental benefits (greenhouse gas reductions) that will result from the uptake of residential PV systems within the Province. Secondly, cost is by far the largest barrier to PV system uptake. A major policy intervention to rebalance the economics of PV systems in BC would be required to support their widespread adoption within the next decade.

Economic interventions to directly subsidize solar PV would likely be expensive relative to other forms of renewable energy in BC, and are therefore unlikely to be justifiable at present. If the price of PV systems reduces sufficiently over time, such measures could be considered. Over the shorter term, then, policies which support PV as well as other forms of renewable energy are recommended.

# Table of Contents

# Executive Summary

Solar photovoltaics (PV) can produce clean electrical energy directly from sunlight. This rapidly evolving technology is receiving increasing support from governments in other jurisdictions, most recently in Ontario. A growing segment of the PV market consists of small-scale, residential PV systems that can input power into the existing electrical grid.

This document was prepared for the Knowledge and Information Services Branch of the Province of British Columbia. The document evaluates the potential of grid-connected residential PV installations to meet key Provincial objectives for energy independence and greenhouse gas reduction, and explores some of the policy interventions that would likely be required to stimulate PV uptake. The document updates the reader on developments in residential PV technology, assesses the environmental impact of PV systems, and explores economic barriers to PV uptake. A brief exploration of the relationship between local government regulatory powers, solar access, and solar PV systems is also included.

**Solar PV Technology Description**

Solar PV technologies for residential applications typically fall into one of two categories: conventional silicon panels, or ‘thin-film’ technologies. Thin-film technologies use far less material and energy in their manufacture, thereby reducing greenhouse gas emissions associated with panel production. Although thin-film represents an increasing market share for residential PV systems, conventional silicon panels still dominate the market at present.

Both conventional silicon and thin-film photovoltaic panels may be integrated directly into building materials, such as facades, rooftops, or windows. These types of PV systems are called Building Integrated Photovoltaics (BIPV). By replacing conventional building materials, BIPV can offset costs while generating electricity.

Other emerging technologies include organic solar cells and polymer-based solar cells, which can even be applied as a “solar paint”. If they perform as promised they may have the potential to significantly reduce costs over time, but these technologies are still in the development stage and are likely years from commercialization.

**Relevant Provincial Objectives**

The Province of British Columbia has committed to reduce greenhouse gas emissions 33% by 2020 and to become self-sufficient in energy production by 2016. The two objectives are complementary as BC currently imports a significant portion of its power from other jurisdictions that use non-renewable resources. Substantial growth in the demand for electricity is also expected over the next 20 years, therefore new supplies of clean energy will be required to meet these objectives.

**Current Policies to Support PV in BC**

A small subsidy is provided through Livesmart BC, and solar PV systems are exempt from Provincial Sales Tax. However, the subsidy equates to only 3% of system costs, and the PST tax exemption will cease in July 2010 when the Harmonized Sales Tax comes into effect.

Provincial support for the 100,000 Solar Roofs program likely helps to raise awareness about PV, though the program is focused on solar hot water at present. Overall little has been done to directly support the uptake of residential solar PV within the Province.

**Energy Potential of PV and Suitability to BC's Climate**

There is substantial variation in solar PV potential in British Columbia. In general the south of BC, and especially the southeast, have significantly more solar PV potential than the center, north, and west of the Province. The gap between areas with higher and lower PV potential is approximately 40%. This gap can substantially affect the business case for solar PV in some areas, and implies a need for regionally sensitive policies.

A high-level estimate suggests residential PV potential in BC may range between 283,000 and 850,000 megawatt-hours annually. Residential PV systems can therefore help to meet a portion of annual electricity demand and to reduce imported electricity.

**Environmental Analysis**

A review of the literature demonstrates that solar PV uptake can deliver environmental benefits. Over the lifecycle of a residential grid-connected PV system using conventional silicon modules, 40-50 grams of Co2 equivalent (Co2e) will be emitted for each kilowatt-hour (kWh) of electricity produced. Thin-film modules are associated with only 25 grams Co2e/kWh. Life-cycle emissions are likely to decline further over time as technological progress decreases manufacturing energy and increases the life of PV panels. In addition, there are few other pollutants or health-risks associated with PV production or end-of-life management.

By reducing the need to import electricity, each kWh of electricity produced by residential PV systems will likely avoid between 27and 47 grams of Co2e. On an annual basis a small (3 kilowatt) residential system would likely reduce emissions by 81 to 141 kilograms of greenhouse gases. Even when compared to an expansion of large-scale hydroelectric capacity to meet demand, residential PV systems compare favorably.[1] In addition, solar PV systems do not require additional transmission lines, dams, or other changes to the landscape in BC and therefore help to protect the natural environment.

Recycling can further increase the benefits associated with PV. If financial support were to be used to encourage PV uptake, a policy on PV module recycling would likely be worthy of consideration.

**Economic Analysis and Outlook**

The cost of PV modules in Canada has been declining by nearly 10% annually. However, the current market prices of solar systems in BC remains between $8,000 and $10,000 per kilowatt of installed capacity. When accounting for maintenance costs (inverter replacement) the life-cycle cost will likely increase by another $1,000-$2,000 per kilowatt. Assuming a 30 year life-cycle and current electricity prices, this delivers electricity at around $0.31/kWh. This is far higher than the current price of electricity delivered through the grid in BC, which is closer to $0.08/kWh.

Much has been said about the possibilities of reducing system costs through Building Integrated Photovoltaics (BIPV). However, BIPV has been slow to uptake in the residential sector. Sample prices suggest that cost savings from BIPV in the residential sector are marginal, and that BIPV is more likely to be selected based on aesthetic considerations than on economic grounds.

Emerging technologies such as organic solar, polymer-based solar, and solar paint appear far from commercialization and are unlikely to drive down the price of PV in the near future.

Predictions from within the industry show continued decline in PV system pricing over the next 10-20 years. However, even optimistic assumptions imply that costs will exceed revenue by $500/kW over the life-cycle of a residential PV system in BC. Potential PV system owners would also likely still need to pay financing costs for their systems, making this an even less financially attractive investment. Therefore if widespread solar PV uptake is considered desirable, some sort of policy intervention that changes the balance of PV economics will be required.

[1] Life-cycle emissions from large-scale hydroelectricity, including dam construction and flooding, are estimated at between 24 and 34 grams Co2e/kWh. This range of emissions is likely a low estimate as it does not account for transmission and delivery infrastructure, which is not required for residential PV systems.

**Considerations in Promoting Solar PV**

The key consideration for promoting solar PV is overcoming the economic barrier. While simply waiting for system prices to decline will help to narrow the gap between the cost of electricity from PV and the current price of electricity, the wait could last for decades. There are several policy options available to address this barrier, including Time of Use rate structures, Feed-in Tariffs, and low or zero-interest financing.

Numerous authors argue that the full economic benefits of electricity from solar PV are not realized by market rates. The cost for a utility to provide electricity varies substantially based on when the electricity is used, with the highest prices highest associated with peak demand. Time of Use (TOU) rate structures help to internalize the full costs of electricity by pricing electricity based on peak demand. Time of Use encourages conservation and provides an incentive to shift demand to off-peak periods. Combining TOU with Net Metering may make solar PV more financially attractive in BC. However, these benefits are likely smaller than in other jurisdictions, such as California or Japan, where peak demand is more closely timed with peak PV output. In BC peak demand is during evenings, especially in winter, and is not as well matched. Therefore TOU is unlikely to significantly change the business case for residential PV systems as a stand-alone measure.

Feed-in Tariffs (FiTs) pay for electricity from renewable energy at above-market rates, generally between $0.40 and $0.80/kWh. FiTs price electricity in order to provide an attractive return on investment in PV systems, and are intended to lower greenhouse gas emissions through increasing the share of renewable energy while providing economic returns through the creation of “green” jobs. Germany has supported solar PV development through a high FiT price since 2000, and recently these policies have been adopted in Ontario and the United Kingdom. Unfortunately the GHG reductions will be much smaller in BC than in these other jurisdictions due to the already-high proportion of renewable energy in BC. In addition, much criticism of the German FiT has emerged recently. Claims that high FiTs for PV are justified based on economic grounds should be examined carefully if similar policies are to be considered in BC.

Another barrier to residential PV is a lack of protection for solar access. Shading of even a small portion of a solar panel (10%) can severely disrupt panel output or cease it from functioning altogether. This represents risk to system owners. Over the long term solar, access needs to be protected and encouraged in order to enable PV development. Local government planning which protects access to sunlight can partially address this issue.

Planning tools already exist for maximizing solar access at the local government level. Zoning and Development Permit Area powers are the most prominent of these tools. Both appear reasonably well suited to influence building form and siting which encourages solar access. In addition, the Province is in the process of granting local governments the power to require Solar Hot Water Ready homes. Although not explicitly intended for PV, this requirement will reduce the future installation costs of PV systems and help to enable PV uptake. As other issues related to local government planning and implementation of on-site renewable energy occur, Provincial support through further enabling legislation could be beneficial to the uptake of solar PV. Additional legislative measures to protect solar energy systems from shade, such as those undertaken in California, could also be import topics for future research.

**Conclusions**

Solar PV has the potential to meet a significant portion of electricity demand, thereby making BC more self-sufficient in electricity generation. As electricity imports are reduced, GHG emissions reductions can also be realized. However, residential PV systems remain an expensive means of achieving these objectives. Even assuming continued decline in the price of PV systems, it is likely that only 'break even' costs could be realized by homeowners installing solar PV systems within the next decade.

Over the shorter term (5 years) increased research and support through the removal of barriers is likely warranted. For example, research and development of guidelines or legislation for the protection of solar access could be beneficial. Providing a continuance of the PST exemption for solar PV systems under the HST would also likely be justified. Changes to utility rate structures, such as through Time of Use, would also likely be low in cost and could benefit the business case of PV systems.

Over the longer term (10 years) as system prices decrease and the price of electricity rises, the gap between electricity delivered from PV and conventional sources such as hydroelectricity will likely narrow. At that point the implementation of more substantial financial incentives, such as subsidies, low-interest loans, and a moderate FiT, can be considered.

# Definitions

**Active Solar –** Active solar systems include space and water heating systems. They are considered "active" because they require some electrical equipment (such as pumps or fans) to operate.

**Balance of System (BOS) Components –** BOS includes all components of a solar system other than the solar panels themselves. For example, frames, wiring, and inverters are included within this category.

**Building Integrated Photovoltaics (BIPV)** – Photovoltaic panels can be integrated directly into the envelope of a building, replacing conventional building materials. Solar roof shingles, solar windows, and solar façades are among the types currently available.

**Feed-in Tariffs (FiTs) –** Feed-in Tariffs allow customers to sell electricity into the grid. A FiT offers above-retail rates for electricity, providing an economic incentive for customers to sell electricity. These programs generally require specialized electricity meters which separately measure consumed energy and produced energy.

**Inverter -** PV panels generate Direct Current (DC) electricity, while most households function using Alternating Current (AC). An inverter converts electricity from DC to AC, making the energy immediately useable within the household.

**Kilowatt-Hours (kWh) –** A standard measure of electrical energy. One kilowatt-hour equals 1,000 watts of energy used over a one-hour period.

**Life Cycle Analysis (LCA) –** A life cycle analysis or life cycle assessment seeks to measure all of the direct and indirect material and energy inputs used over the entire life of a product, from the extraction and processing of materials to end-of-life management (disposal). An LCA is much broader in scope than conventional measures of environmental impact and often uncovers 'hidden' sources of pollution.

**Net Metering –** Net metering is linked to policies which allow customers to put electricity into the grid. Under net metering, a system owner generally receives retail credit for the electricity they generate.

**Solar Ready –** Solar Ready refers to the pre-installation of some of the infrastructure for a solar system. Solar Ready is generally designed for Solar Hot Water systems, and usually includes a pipe (conduit) from the utility room to the roof. Solar Ready reduces the cost of systems installations in the future.

**Time of Use Pricing (TOU) –** The cost to provide electricity changes throughout the day based on demand. During peak demand periods, more expensive forms of electricity are often used. TOU prices internalize the costs of electricity to customers based on when the electricity is used. TOU rate structures encourage conservation during peak periods as a result of the higher peak prices.

# 1. Introduction

Concern over climate change and rapidly increasing conventional energy prices have sparked the search for low-emission "alternative" sources of energy. This search is leading utilities to change the basic paradigm of energy production. The conventional model of large, centralized energy generation is shifting to promote diverse small-scale sources of energy. Within this context, solar energy is seen as particularly promising, owing to the sheer abundance of free energy that strikes the earth every day.[2]

In several jurisdictions (most notably Germany and Japan, and more recently California and Ontario) solar PV uptake has been supported through Feed-in Tariffs and other policy interventions that improve the business case for solar PV.[3] These policies are increasingly targeting small-scale PV installations, including those within the residential sector.

In British Columbia, commitments have been made to reduce greenhouse gas emissions 33% by 2020 and to become self-sufficient in energy production by 2016.[4] The two objectives are complementary as BC currently imports electricity from other jurisdictions that is generated using fossil fuels.[5] BC Hydro has estimated that approximately 1/3 of rooftops in British Columbia are sufficiently free from direct shade to support some type of solar system.[6] This has led to support for solar hot water from the Province, but comparatively little has yet been done to promote solar PV. This begs the question as to whether solar PV might be suited to the BC context, and what sorts of key policy interventions might be required to encourage PV system uptake.

The field of solar PV is changing rapidly as new technologies emerge. The costs for PV systems in Canada have decreased by nearly 10% annually,[7] and are increasingly affordable for the average homeowner. New products such as Building Integrated Photovoltaics are said to further decrease costs by literally replacing conventional building materials while at the same time generating energy.[8] These changes to PV

---

[2] O. Morton, 'Solar energy: A new day dawning?,' *Nature* 443, September 7th 2006, pp. 19-22, accessed February 23rd 2010 from <http://www.nature.com/nature/journal/v443/n7107/full/443019a.html>.

[3] National Renewable Energy Laboratory, *NREL energy analysts dig into Feed-in Tariffs*, June 12th 2009, retrieved March 3rd 2010 from <http://www.nrel.gov/features/20090612_fits.html>.

[4] Province of British Columbia, *Climate action plan*, June 2008, retrieved November 13th 2009 from <http://www.livesmartbc.ca/government/plan.html>.

[5] J. Hanova, H. Dowlatabadi, and L. Mueller, 'Ground Source Heat Pump Systems in Canada: Economics and Ghg Reduction Potential,' 2007, in *Discussion Papers, Resources For the Future*: Washington, DC, retrieved January 13th 2010 from <www.rff.org/documents/RFF-DP-07-18.pdf>.

[6] Community Energy Association, *Powering our communities: Renewable energy guide for local governments in British Columbia*, 2008, p.12, retrieved November 12th 2009 from <http://www.communityenergy.bc.ca/>.

[7] J. Ayoub, and L. Dignard-Bailey, *Photovoltaic technology status and prospects: Canadian annual report 2007*, CanmetENERGY, Natural Resources Canada, retrieved November 20th 2009 from <http://www.canmetenergy.nrcan.gc.ca>.

[8] L. Stamenic, 'Developments with BIPV systems in Canada,' *Asian Journal on Energy and Environment*, Vol. 5, Issue 4, pp. 349-365.

system prices make residential grid-connected systems an important area for exploration.

A substantial body of literature examining the potential of solar PV already exists. However, much of this literature is focused on other jurisdictions, or is becoming out-of-date due to the rapid pace of technological change. This document explores the current status and prospects of residential grid-connected solar photovoltaics in British Columbia. It is intended to provide up-to-date information regarding PV's suitability to BC over the short and medium term, including descriptions of the technology, explorations of system costs and environmental benefits, and potential policy interventions which might promote this type of renewable energy.

*Scope*

This paper was prepared for the Knowledge and Information Services Branch of the Province of British Columbia. The author received a research grant from the Branch via the UBC School of Community and Regional Planning to provide a scoping review of key issues related to PV deployment in the residential sector. Commercial buildings, apartments, and off-grid residential PV systems are excluded from the document as they represent a substantially different business case in both environmental and economic dimensions.

Based on discussions with the selection committee which authorized the grant, it was decided that the document address several research objectives:

- To examine the implications of recent changes to the technology and economics of PV, such as progress in Building Integrated Photovoltaic technologies;
- To examine potential environmental benefits of PV deployment;
- To identify and explore the economic barriers to widespread PV deployment within the housing sector; *and*
- To identify other key barriers.

*Outline*

In order to address these objectives the document has been organized topically. Section two of the document begins by describing current and emerging PV technologies and examining the potential benefits of these systems. This is followed by a description of Provincial objectives relevant to solar PV: independence from imported electrical energy and a reduction of greenhouse gas emissions. The section goes on to describe the current support mechanisms that promote PV uptake within the province.

The third section of the paper describes the solar resources and energy potential of PV systems in BC. An estimate of residential solar PV potential in the province is provided.

In section four of the paper, the environmental impact of solar PV deployment in BC is assessed. A high level estimate of the potential to reduce greenhouse gas emissions within the province is provided. The toxins used in PV production and the potential for recycling of PV modules are also discussed.

Section five of the document focuses on the economics of residential PV systems. The section explores trends in the cost of PV systems, provides a detailed analysis of the life-cycle costs of a PV system installed and operated in BC, and explores some of the potential policy responses that have been used to encourage PV deployment in other jurisdictions.

The sixth section explores the ways in which Local Governments may enable or constrain PV deployment through the regulation of solar access. The section describes some of the planning tools and powers available to local governments and identifies one of the remaining gaps that could be addressed at the Provincial level.

Finally, the paper closes with a discussion and conclusions section.

*Methods*

The document uses a combination of a literature review and key informant interviews in order to explore the topic. Where possible, calculations of energy payback, greenhouse gas emissions, and market pricing drawn from literature or media sources were adjusted to reflect local economic, environmental, and climatic factors.

Interview participants were selected through a variety of means. Five installers located in BC were interviewed. These installers were selected based on advice from a Solar BC representative and a representative of the Canadian Solar Industries Association. In addition, representatives from BC Hydro, Powerex, the Provincial Government, and a PV manufacturing firm located in BC were also contacted.

# 2. Background

## Technology and Characteristics of Solar PV

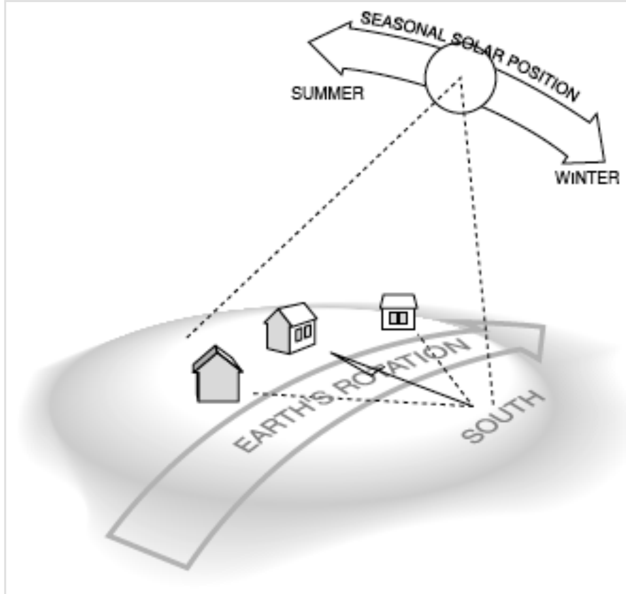



**Figure 1 – Solar Exposure & Sunpath**
Solar exposure is key to all solar technologies: passive, active, or photovoltaic. In general a south-facing section of the building oriented within +/- 30 degrees of the sunpath is necessary.[9]

Sunlight is made up of particles of energy known as photons. Different types of solar energy technology are able to concentrate, store, or convert these particles into heat or electricity.

Solar energy technologies are often divided into three categories: passive, active/thermal, or photovoltaic. Although the emphasis of this paper is solar PV, all three technologies are complementary to each other. Therefore some basic information regarding passive and active/thermal solar technologies is also included in this section.

**Solar Photovoltaics (PV)** directly convert sunlight into electricity. Individual solar cells are quite small and can convert little electricity. They are therefore combined into solar modules. Several modules together make up a solar array. In common parlance, however, arrays are simply referred to as solar panels or solar collectors.[10]

The capacity of a residential PV system is generally measured in kilowatts (kW). The amount of space required for a PV system varies based on the efficiency of cells and the way in which they are mounted. If panels are mounted flush with the roof they will take up more area than if they are stacked using a vertical frame. As a rule of thumb, each kW of capacity requires at least 6 square meters of panels.[11] In BC the average home consumes 10,000 kilowatt-hours (kWh) of electricity annually.[12] With a 3.5kW system (around 20 square meters) a roof-mounted PV system would provide around 1/3 of the annual electricity needs for an average BC home.

[9] US Department of Energy Office of Building technology, *Passive solar design technology fact sheet,* December 2000, retrieved September 20th 2009 from <http://www.energysavers.gov/your_home/designing_remodeling/index.cfm/mytopic=10250>.
[10] Because active and PV technologies are referred to as "solar panels" they can sometimes be confused with each other. For the remainder of this document, "solar panels" refers specifically to solar PV unless otherwise specified.
[11] Calculated based on polycrystalline PV modules with approximate efficiency of 16%.
[12] BC Ministry of Energy, Mines, and Petroleum Resources, *Energy plan: A vision for clean energy leadership*, 2007, retrieved February 20th 2010 from <http://www.energyplan.gov.bc.ca/efficiency/>.

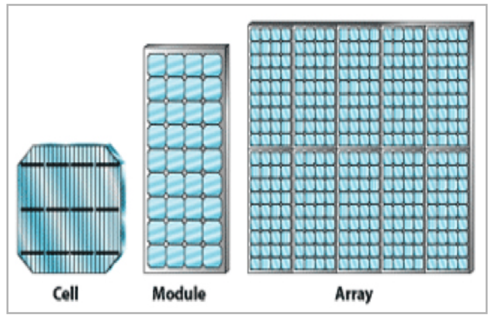



Figure 2 - Cell, Module, Array[15]

Technological developments have yielded various types of PV cell. Currently the most common are variants of silicon, especially multi-crystalline or poly-crystalline silicon cells. More recently, "thin-film" PV has garnered substantial attention in the media. Thin-film solar uses a fraction of the material of conventional silicon panels, thereby requiring less energy and having a lower environmental impact.[13] Thin-film cells are also flexible and can allow light to penetrate, opening up a range of new applications such as glass atriums. Amorphous silicone, Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS) are the materials which dominate the thin-film market.[14]

Solar PV may also be integrated directly into walls, facades, or even solar glass. These solar applications are known as **Building-Integrated Photovoltaics (BIPV)**. Because BIPVs directly replace building materials, they can decrease the price of PV installations over other types of solar system installation.[16] A common example of BIPV is "solar shingles", which can directly replace conventional roofing materials. These types of PV system are likely to be less visually obtrusive than mounted solar panels. BIPV can be built using conventional silicone cells, but the flexibility of thin-film cells make the latter type of PV better suited to building integration.

Electricity generated by PV is direct current (DC) electricity, which cannot be used directly in household applications. Therefore residential PV systems include an **inverter**, which converts electricity into alternating current (AC) for use with standard household appliances. The inverter, along with other components such as the mounting system or frame, are referred to as the Balance of System (BOS) components.

At present, solar photovoltaic systems are relatively expensive for residential applications. Many installers charge $8,000 to $10,000 per kW of installed capacity for a grid-tied system.[17] For remote applications without access to the grid, this may

---

[13] A, Curtright, M. G. Morgan, and D. Keith. 'Assessments future pv,' *Environmental Science and Technology*, 2008, Vol. 42, No. 24, pp. 9031-9038.
[14] Solar Buzz, *Solar Cell Technologies*, Solar Buzz website, retrieved January 3rd 2010 from <http://www.solarbuzz.com/technologies.htm>.
[15] US Department of Energy, *Cell, Module, Array*, image retrieved November 7th 2009 from<http://www1.eere.energy.gov/solar/pv_systems.html>.
[16] Stamenic, *Op. cit*.
[17] For more information on PV system economics, see Section 4 of this document.

be less expensive than paying for utility grid extensions. Therefore most residential PV systems installed in Canada are for off-grid or remote applications.[18]

The economics of grid-tied residential systems improve where excess electricity can be sold into the grid through Net Metering or Feed-in Tariffs. In these cases batteries are not required to store electricity, as the grid is capable of meeting the building's electrical load. These systems are increasingly popular due to a variety of benefits they can provide. Some of the more commonly cited benefits include:

- PV reduces reliance on fossil fuels, which are often used to generate electricity. This reduces emissions associated with the production of electricity;[19]
- PV systems provide energy security and can provide a hedge against rising electricity costs;[20]
- PV provides benefits to the utility by meeting peak energy demand[21] and reducing wear-and-tear on existing infrastructure;
- PV systems are located at the point of use, which can reduce line losses associated with transmission.[22]

In addition, government intervention to support these systems is often justified on the basis of economic development, including the creation of "green" jobs. A basic diagram of a residential grid-connected PV system is shown below in Figure 3 below, and an example of BIPV is shown in Figure 4.

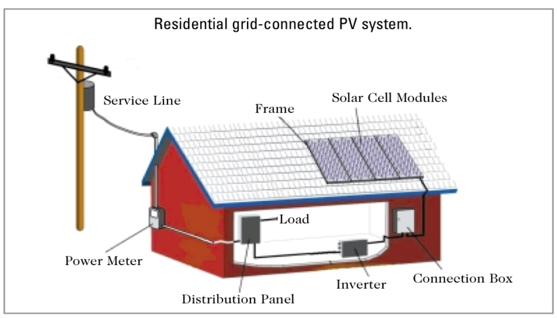



**Figure 3 - Diagram of a Residential Grid-Connected PV System**[24]

**Figure 4 Solar Shingles** are solar panels which can replace traditional asphalt shingles.[23]

---

[18] J. Ayoub, and L. Dignard-Bailey, *Photovoltaic technology status and prospects: Canadian annual report 2007*, CanmetENERGY, Natural Resources Canada, retrieved November 20th 2009 from <http://www.canmetenergy.nrcan.gc.ca>.

[19] US Department of Energy Efficiency and Renewable Energy, *Get your power from the sun: A consumer's guide*, December 2003, p. 5, retrieved October 20th 2009 from <www.nrel.gov/docs/fy04osti/35297.pdf>.

[20] *Ibid*.

[21] R. Wiser, G. Barbose, and C. Peterman, *Tracking the Sun: The installed cost of photovoltaics in the U.S. from 1998-2007*, Lawrence Berkeley National Laboratory, February 2009, retrieved Tuesday March 2nd 2010 from <http://eetd.lbl.gov/ea/emp/reports/lbnl-1516e.pdf>.

[22] *Ibid*.

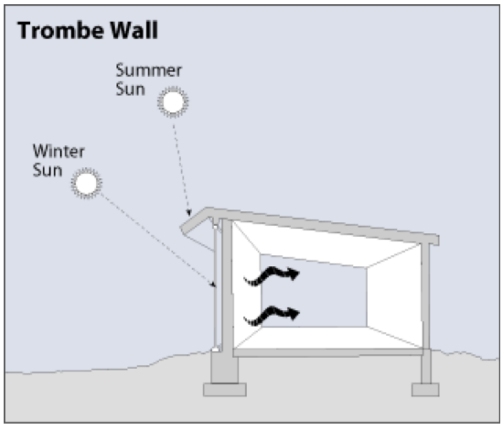
[23] US Department of Energy, *Solar history timeline*, image retrieved March 1st 2010 from <http://www1.eere.energy.gov/solar/m/solar_time_1900.html>.

[24] J. Ayoub, L. Dignard-Bailey, and A. Fillion, *Photovoltaics for buildings: Opportunities for Canada, Natural Resources Canada*, 2000, image retrieved August 1st 2009 from <http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/buildings/pv_buildings/publications.html?2001-123>.

*Synergies: Passive, Active, and PV*

**Passive Solar** generally refers to the use of solar energy without the aid of any energy inputs or mechanical system. This is the simplest and most direct form of solar energy use. In the residential sector passive solar is often characterized by careful siting and orientation of a building along with the selection of building materials that absorb and store solar energy as heat.[26] A greenhouse can be used as an instructive example: solar energy penetrates the building envelope of the greenhouse. As it strikes solid surfaces inside the structure, the solar energy transforms into heat energy and the temperature in the greenhouse rises.

**Figure 5 – Passive Solar Example**
A Trombe Wall is designed to absorb solar heat and release it gradually into the home.[25]




In passive design, windows are often placed on the south side of the home to maximize the penetration of heat, while windows facing other directions will be smaller or better designed to retain heat.[27]

Another common example of passive solar design is the Trombe Wall, as shown in Figure 5. The wall system is generally made of a dense material (such as stone) which will gradually absorb and retain heat. This reduces both heating and cooling needs under extreme temperatures as it 'smooths out' the highs and lows in temperature. Figure 5 also demonstrates another important principle in passive solar design: cooling. In hotter climates, shading during peak temperatures (summer) is an important element of effective solar design. Overhangs and vegetation are often used to decrease solar gain during the hottest parts of the year.

In general passive systems require an additional investment of time during the design phases of a building, but cost little additional capital up-front and generally have quick return on investment.[28]

By contrast to the simplicity of passive systems, **Active Solar Systems** require some sort of mechanical component or electrical input to function. Active solar systems use solar collectors for space heating or water heating.

---

[25] US Department of Energy, *Passive solar design technology fact sheet*, Department of Energy Office of Building Technology, State and Community Programs, December 2000, retrieved September 20th 2009 from <http://www.energysavers.gov/your_home/designing_remodeling/index.cfm/mytopic=10250>.
[26] *Ibid*.
[27] *Ibid*.
[28] *Ibid*.

The most common example of active solar systems is solar hot water. These systems use a solar panel to directly heat water. The water is then pumped into the building's hot water tank.[29] A simplified solar hot water system diagram is shown in Figure 6 below.

A solar hot water collector of approximately 6 square meters can meet more than half the hot water needs of a BC family during the course of a year.[31] The typical cost for such a system is approximately $7,000.[32]

In general solar hot water systems appear to work well despite cloud-cover. SolarBC claims that 60% of daily hot water needs can be met on cloudy days in BC.[33]

**Figure 6 - Solar Hot Water Diagram[30]**

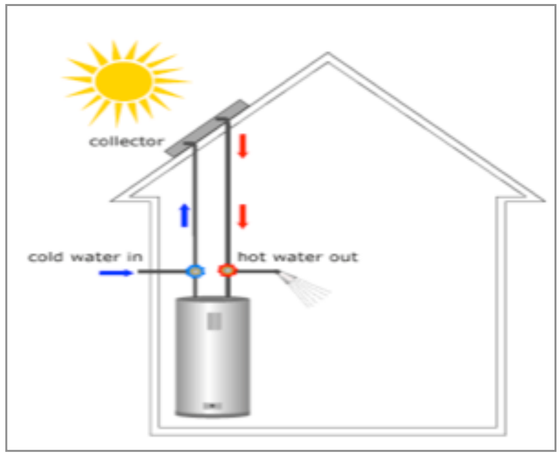



Table 1 below summarizes some of the similarities and differences between passive, active, and PV systems. All three systems can be complementary: a single home may choose to heat a portion of its heat from passive and active solar energy while also mounting a PV system to meet a portion of its electrical needs. Because all three systems require direct sunlight to function effectively, there is a shared need for building orientation, siting, and planning processes that promote solar access. This issue will be returned to at various points throughout the document.

**Table 1: Comparing Passive, Active, and Photovoltaic Solar Systems**

| | Characteristics of a Passive Solar building | Characteristics of a Solar Hot Water System | Characteristics of a Solar PV System |
|---|---|---|---|
| **Function** | Space heating | Space or Water Heating | Electricity Production |
| **Materials** | Building materials allow heat to enter (eg. windows) or store heat (eg. brick); | Solar collector converts solar radiation into heat; heat is transferred to hot water tank or air entering building; | Solar collector converts solar radiation in to electricity; |
| **Size and placement** | A large portion of the homes wall-area should face due south; | At least six square meters of south-facing roof space; | At least six square meters of south-facing roof space; |

[29] Solar Direct, *Solar Water Heater*, retrieved March 4th 2010 from <http://www.solar-water-heater.com/~images/pt-house.gif>.
[30] *Ibid.*
[31] SolarBC, *Solar hot water simplified*, SolarBC website, accessed March 3rd 2010 from <http://www.solarbc.ca/learn/solar-hot-water-simplified>.
[32] SolarBC, *Incentives and costs*, SolarBC website, accessed March 1st 2010 from <http://www.solarbc.ca/learn/incentives-costs>.
[33] SolarBC, *Solar in BC's climate*, SolarBC website, accessed March 1st 2010 from <http://www.solarbc.ca/learn/solar-in-bcs-climate>.

## Policy Context in British Columbia

### Goals and Objectives

Resources such as staff time and funding will only be devoted to solar PV if doing so meets Provincial objectives. This section summarizes the key Provincial objectives, plans, and strategies which might be served by the uptake of grid-connected solar PV systems.

Climate change has become a major policy issue. In 2007 the Province committed to reducing greenhouse gas emissions (GHGs) by at least 33% below 2007 levels by 2020 and 80% below 2007 levels by 2050.[34] These targets form the basis for the Climate Action Plan.[35] The degree to which PV can reduce the emissions of greenhouse gases is therefore a key measure of their utility.

Currently BC imports some electricity from "dirty" out-of-province sources. Lower water availability has restricted energy available from hydroelectricity. This has led BC to become a net importer for seven of the last ten years.[36] In addition, electricity demand growth of up to 45% is expected over the next two decades implying increasing strain on existing supplies.[37]

The BC Energy Plan lays out objectives and strategies for meeting growing energy demand while reducing greenhouse gas emissions.[38] Relevant targets and policies laid out in the plan include:

- Electricity self-sufficiency "including insurance" by 2016;
- All new and existing electricity produced in B.C. will be required to have net zero greenhouse gas emissions by 2016;
- Ensure that clean or renewable electricity continues to account for at least 90% of electricity generation; *and*
- Continued promotion of the Standing Offer program and Net Metering.

**Net Metering**
One of the major barriers to solar PV uptake is grid interconnection. In the absence of grid-connection, electricity generated and not used immediately would either require storage in a battery or would be wasted. Net metering agreements give customers credit for electricity put back into the grid, increasing the overall efficiency and lowering the cost of PV systems. Both BC Hydro and Fortis BC now allow net metering contracts. At the end of the year, if the net balance on the meter is negative (the household has put more electricity into the grid than it has used) then the utility will pay the customer for excess electricity at market rate. At current market rates excess electricity will receive $0.08/kWh.

---

[34] BC Ministry of the Environment, *Greenhouse gas reduction target act*, January 2008, retrieved September 18th 2009 from <http://www.env.gov.bc.ca/epd/codes/ggrta/>.
[35] Province of British Columbia, *Climate action plan*, June 2008, retrieved November 13th 2009 from <http://www.livesmartbc.ca/government/plan.html>.
[36] BC Ministry of Energy, Mines, and Petroleum Resources, *For the record: Facts on independent power production*, March 25th 2009, accessed March 1st 2010 from <http://www.gov.bc.ca/fortherecord/independent/in_environment.html?src=/environment/in_environment.html>.
[37] *Ibid*, p. 9.
[38] *Ibid*.

The Standing Offer and Net Metering programs represent a change in the accepted model for utility provision of energy. Where previously large and centralized sources of energy generation dominated utilities, there is now a trend towards diversification and localization of energy supplies. In many jurisdictions it is increasingly common to see Net Metering or Feed-in Tariffs, both of which support smaller-scale electricity projects and encourage them to sell power into the conventional grid. This decentralized model is often referred to as "distributed generation".[39]

Much of the electrical energy consumed in BC is used in buildings.[40] The desire to make building more efficient led the Province to develop the Energy Efficient Buildings Strategy, which seeks to reduce average energy demand per home by 20% by 2020.[41] This goal at least partially addressed through new energy efficiency standards under the rubric of Greening the Building Code.[42] Higher standards are also encouraged through Livesmart BC, an incentive program that provides subsidies for energy efficiency upgrades and renewable energy technologies, including solar PV.[43]

These commitments for electricity self-sufficiency and GHG reduction have been made within the context of rapidly aging electrical infrastructure. Over $3.4 billion have been allocated to infrastructure repairs and upgrades over the next two years alone.[44] One of the advantages on-site generation of electricity have over other sources is that they do not require distribution infrastructure; electricity is more likely to be used on or near the site of generation. This creates the potential to reduce expenditures on infrastructure capacity.

**Table 2: Provincial Goals Relevant to PV**

| Plan or Strategy | Target |
|---|---|
| Climate Action Plan | Reduce GHG emissions at least 33% below 2007 levels by 2020 and 80% by 2050. |
| BC Energy Plan | Electricity self-sufficiency by 2016;<br>At least 90% of electricity from clean/renewable sources. |
| Energy Efficient Buildings Strategy | Reduce average energy demand per home by 20 per cent by 2020. |
| 100,000 Solar Roofs | Install some type of solar energy system on 100,000 rooftops in BC by 2020. |

Local governments are increasingly seen as the level of government that can best influence reductions in emissions. The Province has required that local government in BC create targets, actions, and policies to reduce GHG emissions[45] and has

[39] N. Miller and Z. Ye, *Report on Distributed Generation Penetration Study*, August 2003, National Research Energy Laboratory, accesses September 13th 2010 from <www.nrel.gov/docs/fy03osti/34715.pdf>.
[40] BC Ministry of Energy, Mines, and Petroleum Resources, *Energy efficient buildings strategy: more action less energy*, 2008, p. 9, retrieved February 20th 2010 from <http://www.energyplan.gov.bc.ca/efficiency/>.
[41] *Ibid*.
[42] BC Ministry of Housing and Social Development, *Greening the BC building code: First steps*, accessed August 29th 2009 from <http://www.housing.gov.bc.ca/building/green/ >.
[43] Province if British Columbia, *Livesmart BC*, accessed November 20th 2009 from <http://www.livesmartbc.ca/>.
[44] BC Hydro, *Reinvesting for generations*, retrieved February 12th from <http://www.bchydro.com/news/press_centre/hot_topics/hot_topics_features/hot_topic__renewing.html>.
[45] BC Ministry of Community and Rural Development, *Greenhouse gas (GHG) emission reduction targets, policies and actions,* accessed January 13th 2010. From http://www.cd.gov.bc.ca/lgd/greencommunities/targets.htm>.

amended the Local Government Act to provide new powers for the regulation of energy use. These powers include the Solar Hot Water Ready standard described below and the new Development Permit Area powers described in Section 6 of this document.

The Province has also provided funding and support to the 100,000 Solar Roofs initiative[46] administered through SolarBC. This initiative seeks to facilitate the installation of 100,000 roofs with some form of solar energy system by 2020. However, the program is focused almost exclusively on solar hot water systems.

### Current Support for Solar Energy in BC

**100,000 Solar Roofs for B.C.**
The goal of the project is to see the installation of solar roofs and walls for hot water heating and photovoltaic electricity generation on 100,000 buildings around B.C. by 2020.
More information can be found at www.solarbc.ca.

More has been done to support solar hot water systems than solar PV systems. Due to the similarities between these forms of energy generation, some of the policies oriented to promoting solar hot water have positive knock-on effects for PV systems.

*Incentives*

Under Livesmart BC, a subsidy of $260 is available for each kilowatt of installed PV capacity. This reduces system costs by approximately 3%. In addition, an exemption for Provincial Sales Tax is provided, which reduces system costs by approximately 7%. The Provincial Sales Tax exemption is likely to be eliminated in the near future as BC moves to the Harmonized Sales Tax (HST).[47]

*Solar Ready Standards*

Under the Greening the Building Code initiative, BC Housing and Construction Standards is currently developing a "Solar How Water Ready" standard.[48] The standard is likely to include the following requirements:

- Required roof space for solar collector, an area of at least 2.7 square meters;
- Mandatory roof loading requirement suitable to solar panels;
- Provisions for a conduit running between the roof and the utility room. The conduit would facilitate the installation of electrical cables and plumbing equipment, reducing the cost of retrofits.

[46] Ministry of Energy, Mines, and Petroleum Resources, *Energy in action*, retrieved September 30th 2009 from <http://www.energyplan.gov.bc.ca/bcep/default.aspx?hash=12>.
[47] G. Duancey, 'HST should have been an ecologically harmonized sales tax,' *BC Sustainable Energy Association,* August 24th 2009, retrieved February 1st 2010 from <http://www.bcsea.org/blog/guy-dauncey/2009/08/24/hst-should-have-been-ecologically-harmonized-sales-tax>.
[48] BC Ministry of Housing and Social Development, *Op. cit.*

While the standard is focused on hot water it may also aid in the installation of solar PV systems. Owing to its unique regulatory powers, the City of Vancouver has already implemented a Solar Ready standard similar to the Provincial standard. The City explicitly states that the Solar Ready standard will lower the cost of retrofitting both solar hot water and solar PV systems.[49]

*Net Metering*

Net Metering increases the efficiency of PV systems by eliminating the need for a battery to store electricity. The process of grid interconnection in BC is relatively straight forward and takes approximately two months. An important part of the process is the electrical permit, which must be received from the duly authorized Electrical Inspection Authority for the area. None of the key informants interviewed identified the permitting or grid interconnection processes as significant barriers to PV uptake. Details regarding the process of Grid Interconnection are included in Appendix A of this document.

**Table 3: Provincial Incentives Promoting Solar Energy Systems in BC**

| Support | Solar hot water | Solar PV | Comments |
|---|---|---|---|
| PST Exemptions | 7% price reduction | 7% price reduction | At risk, as there are currently no provisions for continuing the exemption under the HST |
| Subsidies | $1,250 regardless of system size<br><br>(Of these funds, *$125 is provided through Livesmart BC and $1,000 through SolarBC.)* | $260 per kW, up to a *maximum of $1300* | Combined subsidies for Solar Hot Water amount to half of total system costs, while the subsidy for Solar PV covers approximately 3% of installed PV system costs. |
| New powers for local government | Provision for Solar Hot Water Ready | No provision for Solar Ready | It appears that "solar ready" will assist with the installation of either type of system. However, the amount of roof space assigned for the installation of solar panels is relatively small compared to likely PV system sizes. |

*Federal Initiatives*

Federal support is allocated for standardized training for solar installers across Canada, including solar PV installers. Providing consistent quality among installers can benefit the solar PV market by decreasing the chances of shoddy installations.[50]

---

[49] City of Vancouver, *Pre-piping for roof-mounted Solar Energy generation*, retrieved February 13th 2010 from <http://vancouver.ca/commsvcs/cbofficial/greenbuildings/greenhomes/solarenergy.htm>.
[50] Association of Canadian Community Colleges,*Government of Canada supports training for solar energy workers*, December 8th 2008, retreived January 10th 2010 from <http://www.accc.ca/english/publications/media/0812_solar_energy_workers.htm>.

# 3. Solar Resources in British Columbia

BC has defined a clear mandate to reduce GHG emissions by meeting growing demand with clean and renewable energy generating technologies. The potential for small-scale PV systems to meet these objectives will likely determine the willingness to devote resources in promoting PV. One of the potential constraints on the viability of residential PV systems to address these goals is the potential quantity of electricity that can be produced through this type of system.

Solar PV potential differs by region, locality, and by site-specific conditions. Even the most efficient solar PV technology will not be able to compensate for a lack of sunlight. This section of the document explores solar PV potential in BC at the regional scale and describes some of the site-specific issues related to shading and solar access.

## Available Solar Energy: Regional Scale

While much of BC has a reputation for rain, it is commonly stated that BC has as much or more sunlight than the world's leaders (Japan and Germany).[51][52][53] As BC is approximately 2.5 times larger than either country, a more refined understanding of the climactic factors affecting Solar PV in British Columbia is helpful.

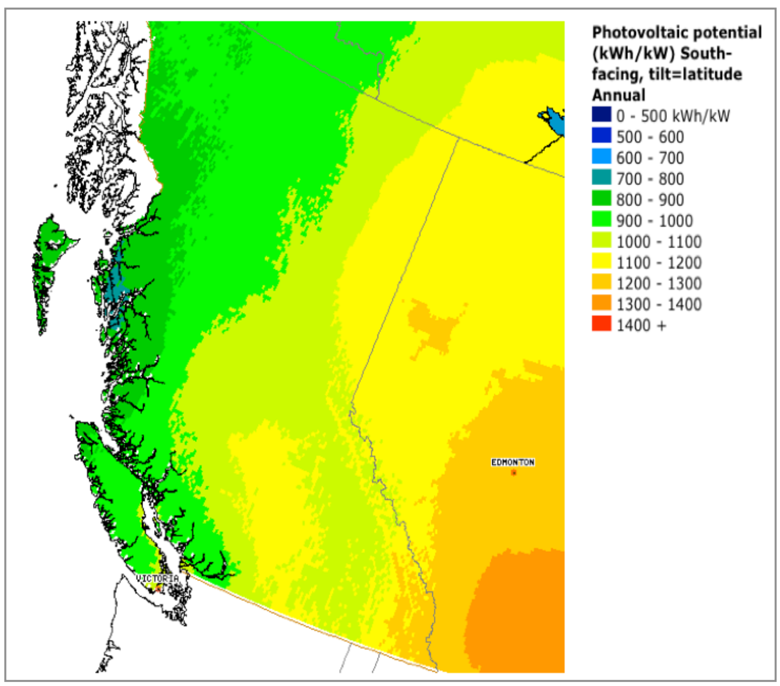



**Figure 7 - Solar Resources in British Columbia**
The map shows photovoltaic potential in kWh per kW of installed capacity. The Provincial average hides substantial variation in solar availability.

---

[51] BC Ministry of Energy, Mines, and Petroleum Resources, *What is solar energy?,* retrieved November 20th 2009 from < http://www.empr.gov.bc.ca/RET/RenewableEnergyTechnologies/Solar/Pages/default.aspx>.
[52] SolarBC, *Solar BC incentives double up: $2000 now available for new buildings and existing homes*, accessed February 3rd 2010 from < http://www.solarbc.ca/blog/liz-kelly/2010/02/01/solarbc-incentives-double >.
[53] Society Promoting Environmental Conservation, *Solar technology tours at SPEC*, accessed February 1st 2010 from <http://www.spec.bc.ca/article/article.php?articleID=488>.

Natural Resources Canada hosts a Photovoltaic Potential and Solar Resource Map of Canada.[54] The interactive map provides high-level regional data for solar PV potential, measured in kilowatt-hours (kWh) of energy per kilowatt (kW) of installed capacity.[55] Information can be derived based on different solar panel orientations (tilt), and users may also search the data by individual municipality to information on local PV potential. A map of BC is shown in Figure 7 above.

On average, the west and northwest of the province have substantially less solar resources available than the east and southeast. Other areas of the province fall in between. The more populous south of BC has solar exposure comparable to some jurisdictions that are aggressively promoting solar energy, such as Germany[56] or southern Ontario.[57][58] However, this generalization hides substantial regional variation within BC.

**Table 4 – Solar PV Potential for Selected BC Municipalities**
(south-facing panel tilted at latitude -15°)

| Municipality | Region | PV Potential (kWh/kW) |
|---|---|---|
| Kelowna | Okanagan | 1133 |
| Vancouver<br>Victoria | South-Western BC | 1026<br>1110 |
| Sparwood | South-Eastern BC | 1240 |
| Fort Nelson | North-Eastern BC | 1077 |
| Prince Rupert | North and Central- Western BC | 787 |
| **Provincial Average** | All | ~1,000 |

Table 4 shows the PV potential for selected BC municipalities. The figures demonstrate the range of variation in PV potential between different municipalities within the province. For example, Prince Rupert has some of the lowest PV potential in BC while Sparwood has some of the highest. There is a difference of approximately 40% in solar PV potential between these two municipalities. This gap is wide enough that it could affect the business case of solar PV: revenue[59] will accrue 40% more quickly for system owners in some municipalities than others.

For the remainder of the paper, calculations will be made assuming solar potential of 1,000 kWh for each kW of installed solar PV capacity in BC (1000 kWh/kW). This figure broadly reflects the provincial average, although PV potential ranges 20% higher or lower than this figure depending where in BC the panel is being installed.

---

[54] Natural Resources Canada, *Photovltaic Potential and Solar Resource Map of Canada*, accessed November 29th 2009 from <https://glfc.cfsnet.nfis.org/mapserver/pv/index_e.php>.
[55] For example, with annual solar potential of 700kWh/kW, a two kW PV system will likely yield 1400 kWh of electricity each year.
[56] European Commission, *Global irradiation and solar electricity potential: Germany*, retrieved January 3rd 2010 from <http://re.jrc.ec.europa.eu/pvgis/cmaps/eu_opt/pvgis_solar_optimum_DE.png>.
[57] Natural Resources Canada, *Op. cit.*
[58] Compared to other jurisdictions with more sun, such as California, solar PV potential in BC is relatively low.
[59] Under Net Metering revenue is realized through the avoided cost of grid-based electricity.

## Winter and Solar Availability

Winter weather can affect PV panel performance. One case study showed that between .3% and 2.7% of total annual solar output capacity could be lost to snow cover, depending on yearly snowfall patterns.[60] Rapid snowfall is the mostly likely to affect performance and can entirely cover panels, stopping panels from functioning. However, snow buildup tends to shed after approximately 24 hours as a water slick builds up.[61] Careful panel orientation can also reduce buildup, and panel owners may also clear snow with a broom or other reaching object.[62]

Complicating matters further is the fact that winter conditions can also *increase* PV system performance.[63] Snow covering the ground creates glare, which can increase the amount of solar energy striking solar panels. At the same time, the photovoltaic reaction occurs more easily in lower temperatures than higher temperatures. While these factors will not compensate for the lower solar availability during the winter, they do imply that residential solar PV systems are suitable to colder regions of BC.

## Shading and Solar Access

Regional PV potential does not capture site-specific solar availability, which is dictated largely by shading. PV systems can only function with direct access to sunlight and will be adversely affected by obstructions. Much like a string of Christmas lights, problems in one part of a solar array can 'turn off' large portions of the system.[64] The disruption is not proportionate to the amount of shading: shading of 10% of a module can reduce system output by 100%.[65]

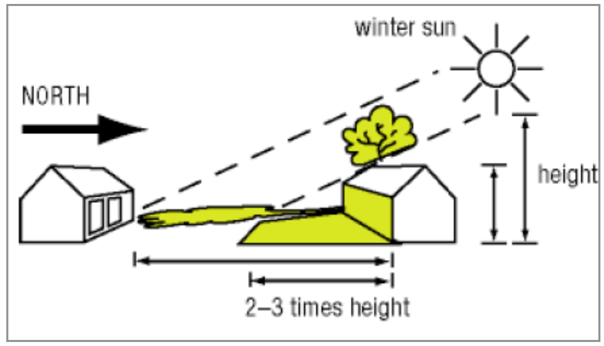
At the site-specific level, tools have been developed for calculating how existing obstructions will affect solar performance. SolarBC provides a free tool at http://www.solarrating.ca/ that calculates the effect of building location, orientation, roof slope, and shading factors.

Specialized hand-tools for calculating solar path and assessing shading variables are also available and virtually any qualified installer will provide a free site-assessment.

---

[60] G. Becker *et al., An approach to the impact of snow on the yield of grid-connected PV systems*, n.d., retrieved January 30th 2010 from <www.sev-bayern.de/content/snow.pdf>.
[61] Canadian Solar Industries Assocation, *Frequently asked questions*, CANSIA website, accessed March 1st 2010 from <http://www.canadian-solar.ca/faq/ >.
[62] *Ibid.*
[63] *Ibid.*
[64] R. Muenster, 'Shade happens,' *Renewable Energy World*, February 2nd 2009, accessed March 2nd 2010 from <http://www.renewableenergyworld.com/rea/news/article/2009/02/shade-happens-54551>.
[65] Canada Mortgage and Housing Corporation, *Photovoltaics (PVs)*, n.d., accessed February 19th, 2010, from <http://www.cmhc-schl.gc.ca/en/co/maho/enefcosa/enefcosa_003.cfm>

**Figure 8 - Shadows can extend 2-3 times the height of the object during winter sun.**[68]




Shading obstructions may be located on-site, such as from a chimney or a tree, which casts a shadow onto the south-facing portion of a roof. More often shading is from neighboring properties and buildings. During the lengthy life of a solar system (20-40 years) changes to neighboring property may block direct solar access. In BC there is no legal guarantee that solar access will be protected over time, leaving conflicts open to court cases. This lack of protection for solar access creates a serious risk for potential system owners and may present a barrier to solar PV uptake.[66][67]

A variety of planning tools are currently available for Local Governments in BC to encourage solar access, including zoning and development permit areas. These tools are explored in Section 6 of this document.

## Estimating Residential PV Potential in British Columbia

BC Hydro has estimated that one third of rooftops in BC can support some type of solar system.[69] At last census there were approximately 850,000 detached or semi-detached homes in the Province.[70] Assuming that one third of these homes could support systems between 1kW and 3kW, this suggests a range between 283,000 megawatt-hours and 850,000 megawatt-hours of energy could be produced every year.[71]

Residential grid-connected PV systems could aid with the goal of becoming self-sufficient in electricity within the Province, although as indicated above the solar potential for some regions is much higher than others. This suggests a need to look at comparative regional advantages for energy production, and not a blanket-approach to PV uptake.

---

[66] C. Higgins, *Personal communication with the author*, February 11th, 2010.

[67] R. Kruhlak, *A legal review of access to sunlight in sunny Alberta,* Edmonton, 1981, retrieved March 1st 2010 from <http://www.cansia.ca/government-regulatory-issues/archives>.

[68] Sustainable Energy Authority Victoria, *Info fact sheet: Siting and solar access*, n.d., retrieved March 3rd from <www.sustainability.vic.gov.au/resources/.../Siting_and_solar_access.pdf>.

[69] Community Energy Association *Powering our communities: Renewable energy guide for local governments in British Columbia*, 2008, p.12, retrieved November 12th 2009 from <http://www.communityenergy.bc.ca/>.

[70] Canada Mortgage and Housing Corporation, *Occupied Housing Type by Structure Type and Tenure, 1991-2006: British Columbia*, retrieved March 1st 2010 from <http://www.cmhc.ca/en/corp/about/cahoob/data/data_007.cfm>.

[71] These statistics should be treated with caution due to the assumptions regarding the suitability of rooftops to PV systems. The data is intended only to illustrate that a significant quantity of energy could be generated by residential PV systems within the province. This estimate should be supplemented by higher-quality data when available.

# 4. Environmental Impacts of Residential Solar Photovoltaics in British Columbia

As indicated in Section 3, there is a substantial quantity of residential solar PV potential within BC. Where Solar PV offsets energy produced from fossil-fuels, such as coal and natural gas, it is likely to provide substantial environmental benefits. But how meaningful is this claim in British Columbia, which receives it energy primarily through hydroelectricity?

This section of the document provides a literature review and brief analysis of the environmental issues related to residential PV installations and how these might be manifested in the BC context. Specifically, the effect of PV production and use on GHG emissions and the release of toxins are explored. A brief discussion of end-of-life management (recycling) is also included as this process can further reduce emissions.

## Greenhouse Gas Emissions Profile for Residential Solar PV

*Life Cycle Analysis:*

The BC energy plan assumes zero emissions from energy provided by solar.[72] While it is true that the operation of solar PV does not produce greenhouse gas emissions during operation, there are indirect emissions associated with other stages in the system's life-cycle.

The most appropriate method for exploring environmental impact is often through a life-cycle analysis (LCA). LCAs attempt to quantify the environmental impacts of a product or service. When an LCA is performed, results can vary widely based on the scope ("system boundaries") of the analysis. For instance, emissions related to transport might be included in an LCA while emissions related to disposal might not. In addition, certain assumptions made about the product (eg. product lifespan) may substantially affect the outcomes of the LCA. In general a more thorough and more robust measure will paint a more accurate picture of emissions and will better allow comparison between different technologies.[73]

---

[72] BC Ministry of Energy, Mines, and Petroleum Resources, *Energy plan: A vision for clean energy leadership*, 2007, p. 25, retrieved February 20th 2010 from <http://www.energyplan.gov.bc.ca/>.

[73] For example, the emissions associated with a solar panel's life-cycle change substantially based on manufacturing efficiency or the type of solar panel used. Factors such as the energy used by construction workers driving to a worksite every morning can even be included in the analysis, although such an inclusion would represent a fairly wide system boundary.

Carbon dioxide equivalent (Co2e) has become the standard metric for measuring greenhouse gas emissions, and can be calculated per unit of energy. For PV the most appropriate unit to use for small scale systems is Co2e/kWh. This metric represents the total emissions used to produce and assemble a solar panel and its associated components, and then amortizes these emissions over the panel's useful life. This type of emissions/energy ratio is often referred to as an "emissions factor", and it provides a standard by which different energy sources can be measured.

The author reviewed several LCAs for residential solar PV systems. The results are compared in Table 5 below. These studies were selected because they included similar or identical assumptions regarding scope (system boundary) and panel life. Key assumptions[74] included the following:

- Emissions from materials extraction, manufacturing, and production of system were included;
- Balance of System (BOS) components such as aluminum frames and inverters were included; *and*
- Panel life was assumed at or around 30 years.

The use of similar assumptions allows longitudinal comparison between studies. Results indicate a decline in life-cycle emissions over time which correlated with when the systems were produced. This is likely due to increases in manufacturing efficiency (less energy required) and increasing solar cell efficiency (longer life; higher energy production). For example, a Japanese study published in 1997[75] showed 91 grams of Co2e/kWh, while most of the more recent studies predict approximately half these emissions.

> Life-cycle emissions from recently produced conventional silicon panels will be approximately 40-50 grams of Co2e/kWh while thin-film would be closer to 25 grams Co2e/kWh. These emissions would likely be lower if the systems were produced using a higher percentage of renewable energy.

By far the largest source of emissions during a PV system's life-cycle is the energy-intensive production of silicon. In accordance with industry claims, thin-film technologies appear to have substantially lower life-cycle emissions. Emissions could be even lower with BIPV, which eliminates the need for a frame and avoids the use of other products. The amount of avoided emissions from BIPV will be quite different on a case-by-case basis as they depend highly on the material being replaced.

---

[74] A limitation of most of these studies is that they did not include emissions associated with end of life management (decommissioning, recycling, and disposal) of the system. This issue will be explored in the next section of the document.

[75] K. Kato, A. Murata, and K. Sakuta.,'An evaluation on the life cycle of photovoltaic energy system considering production energy of off-grade silicon.' *Solar Energy Materials and Solar Cells*, 1997, Vol. 47, pp. 95–100.

**Table 5 -** Summary of Life Cycle Analyses for GHG Emissions from Residential Roof-Mounted Photovoltaic Systems.

| Year of Study | Author/s | Location | Module Type | Co2e/ kWh | Study Assumptions |
|---|---|---|---|---|---|
| 1997 | Kato, Murata, and Sakuta[76] | Japan | C-Si | 91 | Assumes 1427 kWh per square meter of annual solar insolation. |
| 2006 (panel installed in 2002) | Kannan *et. al.*[77] | Singapore | Mono-Si | 68-217 | Higher emissions explained by different assumptions about emissions from electricity (global average), emissions from recycling, date of panel construction (2002), and lower assumed manufacturing efficiency than other studies. |
| 2006 | Hondo[78] | Japan | P-Sci<br>**A-Sci*** | 44-53<br>26 | Some details of LCA system boundaries not specified. |
| 2006 | Fthenakis & Alsema[79] | Europe & US | Multi-si<br>Ribbon<br>Mono-Si<br>**CdTe*** | 37<br>30<br>45<br>21 | Assumes 1300 kWh per meter square of annual solar insolation.<br><br>Study looked at 11 European and US PV manufacturers; Estimate vary substantially depending where panels are produced (US-made panels have almost twice the embodied GHG emissions due to different electricity mix) |
| 2008 | Fthenakis, Kim, & Alsema[80] | USA | Multi-Si<br>Ribbon<br>Mono-Si<br>**CdTe*** | 52<br>42<br>54<br>25 | Assumes 1700kWh per square meter of annual solar insolation. |
| 2008 | Suna *et. al.*[81] | Canada | Sc-Si<br>Mc-Si | 52<br>41 | Assumes panels produced in Canada based on average electricity mix. |
| Average for conventional silicon panels produced since 2005: 44 grams Co2e/kWh<br>Average for thin-film panels: 23 grams Co2e/kWh | | | | | |

* indicates thin-film technologies.

[76] K. Kato, A. Murata, and K. Sakuta, *Op. cit*.
[77] R. Kannan, *et al.* 'Life cycle assessment study of solar PV systems: An example of a 2.7kW distributed solar PV system in Singapore,' *Solar Energy* 80, 2006, pp. 555–563.
[78] H. Hondo, 'Life cycle GHG emission analysis of power generation systems: Japanese case', *Energy*, Vol. 30, 2005, pp. 2042-2056.
[79] V. Fthenakis and E. Alsema, 'Photovoltaics energy payback times, greenhouse gas emissions, and external costs: 2004–early 2005 status', *Progress in Photovoltaics: Research and Applications* 14, 2006.
[80] V. Fthenakis, H. Kim, and E. Alsema, 'Emissions from photovoltaic life cycles,' *Environmental Science & Technology* 42, 2008, pp. 2168–2174.
[81] D. Suna, R. Haas and A. Lopez Polo, 'Analysis of pv system's values beyond energy: by country and stakeholder', *Photovoltaic Power Systems Program, International Energy Association*, p. 24. Retrieved January 3rd, 2010, from <www.iea-pvps.org/products/download/rep10_02.pdf>.

For operating conditions and available solar energy in BC, it appears reasonable to assume that emissions from energy produced by conventional silicone panels will be approximately 40-50 grams of Co2e/kWh while thin-film CdTe would be closer to 25 Co2e/kWh.[82] It is important to note that these life-cycle emissions can differ substantially between manufacturers. The life-cycle emissions primarily reflect the energy used to produce the panels and other system components, therefore these emissions can differ substantially based on where the components are produced. For example, panels produced in the US are associated with more emissions than panels produced in Europe.[83] If a PV system were produced in BC, or in another jurisdiction that primarily draws on clean energy, life-cycle emissions would be lowered significantly.

In virtually all of the above-cited studies PV produced far less emissions than fossil-fuel derived electricity. However, PV systems may not have the same net GHG benefits for British Columbia, where the electricity mix draws predominately from hydropower. The following section provides a comparison to BC Hydro's existing electricity mix in order to estimate potential GHG savings.

## Emissions from status quo grid electricity: BC's "Clean" Hydropower

Hydropower is broadly considered to be "clean" energy as its operation emits virtually no air pollutants. As with solar PV, the Energy Plan assesses emissions from a hydroelectric facility as zero.[84] While this is true from the perspective of direct emissions (those emitted during operation) it does not account for life-cycle emissions.

Currently BC Hydro itself assesses its indirect emissions for hydroelectricity at 22 tonnes Co2e per gigawatt-hour produced.[85] This equates to 22 grams of Co2e/kWh.[86] However, this statistic is extremely limited in scope: it focuses on emissions from land conversion, namely the area of land flooded by a dam and the additional methane emissions which result. Other factors omitted from this statistic are addressed below:

*BC imports power from coal and gas-fired energy facilities*

Most of BC shares an electricity grid with Alberta and numerous US states. Energy is exported from and imported to BC through this grid. Since 2001, BC has largely been a 'net importer' of electricity.[87][88] This statement is somewhat controversial as BC

---

[82] This assumes that the panels were produced recently in Europe or the US, and have a life-cycle of 30 years.

[83] V. Fthenakis and E. Alsema, *Op. cit*.

[84] BC Ministry of Energy, Mines, and Petroleum Resources, *Energy plan: A vision for clean energy leadership*, 2007, p. 25, retrieved February 20th 2010 from <http://www.energyplan.gov.bc.ca/>.

[85] BC Housing, *Technical bulletin no. 14-08*, issued January 18th 2008, retrieved August 20th 2009 from <http://www.bchousing.org/resources/Programs/ILBC/technical bulletins/TB_14_Energy_Performance.pdf>.

[86] 1 gWh = 1,000,000 kWhs; 22 tonnes = 22,000,000 grams; 22,000,000/1,000,000 = 22 grams/kWh.

[87] BC Ministry of Energy, Mines, and Petroleum Resources, *Energy plan: A vision for clean energy leadership*, *Op. cit*.

also sells a portion of its 'clean' energy. However, the electricity that is imported reflects the emissions factor of its sources, which are much higher than those in BC.[89] The official emissions factor does not account for the emissions from imported electricity.

Quantifying the emissions from imported electricity is difficult as it varies from year to year based on the availability of water in reservoirs, and because there is a difference between electricity imported by BC Hydro and the total province-wide net imports and exports.[90] For example, in 2009 BC Hydro's net imports were over 4,600 gWh.[91] One comparative analysis indicates that accounting for the emissions from net imports raises the average emissions factor in BC to 80 tonnes Co2e per gWh,[92] approximately four times higher than the emissions factor used by BC Hydro. When converted to grams per kWh, a unit more appropriate to comparison with PV, the ratio becomes 72 grams/kWh. This is substantially higher than emissions associated with residential solar PV systems. Based on these numbers alone, one can expect that each kWh of electricity produced by residential PV systems will avoid between 27and 47 grams of Co2e.

*The BC Hydro Emissions Factor is not sensitive to Life Cycle Emissions*

Emissions associated with the hydropower infrastructure itself are also seemingly not included in BC Hydro's emissions factor. Both the hydro facilities themselves and the supporting infrastructure (transmission lines) would need to be assessed for an accurate view of embodied energy.

As described above, land-use change resulting from new hydroelectric capacity in BC is associated with emissions of approximately 22 grams Co2e/kWh as a result of land-use change. Emissions from the generating facilities themselves likely fall between 2 and 9 grams Co2e/kWh.[93] This suggests a range of 24-31 grams Co2e/kWh when accounting for BC Hydro's current emissions factor, which accounts only for land-use change. This statistic does *not* account for emissions associated with the construction and maintenance of the transmission infrastructure required to move electricity from the point of generation to the point of consumption. Unfortunately no documents could be found which provided a useful estimate of the emissions associated with transmission infrastructure.

---

[88] BC Ministry of Energy, Mines, and Petroleum Resources, *For the record: Facts on independent power production*, *Op. cit*.
[89] J. Hanova, H. Dowlatabadi, and L. Mueller, 'Ground source heat pump systems in Canada: Economics and GHG reduction potential,' 2007, in *Discussion Papers, Resources For the Future*, Washington, DC. retrieved January 13th 2010 from <www.rff.org/documents/RFF-DP-07-18.pdf>.
[90] G. Hoberg and C. Mallon, *Electricity trade in British Columbia: Are we a net importer or a net exporter?,* March 17th 2009, retrieved January 13th 2010 from <http://greenpolicyprof.org/wordpress>.
[91] BC Hydro, *BC Hydro Annual Report 2009*, retrieved March 2nd 2010 from <www.bchydro.com>.
[92] J. Hanova, H. Dowlatabadi, and L. Mueller, *Op. cit.,* p. 27.
[93] D. Weisser, *A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies*, n.d., International Atomic Energy Association, p. 17., retrieved February 20th 2010 from <http://www.iaea.org/OurWork/ST/NE/Pess/assets/GHG_manuscript_pre-print_versionDanielWeisser.pdf>.

*Comparing Residential PV Systems to the Status Quo Electricity Mix*

A few tentative conclusions can be reached. Firstly, residential solar PV systems do have the potential to reduce electricity imports, thereby reducing emissions associated with electricity consumption in the province. Secondly, even when comparing to a Business as Usual scenario, such as the expansion of hydroelectric capacity, residential solar PV systems are associated with comparable life-cycle emissions.

Table 6 below compares and summarizes emissions from residential PV systems and compares these to both the current emissions factor for hydroelectricity (including imports) and to the likely emissions that would result from additional hydroelectric capacity. Quantifying these potential GHG emissions is extremely challenging; results will differ based on where solar panels were produced, and based on what type of solar panels are considered. In addition, no estimates of emissions embodied in transmission infrastructure could be found which would directly apply to this analysis. Some simple calculations imply the following:

Based on electricity imports, at least 27-47 grams of Co2e will be avoided for each kWh of electricity generated from residential PV systems. This picture could change substantially if the PV systems were produced in a region with a relatively clean electricity mix, such as BC, which would substantially increase life-cycle GHG benefits.

When compared to status quo electricity and ignoring the emissions associated with electrical transmission infrastructure, life-cycle emissions from thin-film PV systems appear to be equivalent to or lower than large-scale hydro projects. Life-cycle emissions based on conventional silicon panels will be associated with higher emissions than hydroelectric or thin-film. More exact quantification could only be derived from a more complete picture of emissions associated with the Business as Usual scenario.

| **Table 6: Summary of Emissions From PV Compared to Business As Usual** | | |
|---|---|---|
| **Life-Cycle Emissions of Residential PV Systems** | **Average emissions from grid-electricity in BC** (including imports) | **Approximate Emissions from Large Hydro** (no imports, not counting transmission infrastructure) |
| Multicrystalline Silicon: 40-50 grams/kWh | ~72 grams/kWh | >24-31 grams/kWh |
| Thin-film: 25 grams/kWh | | |

## Other Environment Considerations: Toxins and Recycling

While there are clear GHG benefits to using PV systems to offset fossil fuel generation, these benefits could be reduced if other forms of pollution (toxins) create other adverse effects, either at time of production or at end-of-life of a product. Concerns have been raised over the toxins present in some PV modules through some non-governmental organizations, such as Greenpeace[94] and the Silicon Valley Toxics Coalition.[95]

End-of-life management is increasingly a target of government policy. Provincial and local government policies now frequently encourage or require recycling as a means to lower environmental impact: construction and demolition policies at the local government level include provisions for materials reuse and recycling, and the recovery of energy from "waste" streams appears increasingly popular.[96] This raises questions regarding the potential of PV systems to be recycled, and whether PV recycling might be an appropriate area for policy intervention.

With a better understanding of non-GHG pollutants associated with PV and prospects for recycling PV modules, it becomes easier to effectively compare photovoltaics with other renewable energy generating technologies. Therefore this section explores the closely related issues of toxins and recycling as related to residential PV system manufacture and use.

### Toxins

Each type of PV panel contains different materials, and these materials are associated with different levels of environmental risk. Three of the main PV panel materials are explored below: silicon, cadmium telluride (CdTe) and Copper Indium Gallium Selenide (CIGS).

[94] V. Fthenakis, *Could CdTe PV modules pollute the environment?,* National Photovoltaic Environmental Health and Safety Assistance Center, Brookhaven National Laboratory, 2002, retrieved January 3rd 2010 from <www.abound.com>.
[95] Silicon Valley Toxics Coalition, *Towards a just and sustainable solar industry,* January 14th 2009, retrieved March 9th 2010 from <www.svtc.org/>.
[96] For example, Metro Vancouver is considering the addition of new Waste to Energy facilities, and a new facility of this type is likely to be constructed at Gold River on Vancouver Island.

*Silicon*

Silicone production creates various bi-products, including silicon tetrachloride. For each ton of polysilicon produced, the process generates at least four tons of silicon tetrachloride liquid waste.[97] This waste is commonly recycled at point of manufacture into silicon, but the infrastructure and process for recycling and pollution control nearly doubles the production costs of polysilicon.[98] In China, currently the largest producer of solar PV panels in the world, at least one incident occurred in which silicon tetrachloride was dumped illegally near the factory. The dumping has been linked to health complications and damaged crops.[99] This practice was directly contrary to local regulations, and regulations to control the dumping of hazardous substances exist in most countries. As in any industry, illegal dumping of toxins can be carried out by manufacturers and will result in environmental harm.

Once produced, silicon itself is benign. No linkages were found in the literature that suggested serious health risks from polysilicon modules at end-of-life. These panels can seemingly be safely recycled or disposed of in landfill.

*Cadmium Telluride*

Many thin-film modules are made from cadmium telluride (CdTe), which contains cadmium. One study showed that 0.02 g of cadmium per gWh of electricity would be produced over a panel's lifecycle. This is extremely low when compared to life-cycle cadmium releases from rechargeable batteries.[100] One author argues: "even if pieces of modules inadvertently make it to a municipal waste incinerator, cadmium will dissolve in the molten glass and would become part of the solid waste."[101] CdTe may also be recycled effectively.[102] Further, because cadmium used in PV manufacturing is sometimes reclaimed from industrial waste, CdTe modules may actually be diverting/delaying this material from entering the landfill or being otherwise disposed of.[103]

*Copper Indium Gallium Selenide (CIGS)*

CIGS modules use a fairly small amount of toxic materials, even less than CdTe.[104] No significant concerns were raised within the literature reviewed by the author.

---

[97] Cha, A. 'Solar energy firms leave waste behind,' *Washington Post*, Sunday March 9, 2008, retrieved September 30th 2008 from <http://www.washingtonpost.com/wp-dyn/content/article/2008/03/08/AR2008030802595.html>.
[98] *Ibid.*
[99] *Ibid.*
[100] V. Fthenakis, 'Life cycle impact analysis of cadmium in CdTe PV production,' *Renewable and Sustainable Energy Reviews* 8, 2004, pp. 303–334.
[101] *Ibid.*
[102] *Ibid.*
[103] *Ibid.*
[104] V. Fthenakis et al. 'Toxicity of Cadmium Telluride, Copper Indium Diselenide, and Copper Gallium Diselenide,' *Progress in Photovoltaics*, 1999, V. 7, pp. 489-497.

*Organic Solar and Solar Paint*

As organic and polymer-based solar technologies are emerging technologies, it is not clear which types will become commercialized. At this early stage little information is available about the potential for toxicity. A literature review of several academic journal search engines did not find any specific concerns raised regarding organic solar technologies or solar paints. A review of literature related to this subject could be conducted in the future when more data becomes available.

> First Solar, a US-based manufacturer of thin-film solar technologies, is the first company in North America to implement a manufacturer take-back and recycling scheme for its PV modules.[105] Funds for the recycling program are set aside at time-of-sale. Products are clearly labeled with appropriate information for contacting the manufacturer and pickup of the products is free. The company claims a 90% materials recovery rate.

**Recycling of Residential Solar Systems:**

Recycling can further lower the environmental impact of PV systems by keeping materials out of the waste stream and capturing some of the energy embodied in system components.[106]

Recycling is shown to have higher net environmental benefits than Waste to Energy (incineration). For example, a pilot recycling plant in Europe reports substantial benefits for silicon wafer recycling and reuse, including a substantial decrease in energy for wafer production.[107]

There is a clear trend towards PV module recycling already underway. One US-based firm, First Solar, has already begun its own voluntary product take-back scheme.[108] On a larger scale, PV Cycle is a voluntary organization based in Europe whose members have committed to responsible end-of-life management. PV cycle is expected to begin a manufacturer take-back system this year,[109] and one Canadian PV manufacturer has already joined PV Cycle.[110]

---

[105] First Solar, *Refunded collection and recycling program*, accessed January 13th 2010 from <http://www.firstsolar.com/en/recycle_program.php >.

[106] Metal frames (generally made from aluminum) along with metal wires and other small electrical components are already recyclable and are unlikely to require special policy or infrastructure adaptations. As such they are not considered in this document.

[107] A. Müller, K. Wambach, E. Alsema, 'Life cycle analysis of a solar module recycling process,' *Materials Research Society*, Warrendale, PA, USA, 2007, retrieved February 26 2010 from <http://www.mrs.org/s_mrs/sec_subscribe.asp?CID=6228&DID=170203&action=detail>.

[108] First Solar, 'Refunded collection and recycling program,' retrieved January 13th 2010 from <http://www.firstsolar.com/en/recycle_program.php >.

[109] 'PV CYCLE to initiate solar PV module take-back and recycling programme in 2010,' *Renewable Energy Focus*, 12 October 2009, retrieved February 3rd 2010 from <www.renewableenergyfocus.com>.

[110] 'Canadian Solar joins ranks of PV Cycle,' *Renewable Energy Focus*, July 27th 2009, retrieved February 3rd 2010 from <http://www.renewableenergyfocus.com/view/2720/canadian-solar-joins-ranks-of-pv-cycle/>.

One prediction for the US solar PV market suggested costs of between $0.08 and $0.11 per watt of PV capacity ($80-$100 per kW) in order to make recycling economically attractive to companies where no other incentives are in place.[111] This would equate to approximately $270 for a 3Kw system. In the absence of direct economic incentives or incentives to begin recycling, few industries take voluntary action. Therefore some form of policy to encourage recycling may be required in BC as solar PV systems become more prevalent.

Various models to encourage electronic and electrical recycling exist, and it is beyond the scope of this paper to go into detail on these. However, one example of an existing model already implemented within the province is the Environmental Handling Fee, which is applied to electronics.[112] Unfortunately, flat-fee systems of this type do not provide incentives to individual companies to redesign products differently (eg. making panels easier to recycle). Changes in panel design could substantially improve prospects for recycling.[113] Consideration should also be given to "true" extended producer responsibility models that make individual companies responsible for managing their own waste products.

PV recycling is an emerging industry that has the potential to lower life-cycle GHG emissions and to avoid unnecessary waste (both economic and environmental). If more substantial subsidies are to be provided to solar PV manufacturers, as they are in some jurisdictions, due consideration should be given to encouraging or regulating recycling, as it would better fulfill environmental objectives.

**Conclusions:**

Several aspects of the environmental impact of PV uptake were assessed in this section. Claims that solar PV is "clean" energy are well founded: life-cycle emissions from PV are quite low, even when compared to hydroelectricity, and there is little risk associated with toxins from PV panels. Environmental benefits can be further increased through recycling.

Based on current electricity imports, one can tentatively conclude that at least 27-47 grams of Co2e will be avoided for each kWh of electricity generated from residential PV systems. This implies that for each 3kW system, greenhouse gas benefits could be somewhere between 81 and 141 kg per year.[114] Depending which region of BC these panels were located in and whether or not the PV systems were manufactured using electricity with a low emissions factor, these benefits could improve substantially.

---

[111] V. Fthenakis, 'End-of-life management and recycling of PV modules,' *Energy Policy* 28, 2000, pp. 1051-1058.
[112] Encorp Pacific, 'Electronics Recycling Fees,' retrieved September 13th 2009 from <http://www.encorp.ca>.
[113] V. Fthenakis, 'End-of-life management and recycling of PV modules,' *Energy Policy* 28, 2000, pp. 1051-1058.
[114] Assuming annual solar PV potential of 1,000 kWh/kW.

Thin-film residential PV systems appear to produce life-cycle emissions comparable to large-scale hydroelectric facilities, while existing conventional silicon panels will likely produce higher life-cycle emissions. When compared to other scenarios, such as an expansion of hydroelectric capacity or the use of other renewable energy resources, the relative greenhouse gas benefits which can be provided by PV systems will likely shrink.

A more exact quantification of the potential benefits of on-site renewable electricity generation would require additional information regarding the emissions associated with the construction and maintenance of BC's electrical transmission infrastructure. This could add significantly to the emissions associated with the construction and maintenance of other renewable energy options, and may show an increase in the relative GHG reductions which can be realized through grid-connected PV systems. It should also be noted that life-cycle emissions do not account for other potential environmental impacts of hydroelectricity, such as habitat destruction related to new transmission capacity, dams, or any other large-scale energy generation projects. Research into such areas would help in comparing PV to other means of delivering clean energy to BC.

The relative benefits of residential PV uptake in other jurisdictions, many of which depend more highly on non-renewable resources for electricity, are much higher than those in BC. This likely at least partly explains the higher willingness to provide funding to PV systems in other jurisdictions.

The following section of the document provides an economic analysis of residential PV systems, showing the likely economic costs of achieving these environmental benefits through the uptake of residential solar PV systems in BC.

# 5. The Economics of Residential Solar PV Systems in British Columbia

Solar PV has generally been considered an expensive source of electricity, but prices have been rapidly decreasing. This section of the paper examines trends in the market price of PV, provides sample prices for a system purchased in BC, and calculates the cost and revenue changes which would be required to achieve 'break-even' costs over the life-cycle of the PV system. Results indicate that a substantial policy intervention would be required to make PV viable on purely economic grounds within the next decade.

## Trends in PV Module Pricing in Canada

There is a clear trend towards decreasing costs of PV technologies due to a variety of factors including economies of scale, improvements to existing technology (higher solar conversion efficiencies) and the deployment of new technologies (thin-film). Natural Resources Canada produces an annual report that includes average PV system costs for Canada. Using data from the 2007[115] and 2008 reports,[116] the downward pricing trend is graphed below.

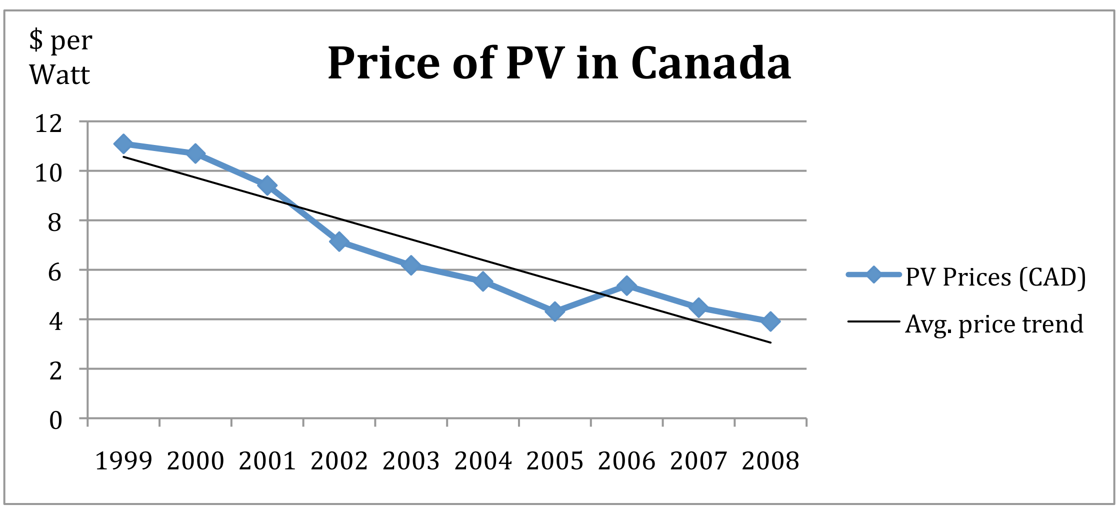



**Figure 9 - Weighted Average Prices for Photovoltaic Modules (1999-2008) -** The prices are shown in dollars per watt of installed capacity and indicate a decline in pricing of nearly 10% annually. The increase in price in 2006 is due largely to a global silicon shortage brought about by high demand and limited production capacity.[117]

[115] J. Ayoub and L. Dignard-Bailey, *Photovoltaic Technology Status and Prospects: Canadian Annual Report 2007*, CanmetENERGY, Natural Resources Canada, retrieved November 20th 2009 from <http://www.canmetenergy.nrcan.gc.ca>.
[116] J. Ayoub and L. Dignard-Bailey, *Photovoltaic Technology Status and Prospects: Canadian Annual Report 2008*, CanmetENERGY, Natural Resources Canada, retrieved November 20th 2009 from <http://www.canmetenergy.nrcan.gc.ca>.
[117] *Ibid.*

The average price of PV modules in Canada shows a decline of nearly 10% annually. The 2008 average was near $4,000/kW. As an average, this price includes commercial/bulk sales. It does *not* include Balance of System components or installation costs, which make up approximately half of total system costs. Therefore the average listed above is significantly lower than the actual prices for small-scale PV systems.

## Current Market Pricing for Solar PV Systems in BC

Sample costs for several solar panel and system types, including conventional silicon, thin-film, and BIPV, are outlined below. Price estimates were obtained through a combination of web-searching and key informant interviews with several companies and installers in BC. Appendix B contains a list of selected component and system prices, and most of the prices and statistics used below draw on the data contained there.

### Factors determining cost of residential PV systems to consumers

The up-front costs of solar PV include the cost of the solar panels (modules), Balance of System components (inverters, wiring, etc.); installation costs (labor); and associated administrative fees (permitting). Any maintenance costs must also be factored in, and potentially disposal costs as well.

In the case of residential grid-connected PV systems in BC, revenue will be realized as avoided costs of electricity that would otherwise be purchased from the grid. Through BC Hydro's Net Metering program, PV system owners are charged for the net balance of electricity used over the billing cycle. In BC most grid-connected residential customers pay around 7-8 cents/kWh.[118]

*Incentives and Subsidies in BC*

Livesmart BC's Efficiency Incentive Program[119] is offering two types of incentive to potential PV system buyers. The more basic type of incentive is an exemption on Provincial Sales Tax. This tax exemption is slated to end when the Harmonized Sales Tax is introduced on July 1st, 2010.

In addition to the tax exemption, BC residents are eligible for a subsidy of $260 per kW of installed capacity through Livesmart BC. This amounts to a small fraction of total system costs, approximately 3%, and is therefore unlikely to influence the economic basis for PV system ownership.

---

118 This figure is approximate because BC Hydro charges a "stepped rate" and therefore the prices per kWh depend on consumption patterns.

119 BC Ministry of Energy, Mines, and Petroleum Resources, *Livesmart BC efficiency incentive program: Home improvement incentive brochure*, accessed February 14th 2010 from <http://www.energyplan.gov.bc.ca/efficiency/>.

*Permits and Fees*

All major electrical work requires a permit from the designated Electrical Inspection Authority. As described in Appendix A, BC customers face Electrical Permit fees of approximately $540 for a 1kW system and $1000 for a 3kW system. Relative to the total cost of PV systems, these fees amount to approximately 3%-5% of installed costs.

*Balance of System Costs*

Nearly half of PV system costs come from BOS components. The most expensive of these components are the inverter and the mounting hardware (frame).

Inverters come in a variety of sizes. However, the price elasticity of inverters is quite low; most inverters listed in the market survey were only available in 2kW size and above. An inverter or set of inverters for a 1kW system would cost approximately $1,200-$2,300, while an inverter matched to a 3kw system costs approximately $2,000-$3,000.

The lifespan of the inverter does not match the lifespan of solar panels. Warranties for grid-tie inverters ranged from 3-10 years, with some companies offering extended warranties for additional cost. In general the price correlated with warranty length: cheaper inverters had shorter warranties. In determining the life-cycle costs of a PV system it is therefore important to assume at least one, if not two, inverter replacements over the life of the system.[120] Assuming that two inverters are used over the life of the system brings inverter costs up to nearly 25% of lifecycle system costs.

The prices for a mount or frame varied little between retailers, and generally totaled $900-$1,000/kW of installed capacity. The cost of a frame can be eliminated through BIPV.

BOS components also include at least several hundred dollars for wiring, disconnects, and smaller electrical components and mounts.

Proportionately, around 50% of the life-cycle cost for a solar PV system is from the module (panel) costs, while approximately 25% is allocated to the two inverters. The remainder is attributed to labor, permits, and smaller BOS components.

---

[120] S. Bornstein, 'The market value and cost of solar photovoltaic electricity production,' *Center for the Study of Energy Markets Working Paper*, Berkley, January 2008, retrieved January 30th 2010 from <www.ucei.berkeley.edu/PDF/csemwp176.pdf>.

*Module Costs*

*Multicrystalline-Silicon*

Conventional multicyrstalline-silicon modules generally cost $3,500 to $7,400/kW in BC, with both an average and median price of $5,200. This is significantly higher than the Canadian average for module prices of $4,000/kW in 2008. For comparison, the US average was US$4,200 per kW for the first quarter of 2010.[121]

*Thin-Film*

Thin-film solar cells are significantly cheaper to produce than conventional panels. By the end of 2008 the least expensive thin-film PV (CdTe) was produced for approximately $1/W.[122] This equates to a hypothetical installed system prices of approximately $3/W, or around $3,000/kW. However, the market is still heavily dominated by traditional multicrystalline panels.[123] As one expert argues, "Many thin film manufacturers are producing cells for under $1/W, and of course selling them for much more because the market price is set by the more expensive crystalline silicon based technology."[124] One study done in the US found thin-film modules were actually slight more expensive on average than silicon-crystalline modules.[125] In addition, some major producers of thin-film products, such as First Solar, do not sell products to the domestic market.[126] Although thin-film is an extremely promising technological development, its uptake appears unlikely to drastically decrease the overall costs of PV over the next several years.

*Building Integrated Photovoltaics (BIPV)*

BIPV is often perceived as being lower cost than frame-mounted PV systems. This is true in application to the commercial sector: when compared to high-end façade materials, especially those used for commercial buildings, BIPV panels are often substantially cheaper than luxury cladding materials.[127] However, façade materials are less well suited to the residential sector, especially in cities, where narrow streets and higher densities limit solar access for façades.

---

[121] Solar Buzz, *Module index retail price per watt peak,* March 2010, retrieved March 14th 2010 from <http://www.solarbuzz.com/Moduleprices.htm>.
[122] V. Fthenakis, 'Sustainability of photovoltaics; The case for thin-film solar cells,' *Renewable and Sustainable Energy Reviews 13,* 2009, p. 2748.
[123] J. Pearce, cited in 'The future of the thin-film solar panel,' *Solar Power Beginner* retrieved February 28th 2010 from <http://www.solarpowerbeginner.com/thin-film-solar-panel.html >.
[124] *Ibid.*
[125] R. Wiser, G. Barbose, and C. Peterman, *Tracking the Sun: The installed cost of photovoltaics in the U.S. from 1998-2007*, Lawrence Berkeley National Laboratory, February 2009, retrieved Tuesday March 2nd 2010 from <http://eetd.lbl.gov/ea/emp/reports/lbnl-1516e.pdf>.
[126] First Solar, *Frequently asked questions*, accessed January 29th 2010 from <http://www.firstsolar.com/en/faq.php#cost>.
[127] D. Suna, R. Haas and A. Lopez Polo, 'Analysis of pv system's values beyond energy: by country and stakeholder', *Photovoltaic Power Systems Program, International Energy Association*, p. 24, retrieved January 3rd 2010 from <www.iea-pvps.org/products/download/rep10_02.pdf>.

Figure 12 **A BIPV product integrated into a metal roof**[128]

In the residential sector BIPV roofing shows more promise than façades. Rooftops are more likely to have unobstructed solar access, and several companies already manufacture BIPV roofs for residential applications.

Cost savings from existing, market-ready BIPV systems in the residential sector appear to be relatively small. For example, if roof shingles cost $1.00 per square foot, there is likely an avoided cost of around $0.10 per watt installed.[129] This equates to an avoided cost of 100$/kW, around 1% of system costs. At present system prices this is a relatively small savings, but may become more significant as the overall cost of PV systems decrease.

Interlock Roofing[130] was the only supplier found in BC who directly imports and installs BIPV roofing products for the residential sector. The system is meant to be integrated into a metal roof, which is also manufactured by the company. The approximate price of a 1.8kW system is $20,000. Standard pricing for metal roofing is $9.00 to $14.00 per square foot, and part of this cost will be offset by the system,[131] implying a cost reduction of approximately $1,300 from offset roofing costs. Additionally, BIPV avoids the cost of a frame, which would be approximately $1800 for a conventional 1.8kW system. This brings the total offset cost of the system to approximately 15%.[132] This is consistent with other estimates of the general potential of BIPV to reduce system costs.[133] However, even with these cost offsets from the replacement of building materials, the total installed system costs remain close to $9,500/kW, which is within the current price range of conventional roof-mounted PV systems.

Cost reductions can be realized through BIPV, but the savings depend highly on the type of building material being replaced. These cost reductions may become more significant as overall system prices decrease over time, but currently they are too small to influence prospective system owners on economic grounds alone. Over the short term, residential BIPV is therefore most likely to be selected for its aesthetic benefits.

---

128 Interlock Roofing, *Solar Roof*, retrieved March 13th 2010 from <http://www.bcsbestroof.com/>.
129 J. Pearce, *Economics of photovoltaic systems*, 2006, retrieved March 1st 2010 from <http://www.appropedia.org/Solar_Photovoltaic_Open_Lectures>.
130 *Interlock Roofing, Op. cit.*
131 Interlock Roofing Representative, *Personal Communication with the Author*, March 12th, 2010.
132 Please note that these estimates reflect only the author's calculations and may differ on a case-by-case basis. The company should be contacted directly for current installation costs.
133 E. Smiley, *Green energy study for British Columbia phase 2: Mainland - building integrated photovoltaic solar and small-scale wind*, BC Hydro, October 2002, retrieved October 2009 from <http://www.bchydro.com/etc/medialib/internet/documents/environment/pdf/green_energy_study.Par.0001.File.greenenergystudy-summary.pdf >.

### *Emerging Technologies: Organic Solar and Solar Paint*

Much has been said in the media about the long-term potential of organic solar, polymer-based solar, and solar paint to reduce the cost of solar modules.[134] There are several promising types under development. However, these all appear to be at least several years from commercialization. For example, organic solar is currently associated with low efficiencies (5%) and a short lifespan (estimated at 5 years) keeping the life-cycle prices relatively high.[135] It is challenging to predict technological breakthrough accurately, but one can assume that it takes a substantial amount of time for an emerging technology to become mass-produced. If thin-film PV is taken as an indicator it appears likely that these emerging technologies are several years from being market-ready and cost-competitive with current solar technologies.

## Sample System Prices

Table 7 below provides a realistic market price for a PV system installed in BC. Prices were drawn from the market survey listed in Appendix B. The system selected is a multicrystalline silicon solar PV system, which is assumed to be purchased and used in the southwest of BC. This implies solar PV potential of 1,000 kWh per kW of installed capacity.

The installed cost of the 2.9kW roof-mounted system was calculated at $24,047, or $8,300 per kW. This system price is at the lower end of estimates provided by system installers, who estimated installed costs in BC between $8,000 and $10,000/kW.[136] However, the sample system price is close to other jurisdictions in North America where Solar PV is more prevalent, such as California, where system costs tend to be closer to $7,000 to $8,000/kW.[137]

The life-cycle costs of the PV system are increased once inverter replacement is included. Assuming a panel life of 30 years, this model implies electricity would be produced at a life-cycle cost of $0.31/kWh. Taking the higher installed cost estimates of $10,000/kW would produce electricity at costs closer to $0.36 cents/kWh.

---

[134] S. Lovgren, 'Spray-on solar-power cells are true breakthrough,' *National Geographic News*, January 14th 2005, retrieved January 18th 2010 from <http://news.nationalgeographic.com/news/2005/01/0114_050114_solarplastic.html>.
[135] J. Kalowekamo and E. Baker, 'Estimating the manufacturing cost of purely organic solar cells,' *Solar Energy,* Vol. 83, 2009, pp. 1224-1231.
[136] For example, Suddwick Homes is a BC-based installer who offers a 4.1kW system for $41,000, including permitting fees and all installation costs. When compared in $/kW, this is almost 20% more thanthe sample costs shown here. Further information is included in Appendix B.
[137] P. Torcellini, *et. al*, 'Solar technologies and the building envelope,' *ASHRAE Journal*, April 2007, p. 14-22, retrieved February 13th 2010 from <www.ashrae.org>.

| Table 7 - Cost and Revenue for a Residential Grid-Tied Solar PV System in British Columbia* | | | |
|---|---|---|---|
| **Cost:** | | **Proportion of Total Cost:** | **Sample Prices:** |
| *Modules (13x230W modules)* | | *48%* | *$13,000* |
| *Balance of System (BOS)* | *Inverter (1x4kW)* | *11%* | *$2,995* |
| | *Frame* | *10%* | *$2,700* |
| | *Remaining BOS* | *6%* | *$1,500* |
| *Electrical Permit* | | *4%* | *$1,000* |
| *Labour/Installation costs* | | *9%* | *$2,500* |
| *Provincial Incentives* | 7% PST Exemption | *7%* | $0 |
| | $260/kW | *3% (decrease)* | $780 |
| *General Sales Tax (GST) 5%* | | 4% | *$1,132* |
| ***Installed Costs*** (including incentives and tax) | | 89% | *$24,047* |
| *Maintenance Cost (1 inverter replacement at 15 years, including GST)* | | 12% | *$3,144* |
| ***Total Life-cycle Costs (including taxes)*** | | 100% | ***$27,191*** |
| **Revenue/Avoided Costs:** | | **Proportion of Revenue:** | **Revenue:** |
| 3,000 kWh of electricity produced annually for 30 years (Constant electricity price of $0.08/kWh) | | 100% | $7,128 |
| | | **Net life-cycle costs after 30 years** (including revenue and incentives) | ***$20,063*** |
| | | **Price per kWh after 30 years** (including revenue and incentives) | **$0.31** |

*Model based on a 2.9kW system, a 30-year time frame, and no costs for capital financing.

## Assumptions, Limitations, and Sensitivities of the Model

### *Assumptions*

The model assumes solar PV potential of 1,000 kWh/kW, as this is close to the BC average and provided simplified calculation. Variation could be expected within around 20% depending on the region in which the panel is installed.

The model assumes electricity prices continue at $0.08/kWh over the entire 30 year lifecycle. This is highly unlikely; electricity costs are likely to increase over the near term as Fortis BC and BC Hydro have recently applied for rate increases.[138]

A module life of 30 years at 100% panel performance is assumed. If panel warranties are an indicator, it is likely that panel performance will have begun to

[138] 'BC Hydro seeks 33% rate hike over next four years,' *CBC News*, Wednesday March 3rd 2010, retrieved Thursday March 4th 2010 from <http://www.cbc.ca/canada/british-columbia/story/2010/03/03/bc-hydro-rate-increases.html?ref=rss>.

decrease by at least 10% by year 25, but it is also likely that panels will continue to operate for longer than 30 years. These two assumptions may cancel each other out.

An inverter life of 15 years is assumed; this is beyond the warranty offered by many companies without added expenditure and may be optimistic. In addition, inverter prices are assumed to remain static over 15 years, although these costs are likely to decline over time.[139] Therefore no labour cost was modeled for inverter replacement, in order to balance the latter assumption.

The model assumes no system financing costs. Given the high up-front costs of a system, financing could add substantially to PV system prices. The exclusion of financing costs (loans) for the panel was left out of the model on the basis that any consumer willing to experience a net loss of over $20,000 is likely making their decision for reasons other than financial costs. This issue is further addressed under the subsection “Changing the Economics of Solar”.

*Limitations*

This data strictly addresses current market prices for PV panels in residential, grid-tied applications. The business case for systems will be quite different for off-grid and remote applications, where the cost of connection to the electricity grid will be much higher.[140]

The business case and sample prices above also do not capture potential savings from more integrated design and installation processes. In California residential PV systems installed during the construction of new buildings were approximately 7% cheaper than systems that were installed as retrofits.[141] It is possible that similar savings would apply in BC if residential PV uptake was widespread.

Finally, this model only measures direct economic costs and benefits. Other benefits, such as energy security, are relatively difficult to quantify and as such have been left out of the model.

*Sensitivities*

The largest determinants of system costs are PV modules, which make up around 50% of system costs, and inverters, which account for 25% of life-cycle costs. The cost-side of the model is therefore highly sensitive to changes in module prices or inverter costs. For example, an additional inverter replacement in the model above (for a total of three inverters) would raise total life-cycle costs of the project by an additional 10%.

---

139 Bornstein, *Op. cit*.
140 Solar Buzz, *Solar energy costs*, accessed February 23rd 2010 from <http://www.solarbuzz.com/StatsCosts.htm>.
141 R. Wiser, G. Barbose, and C. Peterman, *Tracking the Sun: The installed cost of photovoltaics in the U.S. from 1998-2007*, Lawrence Berkeley National Laboratory, February 2009, retrieved Tuesday March 2nd 2010 from <http://eetd.lbl.gov/ea/emp/reports/lbnl-1516e.pdf>.

Electricity prices are the sole determinant of revenue in this model. The model is therefore sensitive to changes in electricity prices. However, these changes would have to be substantial to affect the business case. An immediate doubling of electricity prices to $0.16/kWh would still leave an economic shortfall of nearly $13,000 after 30 years for PV system owners. Under a Net Metering scenario electricity prices of at least $0.31/kWh would be required for system owners to break even on their investment after 30 years. This electricity price is nearly four times higher than the current price of grid electricity, and seems implausible over the short term.

Revenue is also sensitive to the amount of solar energy available. In BC this ranges from around 800 to 1200kWh for every kW of installed capacity. Therefore revenue may range by approximately 20% based on the region in which the panel is located.

The model is slightly sensitive to economies of scale based on changes in system size. Both inverters and electrical permit fees have low price elasticity. This provides slight economy of scale as system size increases; it is approximately 10% cheaper per kW to have a larger system (3kW) than a smaller system (1kW). Beyond the size of 3kW this effect diminishes.

*Volume-Based Cost Reductions*

Bulk purchasing can lower costs. At the residential scale bulk purchases can be made through Community Energy Cooperatives, which purchase several systems from the same installer. Solar PV co-ops documented in Ontario have lowered costs by as much as 10%.[142] These co-ops have also been documented in BC within the solar hot water market, such as the Peace Energy Cooperative in Dawson Creek.[143] However, solar PV co-ops in BC will likely be harder to organize until PV becomes a more popular technology. This is likely to occur only after these systems become more economical for homeowners.

On a wider scale, costs can be reduced through increasing the volume of PV system sales. This can decrease overhead costs for installers and manufacturers[144] and enables more efficient design and installation of PV systems.[145] This potential is indicated by the decline in system prices in jurisdictions that strongly support solar PV. For example, average installed residential PV prices in 2007 were near US$6,000/kW in Japan and $6,600/kW in Germany.[146] The degree to which volume-based cost decreases can be realized in BC are hard to predict, as the economies of scale would likely be linked to demand (population) and possibly whether PV systems were manufactured locally or imported.

---

[142] S. Eng and S. Gill, *Solar PV Community Action Manual*, Ontario Sustainable Energy Association, retrieved September 30th 2009 from <www.ontario-sea.org/Storage.asp?StorageID=445>.
[143] Community Energy Association *Powering our communities: Renewable energy guide for local governments in British Columbia*, 2008, retrieved November 12th 2009 from <http://www.communityenergy.bc.ca/>.
[144] J. Pearce, *Personal communication with the author*, March 2nd 2010.
[145] J. Stonier, *Personal communication with the author*, March 19th, 2010.
[146] Wiser, Barbose, and Peterman, *Op. cit.*

## PV Cost Forecast

Forecasting future prices of PV is challenging. However, there appears to be substantial agreement that costs will continue to decrease, likely by about half over the next 10-20 years. One survey of industry professionals and academics found substantial agreement that average solar module prices would likely reach US $1.20/W by 2030.[147] Another author cites forecasts predicting the cost of producing modules for thin-film PV will fall to US $0.50–0.70/W with system prices of US $1.50– $2.50/W by 2020.[148] However, even one of the more optimistic of these scenarios (around $2,500 per kW) would still leave net loss of $500 to a PV system owner in BC once an inverter replacement is factored in.[149] Only by assuming the panel is installed in a region with higher solar PV potential would a PV system provide net revenue within 30 years.

### Conclusions

Installed prices for a residential, grid-connected PV system in BC range between $8,000 and $10,000/kW, installed. Life-cycle costs should account for at least one inverter replacement, adding approximately $1,000/kW to these costs. At current electricity prices, revenue is likely to be near $2,400/kW over a 30 year period. This leaves a shortfall of $6,600-$8,600 per kW. This is a substantial economic burden for customers. The model also does not account for potential system financing costs, which could provide additional cost to prospective system owners.

Simply to break even financially would require one of the following:

- Revenue to increase by approximately 4 times, such as through increasing the price of electricity from $0.08 to $0.32 per kWh;
- A 70% decrease in installed system costs;
- A subsidy of approximately $7,600/kW, instead of the current $280/kw; *or*
- Some combination of above.

Barring a major technological breakthrough, therefore, some sort of policy intervention which substantially changes the business case for residential PV systems would need to be made in order to encourage widespread uptake of these systems. Some of these interventions are briefly discussed in the following section.

---

[147] A. Curtright, M. G. Morgan, and D. Keith, 'Assessments future pv.' *Environmental Science and Technology*, Vol. 42, No. 24, 2008, P. 9033.
[148] V. Fthenakis, 'Sustainability of photovoltaics; The case for thin-film solar cells.' *Renewable and Sustainable Energy Reviews* 13, 2009, p. 2747.
[149] $US 2.50/W installed equates to $2,500 per kW. Assuming one inverter replacement at the somewhat optimistic price of $1,000/kW this implies a life-cycle cost of $3,500/kW. Substituting this data into the system costs shown in Table 7 and assuming electricity prices of $0.10/kWh, a shortfall of $500 remains at the thirty-year mark. This model still assumes no financing costs would be incurred over the life of the system.

## Changing the Economics of Solar: Rate Structures, Feed-in Tariffs, and Financing

The life-cycle cost of electricity provided by a grid-connected residential PV system in British Columbia is approximately $0.30/kWh. BC Hydro is likely to raise the price of electricity by 33% over the next several years, implying a price of nearly $0.10/kWh.[150] This still leaves a substantial shortfall between the cost of grid electricity and the cost of electricity produced from residential PV systems.

The economics of grid-connected PV systems are most sensitive to changes in the price of electricity, the availability of incentives or subsidies, and the cost of financing.[151] This section describes some of the potential policy options for closing the gap between conventional grid-based electricity and electricity from PV, including internalizing the benefits of PV systems to utilities through 'peak shaving', Time of Use rate structures, and Feed-in Tariffs. A brief discussion of issues related to PV financing is also included.

### Peak Demand, Deferred Infrastructure Costs, and Time of Use Rate Structures

Some authors argue that PV can help to reduce, delay, or avoid utility investments in additional generation capacity and transmission infrastructure.[152] Under Net Metering, customers are not likely to receive the cost reductions that may be realized by utilities. If these "hidden" benefits are sufficiently large, they could provide a rationale for providing financial support to PV system owners.

The "hidden" benefits of residential PV systems, which can deliver electricity on-site, are thought to depend large on the degree to which peak demand for electricity coincides with electrical output from PV systems. Within a conventional electricity delivery system, the capacity to generate and transmit electricity must be sized based on peak electricity demand. This additional transmission and generation capacity is generally idle during large portions of the year. As a result, the actual cost to the utility to deliver electricity can vary based on season, day, and even smaller increments. These cost variations are not internalized by most residential customers, who pay what is essentially an average price for electricity.[153] Variations in the cost of electricity are hidden within this average price.

---

[150] 'BC Hydro seeks 33% rate hike over next four years,' *CBC News*, Wednesday March 3rd 2010, retrieved March 4th 2010 from <http://www.cbc.ca/canada/british-columbia/story/2010/03/03/bc-hydro-rate-increases.html?ref=rss>.
[151] P. Denholm *et. al.*, *Break-even cost for residential photovoltaics in the United States: Key drivers and sensitivities*, National Research Energy Laboratory, December 2009, retrieved February 12th 2010 from <www.nrel.gov/docs/fy10osti/46909.pdf>.
[152] S. Bornstein, 'The market value and cost of solar photovoltaic electricity production,' *Center for the Study of Energy Markets Working Paper*, Berkley, January 2008, retrieved January 30th 2010 from <www.ucei.berkeley.edu/PDF/csemwp176.pdf>.
[153] Although BC Hydro now charges a "Conservation Rate" for residential electricity consumption, this rate is tied to the quantity of electricity used and not the time of use. The rate still represents an average price and does not appear to reflect the cost of delivery at different times of day or during different seasons.

Where peak electricity demand and peak solar supply are well matched, solar PV can help to "shave" the peak prices of electricity and potentially to reduce the costs of infrastructure. The concept is illustrated below in Figure 13. For example, it may be possible to avoid upgrading the capacity of an existing transmission line that is overtaxed during peak hours if that demand can be met on-site.

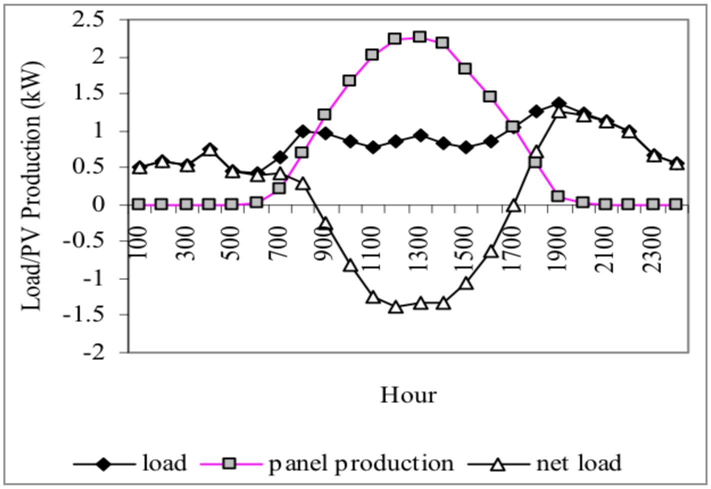



**Figure 13 – This diagram demonstrates the potential of peak-shaving through the use of solar PV systems.[154] The diagram is based on a case study from Ontario, and the data used does not necessarily reflect the situation in BC.**

The potential for utilities to capture such benefits from PV installations depends highly on the state of the infrastructure of the areas in which PV systems are installed, and the timing of peak demand and peak solar output. For example, one US study found that these benefits ranged from $US 0.00 to $0.10/kWh, depending on the area being studied.[155] In California and Japan, peak demand is well matched to peak PV output.[156] In other countries, by contrast, the correlation between peak demand and solar PV potential is highly variable.[157] In British Columbia, peak demand occurs largely during winter evenings.[158] This implies that solar PV may have limited potential for peak shaving or for reducing infrastructure costs.

This criticism is supported by Bornstein, who argues that the ability to reduce transmission and distribution costs through PV has been marginal in California and is unlikely to occur in other jurisdictions.[159] Similarly, in 2001 a BC Hydro report found that necessary upgrades on Vancouver Island could not be avoided through alternative green energy due to the intermittent nature of most renewables; either storage capacity or a guaranteed source of power (*i.e.* grid connection) would be

---

[154] S. Brown and I. Rowlands, 'Nodal pricing in Ontario, Canada: Implications for solar PV electricity,' *Renewable Energy* 34, 2009, pp. 170-178.
[155] J. Contreras *et al., Photovoltaics Value Analysis*, National Renewable Energy Laboratory, February 2008, retrieved September 30th 2009, from <www.nrel.com>.
[156] Suna, Haas, and Lopez Polo, *Op. cit.*
[157] *Ibid*.
[158] BC Hydro Customer Service Representative, *Personal communication with the author*, March 26th, 2010.
[159] Bornstein, *Op. cit.*

required, therefore removing potential avoided costs.[160] Therefore careful analysis is required to determine whether these benefits exist in a given area of BC.

*Time of Use Rate Structures:*

One means of internalizing more of the costs and benefits of electricity delivery is through Time of Use (TOU) rate structures. TOU rates charge customers based on the time the electricity is used, charging higher prices during periods of peak demand. This sends effective price signals that encourage demand reduction and demand shifting to off-peak periods. BC Hydro has experimented with TOU and found the rate structure was effective in changing consumer behavior.[161]

A PV system owner who could sell electricity during on-peak time (or reduce their on-peak costs) could potentially improve the economics of their PV system. One study quantified the potential benefits to PV system owners through a combination of TOU and Net Metering. The study demonstrated that the value of electricity from PV could be increased by between 10% and 40% in many US jurisdictions.[162] It is possible that similar advantages would apply in some regions of BC.

Fortis BC already offers the option of Time of Use pricing. The hours during which on-peak and off-peak rates apply vary based on the day of the week and the season. Rates are shown in Figure 14 below. During summer months, especially, much of the output from a solar PV system matches on-peak hours. However, it is not currently possible for Fortis BC customers to combine Time of Use and Net Metering agreements. In order to quantify the potential benefits of combined TOU and Net Metering further research would be required.

| Summer (July, August) | All other months |
|---|---|
| On-Peak Hours:<br>▪ *9:00 am - 11:00 am* Monday - Friday: 13.564¢/kWh<br>▪ *3:00 pm - 11:00 pm* Monday - Friday: 13.564¢/kWh | On-Peak Hours:<br>▪ *8:00 am - 1:00 pm* Monday - Friday: 13.564¢/kWh<br>▪ *5:00 pm - 10:00 pm* Monday - Friday: 13.564¢/kWh |
| Off-Peak Hours:<br>▪ *11:00 pm - 9:00 am* Monday - Friday: 4.394¢/kWh<br>▪ *11:00 am - 3:00 pm* Monday - Friday: 4.394¢/kWh<br>▪ All hours on Saturday and Sunday: 4.394¢/kWh | Off-Peak Hours:<br>▪ *10:00 pm - 8:00 am* Monday - Friday: 4.394¢/kWh<br>▪ *1:00 pm - 5:00 pm* Monday - Friday: 4.394¢/kWh<br>▪ All hours on Saturday and Sunday: 4.394¢/kWh |

**Figure 14 Time of Use charges for Fortis BC customers**[163]

---

[160] BC Hydro Green & Alternative Energy Division, *Green energy study for British Columbia Phase 2: Mainland*, October 2002, retrieved November 12th, 2009, from <www.bchydro.com>.
[161] BC Hydro, *Conservation Research Initiative*, last modified February 24th 2010, accessed March 1st 2010 from <http://www.bchydro.com/powersmart/residential/conservation_research_initiative.html>.
[162] P. Denholm, *et al., Op. cit.*
[163] Fortis BC, *Rates*, retrieved March 13th 2010 from <http://www.fortisbc.com/about_fortisbc/rates/rates.html>.

**Feed-in Tariffs**

The world's leaders in solar PV deployment have promoted solar through Feed-in Tariffs (FiTs).[164] There are many versions of FiTs, but in general they are characterized by fixed electricity prices at above-market rates. These rates are guaranteed by long-term (20-30 years) contracts, providing stable revenue over the life of the system. By improving the business case for renewable energy, these policies are thought to provide economic and environmental returns by stimulating employment and by decreasing reliance on fossil fuel energy. For example, Ontario offers a FiT under the Green Energy and Economy Act, which is intended to:

- Help Ontario phase out coal-fired electricity generation by 2014; *and*
- Boost economic activity by creating new green industries and jobs.[165]

Many FiT policies offer prices for electricity generated by PV well above the prices offered to any other renewable energy source. One of the most well documented examples is the FiT in Germany, which has been in effect since 2000. The program has increased the share of energy provided by PV and decreased the installed costs for residential PV systems to nearly US $6,600/kW.[166] Other jurisdictions are following similar policies, most recently including Ontario and the United Kingdom. Table 8 below shows sample tariff-rates for electricity from residential PV systems for these jurisdictions. FiT programs are generally funded with a rider on electricity bills. In Germany, for example, this rider has amounted to €1 per month (around $16.00 per year).[167]

**Table 8 – Selected FiT Prices for Residential PV**

| Country | In place since | Current Tariff Rate |
|---|---|---|
| Germany | 2000 | <$0.60 |
| Ontario | 2009 | $0.80/kWh |
| United Kingdom | 2010 | <$0.60/kWh |

If a similar FiT were to be created within the next several years in BC, it is likely that the tariff would need to be priced similarly to these other jurisdictions.[168] As described above, these high prices are not likely to be justified benefits to the utility, such as coincidence of PV output with peak demand. Therefore the decision to implement a high FiT for PV in BC would need to be based on the environmental and economic benefits.

---

[164] National Renewable Energy Laboratory, *NREL Energy analysts dig into Feed-In Tariffs*, June 12th 2009, retrieved March 3rd 2010 from <http://www.nrel.gov/features/20090612_fits.html>.
[165] Ontario Power Authority, *What is the Feed-in tariff program*?, Ontario Power Authority website, retrieved February 20th 2010 from <http://fit.powerauthority.on.ca/Page.asp?PageID=1115&SiteNodeID=1052>.
[166] Wiser, Barbose, and Peterman, *Op. cit.*
[167] M. Landler, 'Germany debates subsidies for solar industry,' May 16th 2008, retrieved March 13th 2010 from <http://www.nytimes.com/2008/05/16/business/worldbusiness/16solar.html?pagewanted=2&_r=3&sq=Solar%20Valley%20Overcast&scp=1>.
[168] The current FiT in Ontario replaces the former RESOP program, which offered electricity prices of $0.42/kWh on 20 year contracts. This program did not bring about widespread PV uptake, implying that a FiT for PV in BC would need to be priced higher than the former RESOP program.

Unfortunately, FiTs for solar PV may not deliver either the environmental or economic benefits promised in other jurisdictions. In regards to environmental benefits, BC's electricity mix is already relatively clean and draws a high proportion of its electricity from renewable sources compared to most other jurisdictions. Meanwhile, recent criticisms of the FiT in Germany have stated that job creation has been grossly overestimated.[169] Indeed, it appears likely that the *net* employment effect of the FiT may actually have been negative.[170] Of the jobs which were created within the PV sector, the FiT program may have indirectly subsidized each job by as much as €175,000 (CAD$230,000).[171]

One of the problems in the German case appears to be international competition for PV manufacturing. Other countries have been able to produce PV systems at lower costs than in Germany, and as a result a large portion of PV systems have been imported. This likely created jobs in other countries, but the benefits were not felt domestically.[172] Ontario's FiT appears to be trying to avoid this problem by tying their FiT for PV to a required "domestic content" requirement, although this requirement is not without its own challenges.[173] It may be too early to accurately measure the net effect of the FiT for PV in other jurisdictions. However, there is a need to approach high FiT policies cautiously.[174][175]

**Financing**

The up-front costs of PV remain a substantial barrier to PV ownership, even in jurisdictions with high FiTs or other incentive programs.[176] For many potential system owners, financing and loans will be important determinants of their willingness to purchase these systems.

Where FiTs and other financial support mechanisms provide guaranteed rates of return to customers, financing becomes much easier to acquire from the private sector. In Ontario, for example, Pure Energies Inc[177] leases rooftops on 20-year contracts. During the course of the contract, the customer is paid between several

---

[169] M. Frondel *et. al.*, *Economic impacts from the promotion of renewable energy technology: The German experience,* Ruhr University Economic Papers, November 2009, retrieved online February 13th 2010 from <http://repec.rwi-essen.de/files/REP_09_156.pdf>.
[170] M. Frondel, N. Ritter, and M. Schmidt, 'Germany's solar cell promotion: Dark clouds on the horizon,' *Energy Policy* 36, 2008, pp. 4198–4204
[171] M. Frondel *et. al.*, *Op. cit.*
[172] *Ibid*.
[173] Worren, J.,'Ontario FIT program off to a cautious start,' *Renewable Energy World*, October 12th 2009, retrieved March 3rd 2010 from <http://www.renewableenergyworld.com/rea/news/article/2009/10/ontario-fit-program-off-to-a-catious-start>.
[174] A. Curtright, M. G. Morgan, and D. Keith, 'Assessments of future pv.' *Environmental Science and Technology*, Vol. 42, No. 24, 2008, P. 9033.
[175] International Energy Agency, *Energy Policies of IEA Countries: Germany, 2007 Review*, International Energy Agency, OECD, Paris, retrieved March 13th 2010 from <http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1922>.
[176] P. Denholm *et. al., Op. cit.*
[177] T. Hamilton, 'Solar panel startup to lease residential rooftops,' *Yourhome.ca*, March 10th 2010, accessed March 13th 2010 from <http://www.yourhome.ca/homes/realestate/article/777492--solar-panel-startup-to-lease-residential-rooftops>.

hundred and $1,200, depending on system size. At the end of the contract the solar system becomes the property of the homeowner. As the interest rates related to private sector financing are generally determined by perceived risk, such innovative financing mechanisms are likely to occur only after the risk of engaging in a loan appears minimal. Risk reduction will likely only occur after the business case for PV systems improves.

There are a variety of models for clean energy loans, including conventional financing and utility-led financing.[178] Loan programs for PV systems could be implemented as stand-alone measures, but realistically widespread PV uptake would still depend on an attractive long-term business case. Any potential system owners who cannot afford the up-front capital to purchase a system are also unlikely to be able to afford a substantial net financial loss over the life of the system.

**Conclusions**

There appears to be no low-cost solution for stimulating widespread PV uptake in BC. Internalizing the full costs and benefits of renewable electricity may go some way to improving the business case for residential PV systems, but will likely not be enough to make PV a viable investment for most BC homeowners. Fortunately, policies such as TOU can also provide an incentive for conservation or increased energy efficiency. Such policies, which serve multiple objectives, are likely to afford higher benefits at lower cost than policies designed only to support PV systems.

FiTs appear to be the most popular and successful means to support widespread PV system uptake. However, the high FiT for solar PV in Germany is receiving mounting criticism. It remains an open question whether other jurisdictions will realize positive long-term economic effects, such as gains in net employment. The decision to support PV financially must also be weighed against alternative technologies for renewable energy, which may provide higher environmental benefits at lower economic cost.

In the short term, it appears more prudent to explore ways in which the benefits of PV for utilities can be internalized for PV customers. Over the longer term, as PV system costs decrease, further consideration could be given to programs like FiTs, loans, or direct subsidies designed to promote the uptake of residential grid-tied systems.

---

[178] Clean Energy Group and Clean Energy States Alliance, *Developing an effective state clean energy program: Clean energy loans*, March 2009, retrieved February 13th 2010 from <www.cleanenergystates.org/publications/CESA_Loan_Programs_March09.pdf>.

# 6. Local Government: Planning and Regulatory Powers for Promoting Solar PV

While immediate widespread uptake of PV may be unlikely in BC, there are other important policy measures that can be undertaken to support medium and longer-term uptake of PV in the residential market.

Policies that encourage and protect solar access may be one of the most important measures for promoting solar PV. Due to Solar PV's high sensitivity to shade, future uptake of solar systems may be enabled or constrained by the degree to which solar access is encouraged by local government. Once solar access is lost, it is not easy to regain: buildings are often in place for decades and will continue to block solar access long after solar systems become a more common source of energy. This can create a major barrier to solar energy development. Planning for solar access can enable all types of solar energy systems, including not only PV but also passive and active systems.[179] Solar access can also provide economic and aesthetic benefits.[180]

Solar access has in some jurisdictions been protected as a "Right to Light". Historically this protection arose from concerns related to human health, and not from a desire to protect access to energy.[182] More recently legislation has been passed in other jurisdictions to protect solar energy installations from shading. In California, for example, the Solar Shade Control Act provides prescriptions for the protection of solar PV systems from shade due to vegetation on neighboring properties. No equivalent protections exist in BC.

**Vegetation and the Shading of Solar Panels: California's 1978 Solar Shade Control Act[181]**
The 1978 Solar Shade Control Act protects owners of solar systems, including photovoltaic systems, by requiring that no more than 10% of a Solar Collector may be shaded by neighboring trees. A recent court decision applied this law, requiring a family to prune several trees that had grown in size to shade the solar panels on a neighbors property. The case cost each family tens of thousands of dollars in court.

While this case has no legal bearing in BC, it serves to highlight the types of land-use conflicts that can occur as solar energy becomes more prevalent.

Solar access in BC can be regulated most easily using either zoning or development permit areas (DPAs). These tools, as well as development permits, demonstration projects, and requirements for green building standards are explored in this section.

---

[179] US Department of Energy, Efficiency and Renewable Energy, *Community solar access*, accessed March 13th 2010 from <http://www.energysavers.gov/renewable_energy/solar/index.cfm/mytopic=50013>.
[180] *Ibid*.
[181] F. Barringer, 'Trees block solar panels, and a feud ends in court,' *New York Times*, published April 7, 2008, retrieved September 18th 2009 from < http://www.nytimes.com/2008/04/07/science/earth/07redwood.html>
[182] Previously the "Doctrine of Ancient Lights" created under British common law protected solar access in Canada, but is no longer in effect. Such guarantees are challenging to regulate and no equivalent law has been enacted in Canada since.

## Zoning to Promote Solar Access and Solar PV Systems

Zoning is perhaps the most oft-cited local government tool. Zoning includes provisions not only to regulate permitted uses of land, but also to dictate the envelope of a building, including positioning of the building through setbacks and building height restrictions. These can substantially influence solar access.

In addition, zoning can determine the ease with which homeowners may install solar PV equipment. For example, BC's Climate Action Toolkit recommends the following considerations:

- Zoning code can include provisions for solar collectors to extend into setback areas;
- Solar rooftop equipment can be excluded form building height measurement;
- Policies can be created to provide variances in trade for green building features.

*Comprehensive Development (CD) zoning* allows even greater control over an area than standard zoning measures. This type of zoning can allow extremely specific features to be added to a development, and may include provisions for building orientation.[183]

## Development Permit Areas (DPAs) and Solar Access

Development Permit Areas are another valuable tool in protecting and promoting solar access. Once a DPA has been specified in the Official Community Plan, development within a specified area becomes conditional on certain criteria, which include rules for:

- Landscaping;
- Siting or form of buildings and other structures;
- Specific features in the development; *and*
- Equipment and systems external to buildings.[184]

The conditions can be provided in a somewhat flexible manner, using language such as "should" and "where possible" instead of "must". This flexibility is important as solar availability is often site-specific, and it is generally desirable to avoid unnecessarily burdening development process.

**Development Permit Areas:** Development Permit Areas can be used to promote solar access by specifying objectives which:

- specify the form and character of a development;
- promote energy conservation; *and*
- which reduce greenhouse gas emissions.

Relevant DPA powers traditionally include objectives for the form and character of development. This gives local governments the ability to regulate the siting or form of buildings and structures in a manner similar to zoning, but which can be tied explicitly to solar access. For example, the District of Maple Ridge encourages solar

[183] Province of British Columbia, *Local Government Act*, Part 26, Section 903: Zoning bylaws, Queen's Printer, Victoria BC, accessed January 3rd 2010 from <www.bclaws.ca>.
[184] Province of British Columbia, *Local Government Act*, Part 26, Section 920: Planning and Land Use Management, Queen's Printer, Victoria BC, accessed January 3rd 2010 from <www.bclaws.ca>.

using a DPA. The relevant section of the District's DPA Guidelines are copied in figure 15 below.

Recent amendments to the BC Local Government Act have expanded powers related to Development Permit Areas. Local Governments may now require measures that encourage energy conservation and/or greenhouse gas emissions reduction.[185] For example, municipalities can provide an objective target for GHG emissions reductions and suggest correlations with specific features (eg. different types of solar) without specifically requiring one technology or another. This is an approach more likely to yield GHG reductions at lower cost than more prescriptive regulatory tools.

Within the new DPA powers, it even appears possible that local government may be able to require solar systems (eg. a solar PV panel) as long as they are external to the building or structure. Anything part of, or internal to, the building remains within the jurisdiction of the BC Building Code. This implies that local governments would not have the ability to require BIPVs, which by definition are part of the building itself.

As of yet neither of the "new" DPA powers have been applied in BC any BC municipality. Therefore applying these tools to solar PV has yet to be tested by municipalities or by the courts.[186]

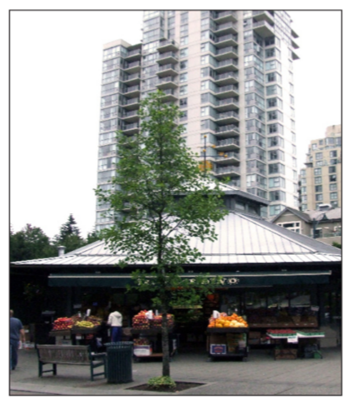
**Development Permit Area Guidelines** **Height**

**A2.6** TCC MU MFR — **Manage phased development.** Ensure each building phase is adequately completed. Visible frontages and accessible areas should be sufficiently finished, with tie-in to future development phases carefully considered. Temporary edges should have a finished appearance and should be durable enough to last for their intended life span and/or maintained as necessary. Incomplete structures, street work or landscaping should be made physically safe and aesthetically compatible with surrounding structures and use.

**A2.7** TCC MU MFR — **Protect views.** Where appropriate, a view analysis should be submitted as part of the development permit application. Care should be taken to avoid disrupting views of Maple Ridge's signature elements, such as Grant Hill, the Golden Ears peaks, and the Fraser River. In addition, residential units should be designed to accommodate views towards street activity and public pathways to contribute to security and eyes on the street. Taller buildings should be stepped back to accommodate views to and from street fronts, pedestrian areas, and public spaces.

**A2.8** TCC MU MFR — **Site buildings to capitalize on daylight and solar opportunities.** Where possible, situate the long axis of the building in the east-west direction to take advantage of solar opportunities such as solar water heating, photovoltaic, and passive solar heating.

**A2.9** TCC MU MFR — **Protect solar access to surrounding buildings and minimize wind tunnel effects.** Buildings should be massed and heights should be considered or stepped back to avoid shading surrounding buildings and public spaces and to minimize possible wind tunnel effects.



*The building is stepped back to reduce the scale of the building and to integrate it with the surrounding neighbourhood village.*

**Figure 15 The District of Maple Ridge is using DPA guidelines to protect solar access.** [187]

---

[185] *Ibid,* Section 919.1.
[186] BC Climate Action Toolkit, *DPA guidelines*, accessed March 1st 2010 from <http://www.toolkit.bc.ca/tool/development-permit-area-guidelines>.

## Educational Tools

Including provisions for solar energy in OCP can be an initial step towards exercising DPA powers while meeting educational goals (raising public awareness). Few tools, however, are as powerful as direct demonstration. Solar PV systems on municipal buildings are visible and can be combined with educational signage or public discourse that raises awareness. This is already being promoted in regards to solar hot water, and solar PV demonstrations could similarly be encouraged.

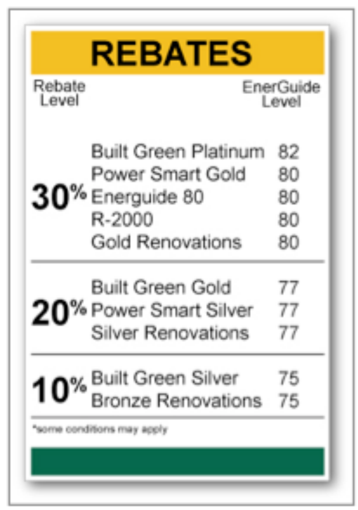
## Other Tools

*Fast-tracking permits:*

Fast-tracking permits for developments which include certain green features is an increasingly common practice and could be applied to Solar PV systems. Currently Local Governments can fast-track re-zoning, development permits, and subdivision applications based on “green” criteria. For example, the City of Port Coquitlam includes a Sustainability Checklist in its development application process. Applications that score highly are fast-tracked.[188]

*Permit rebates:*

Local governments may also provide incentives through rebates for permits. For example the District of Saanich provides rebates on building permits for buildings that achieve certain building energy efficiency ratings. A sample of the requirements for rebates is shown in Figure 16.




*Covenants, Easements, Nuisance Laws, and Other Tools:*

Other legal tools are available but may be somewhat burdensome to use. For example, as a condition of approving a specified number of units or floor area ratio, or a rezoning, a local government may require registration of a Section 219 covenant on title to guarantee green building performance features or requirements for alternative energy. Such tools may be difficult to administer over the long term.[190]

---

[187] District of Maple Ridge, ‘Development permit area guidelines,’ *2006 Official Community Plan*, Chapter 8, p 42. Retrieved January 19th 2010 from <http://www.mapleridge.ca/EN/main/business/4389/ocp.html>

[188] BC Climate Action Toolkit, ‘Fast tracking,’ accessed March 6th from <http://www.toolkit.bc.ca/tool/fast-tracking>

[189] District of Saanich, Green building rebate program, retrieved March 13th, 2010, from <http://www.saanich.ca/business/development/greenbuilding/GreenBuilding.html>

[190] R. Kruhlak, *A Legal Review of Access to Sunlight in Sunny Alberta,* 1981, retrieved March 1st 2010 from <http://www.cansia.ca/government-regulatory-issues/archives>

## Green Building Standards and Solar PV: LEED, Built Green, and R-2000

Green building standards are frequently used as a means to promote more sustainable buildings. Local governments have in some cases adopted green building standards for municipal buildings. These standards may also be applied to the residential sector through a variety of means, such as fast-tracking development permits which meet green building standards criteria. Common points-based systems for residential development in British Columbia include LEED, Built Green, and R-2000.[191]

*Leadership in Energy and Environmental Design (LEED):*

LEED is the most prominent green building rating system in Canada. PV is accounted for in the LEED standard. For example, LEED for New Construction (NC) provides points based on the percentage of a building's total energy use provided by on-site renewable energy systems. Meeting 5%, 10%, or 20% of annual energy needs with renewable energy will earn 1, 2, or 3 points respectively.[192]

*Built Green:*

Built Green is another green building rating system that also accounts for solar PV systems. Under this standard a renewable energy system capable of meeting 30%, 50%, or 80% of the electrical load will provide 4, 6, or 8 points respectively.[193]

*R-2000:*

R-2000 is a voluntary national standard for the environmental performance of homes.[194] Energy efficiency is measured using the Hot2000 software available through NRCan. This tool appears to include provisions for including Solar Hot Water systems,[195] but there is no mention of Solar PV systems. This implies that solar PV systems will not contribute towards meeting R-2000 status.

---

[191] BOMA is another Canadian building standard that assigns points to on-site renewables, including Solar PV. However, because it targets commercial buildings instead of residential buildings it is not discussed here.
[192] Canada Green Building Council, 'LEED green building rating system,' *Rating System and Addenum for New Construction and Major Renovations Version 1.0*, December 2004, p. 42-44.
[193] Built Green, *2010 Checklist*, 2010, p. 3. <http://www.builtgreencanada.ca/>
[194] Natural Resources Canada, *About the R-2000 standard*, retrieved February 25th 2010 from <http://oee.nrcan.gc.ca/residential/personal/new-homes/r-2000/standard/standard.cfm?attr=4>
[195] Natural Resources Canada, *Hot2000 features*, retrieved February 25th 2010 from <http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools/hot2000/features.html>

**Conclusions:**

Existing green building standards do account for solar PV and provide points for its use as an on-site renewable energy generating technology. The adoption of these standards as a means to determine incentives (such as building permit fee reductions or fast-tracking) will not provide a barrier to solar PV. Over the short term, however, it is likely that developers and homeowners will seek out lower cost options for meeting these green building standards.

Local Governments in BC have planning powers that can be used to encourage solar access through the regulation of urban form and vegetation. New Development Permit Area powers appear fairly well suited to promoting solar PV. Unfortunately these tools do not eliminate the possibility of land-use conflict. Legal measures to protect solar systems may be warranted and could require further exploration. Such legislation may be best dealt with at the Provincial level and would provide more security to PV system owners. Presumably the same law that protects solar access for PV systems would also protect passive and active solar systems. Further research into this issue could draw on experience from other jurisdictions, such as California, which have a longer experience with solar energy planning and regulation.

## 7. Conclusions and Recommendations

The field of solar PV is changing rapidly. Conventional silicon-crystalline modules are being complemented by thin-film technologies, which deliver even greater environmental benefits. PV modules can now be integrated directly into the envelope of a building and offer great potential to meet electricity demand at the point of consumption.

BC has substantial solar PV potential, although regionally this potential differs by up to 40%. A high-level estimate implies that residential PV capacity in the Province is between 283,000 mWh and 850,000 mWh annually. PV systems can therefore help to meet growing electricity demand within the Province.

By reducing the need to import electricity, PV systems can reduce greenhouse gas emissions. A 3kw roof-mounted system could meet up to one-third of average electricity consumption in a BC household. Such a system would potentially reduce emissions by 81 to 141 kilograms of greenhouse gases annually. Even when comparing residential grid-connected PV systems to expanding hydroelectric capacity, emissions associated with PV compare favorably. In addition, these PV systems do not require the conversion of land or extensive electrical infrastructure grids, thereby preserving the environment. This provides additional environmental benefits that are less easy to quantify than GHG emissions, but which add value to electricity generated by PV.

The key barrier to PV deployment in BC is the cost of these systems. Current prices for a residential grid-connected system in BC are between $8,000 and $10,000 per kilowatt of installed capacity. When maintenance costs (inverter replacement) is factored in, these life-cycle costs will increase by at least 10%. Despite much progress within the industry, price reductions from technological innovations are occurring only gradually. The gap between the cost of electricity delivered by a residential PV system and the market price of electricity remains large; current electricity prices are near $0.08/kWh while electricity from residential PV systems may cost closer to $0.30/kWh. Simply put, in the absence of policy interventions to financially support PV system development, residential grid-connected PV systems are unlikely to become economical within the next decade. It therefore appears likely that a substantial incentive would be required to encourage PV uptake. In order to achieve break-even pricing for system owners, it is likely that the following would be required:

- Revenue from PV must increase by approximately 4 times, such as through increasing the price of electricity from $0.08 to $0.32 per kWh;
- Installed system costs must decrease by 70%;
- A subsidy of approximately $7,600/kW, instead of the current $280/kw offered through Livesmart BC; *or*
- Some combination of above.

One of the most popular means of encouraging widespread PV uptake in other jurisdictions is through Feed-in Tariffs. FiTs show promise in greatly increasing PV system uptake by providing high financial incentives to system owners. The rationale behind a high FiT, such as the program in Germany, is that it will achieve substantial GHG reductions and provide economic benefits by creating new jobs and drawing investment. However, the jurisdictions pursuing FiTs at present will derive higher environmental benefits compared to BC, as they do not possess similar hydroelectric capacity. FiTs would be an expensive way to create a relatively small reduction in greenhouse gases. In addition, recent criticisms of the long-term effects of Germany's FiT for solar PV show that the net economic effects (such as net employment) may actually be negative. Although Ontario's program seeks to address some of the shortcomings of other FiT programs through domestic content requirements, it will take time before the results of the program are clear. Until then, the net benefits of high FiTs designed to promote widespread uptake of PV systems remain in question. Substantial additional research would be required to justify a high FiT of the type being applied in Germany, Ontario, or the United Kingdom.

Over the shorter term (approximately 5 years), lower-cost measures to remove barriers to PV may be more feasible. Foremost among these measures could be to renew the PST tax exemption under the HST. This would continue to send a signal of support for PV systems while expending few resources. In addition, tax exemptions can easily be applied to off-grid PV installations, which appear to remain the most economical application of PV systems.

Changes to utility rate structures are likely to benefit both overall electricity conservation efforts and the business case for solar PV. For example, Time of Use charges will deliver both of these benefits while also providing a level playing field for other types of renewable energy generation. The implementation of such rate changes are likely relatively low in cost and may also be more politically feasible than simply increasing the price of electricity. In addition, further research should be undertaken into the potential economic value of expanded on-grid PV capacity in BC. As in other jurisdictions, PV may provide value to utilities by reducing the need for peak generation or transmission infrastructure. Unfortunately these benefits are likely much smaller than in other jurisdictions, as peak demand in BC occurs during winter evenings when no sunlight is available.

Non-financial policies to support PV are also likely to be extremely important over the long term. Recently the Province has taken some important steps which directly or indirectly support solar PV systems, including the promotion of Net Metering, the development of a Solar Hot Water Ready standard, and enabling legislation for local governments through new Development Permit Area powers. Buildings constructed today will last for decades, and what is done now to improve solar access and reduce the cost of PV retrofits may substantially benefit uptake in the future.

Additional policies to encourage and protect solar access, such as laws that protect solar access for PV systems, may also be warranted. A review of laws implemented in other jurisdictions could aid in the development of such regulations.

Over the longer term (approximately 10 years) the gap between the cost of electricity produced by residential PV systems and conventional electricity sources is likely to narrow. Some estimates suggest system price decreases of 50% over the next 10-20 years. If these lower system costs materialize, a variety of financial measures such as Feed-in Tariffs, low-interest loans, and subsidies are more likely to be justified. The rationale for these investments is still likely to depend on wider benefits, such as the creation of new “green” jobs. These wider benefits are important areas for further research, and the results of these policies in Ontario and in other jurisdictions will provide valuable lessons.

Grid-connected solar PV systems can play a role in meeting several of the overarching Provincial goals laid out in the BC Energy Plan, including energy independence and the reduction of greenhouse gases. Clearly, however, the benefits of PV must be weighed against other policy options, which may deliver similar environmental benefits at lower cost. Until the business case for residential PV systems improves, it is mainly non-financial interventions that are likely to be justifiable. Fortunately many of these non-financial interventions are those which also benefit other renewable energy technologies, such as solar hot water, or which encourage energy conservation. This adds value to these measures, making them a more effective use of resources than stand-alone policies to promote residential PV systems.

# Appendix A: The Grid Interconnection Process and Solar PV in British Columbia

One of the major barriers to solar PV uptake is traditionally grid interconnection. BC Hydro and Fortis BC now allow Net Metering in British Columbia. This appendix examines the process of installing a PV system and the steps required for the grid interconnection process.

### Electrical Permits & Fees

As part of any major electrical work homeowners (or their contractors) must arrange for an inspection from the designated Electrical Inspection Authority in their area. The fee for an inspection varies based on location: the BC Safety Authority carries out electrical inspections in most areas of BC but many larger municipalities have their own electrical permit and fee systems.

*The BC Safety Authority (BCSA) Electrical Permit*

BC Safety Authority carries out electrical inspections in most areas in BC. Fees are assessed based on a cost-recovery basis. Two variables affect the cost of an inspection fee for the BCSA: the value of the installation, and whether the installation was completed by a contractor or by a homeowner.

Where installs were completed by a contractor, inspection fees range from $400 for an electrical installation valued at $10,000 to $809 for an installation valued at $30,000.[196] These values correspond to a 1kW or a 3kW system respectively.

*Local Government Electrical Permit Fees*

In several cases, municipalities carry out and assess fees for electrical permits independently of the BC Safety Authority. For example, the City of Vancouver charges $544 for an installation worth $10,000 and $1,063 for an installation worth$30,000.[197] Fees in North Vancouver are virtually identical and fees in Burnaby are 5% lower.

> Solar system owners can expect to pay $540-$1,000 for a solar system sized between 1kW and 3kWs. This represents approximately 3%-5% of total installed system costs.

[196] BC Safety Authority, *Electrical program quick reference fee table: Electrical contractor installations,* January 1st 2010, retrieved February 23rd 2010 from <http://www.safetyauthority.ca/?q=feesforms_feeschedules>.
[197] City of Vancouver Development Services Department, *Electrical permit fee schedule*, 2010, retrieved February 23rd 2010 from <http://vancouver.ca/commsvcs/developmentservices/tradespermits/index.htm>.

Prospective PV system owners can expect to pay approximately $540 for a system valued at $10,000 (around 1kW) and close to $1,000 for a system valued at $30,000 (around 3kW). Relative to the total cost of PV systems, these fees amount to approximately 3%-5% of installed costs. In some jurisdictions outside of BC inspection fees have been reduced or waived entirely, and similar policies could be considered in BC.

**Steps for Homeowners to Install and Operate a Grid-Connected PV System**

There are a variety of steps for the homeowner to complete in order to get 'grid-connected' under net metering programs. For BC Hydro customers, the entire process is projected to take two months or longer from the date of a suitability assessment from the contractor to the point at which electricity can be put back into the grid. The steps and relevant time frames for this connection process are described below.

*1. Site Assessment* *Time: several hours*

A homeowner who wishes to install a Solar PV system would first need a solar assessment. As with solar hot water, these site-assessments are generally offered free by installers and likely take only about an hour.

*2. Net Metering Documentation pt. 1* *Time: several hours*

Assuming that solar access is favorable and the homeowner wished to continue with the process, the second step is as follows:

- Download and complete the Net Metering Interconnection Application form from the Utility, including:
    - An "electric single-line-diagram" of the system to be installed and a site-plan showing the location of the house and means to disconnect the system;

- Submit documents to BC Hydro.

*3. Technical Assessment and Interconnection Agreement* *Time: 2-3 weeks*

- Customer must wait at least two weeks for BC Hydro to complete a Technical Assessment;
- Customer will receive an Interconnection Agreement, which must be signed and returned for the process to continue.

*4. Installation* *Time: 1 day to 2 weeks*

- The customer and contractor may now install the system. The actual installation can be completed within one or two days.

*5. Inspection and Electrical Permit* *Time: 0-2 weeks*

- The designated Electrical Inspector must inspect and approve the system. The fee for this is generally around $400-$550 for a smaller system (1kW) to over $1,000 for a 3kW system;
- The customer must provide BC Hydro with a signed copy of the inspector's final inspection approval document.

*6. Final Documentation* *Time: 2 weeks*

- BC Hydro processes and then sends Distribution Operating Order;
- The Revenue Meter is installed;
- The Customer receives authorization for final interconnection.

Overall the process should take approximately eight weeks. The forms are relatively simple. Customers face an additional step for larger PV projects which incurs some additional cost and additional time.

*Projects over 5kW*

There is no fee for grid connection for PV systems under 5kW.[198] However, if a project is over 5kW there is an additional inspection step and a BC Hydro Site Verification and Assessment Fee of $600. This can also add time to the process. In other jurisdictions, such as Ontario, such additional verifications are only carried out for systems over 10kW.

**System Maintenance and Warranties**

The output efficiency of solar panels decreases over time. Warranties are generally tied to a minimum output efficiency. For example, panels may be warranted to perform at 90% of original efficiency for the first 10 years and 80% for the first 20 years. In general solar panels in Canada are warrantied for a period of 25 years,[199] and the world-wide failure rate appears to be low at near .01% per year.[200] This leads to an expected useful life of at least 30 years for solar panels.[201] 30+ year warranties are likely to become more common in the near future.

---

[198] BC Hydro, *Net Metering FAQ*, retrieved January 30th 2010 from <http://www.bchydro.com/etc/medialib/internet/documents/info/pdf/info_net_metering_faq.Par.0001.File.info_net_metering_faq.pdf>

[199] Eng, S. and Gill, S., *Solar PV Community Action Manual*, Ontario Sustainable Energy Association and Canadian Solar Industries Association, Canada, 2008, page 40.

[200] US Department of Energy: Building America, 'High-performance home technologies: Solar thermal and photovoltaic systems,' *Building America Best Practices Series Volume 6*, June 4th 2007, p. 6, retrieved August 2008 from <http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/41085.pdf>

[201] R. Harrabin, Solar panel costs set to fall, BBC, updated Monday November 30th 2009, retrieved January 5th 2010 from <http://news.bbc.co.uk/2/hi/science/nature/8386460.stm>.

Inverters are the 'weak link' in the system as they are likely the first component to fail: inverter life in Europe is generally 10-15 years.[202] Warranties for inverters sold in Canada are often 5-10 years[203] although longer warranties are available from some companies.

Other small parts (eg wiring) as well as frames and mounts are highly reliable. However, warranties for the installation itself should also be considered. The Ontario Sustainable Energy Association cautions:

> Possibly the most important warranty to consider is that which the installer will offer on the installation itself. This should be a minimum of one year, and it is recommended to request a longer warrantee. It should also explicitly include coverage for any roof leaks resulting from the mounting of panels. Prior to the warrantee expiring, it is recommended that the system owner inspect the entire system, including wiring, connections and performance, and report any issues to the installer to ensure repairs or corrections will be covered.[204]

[202] US Department of Energy: Building America, *Op. cit.*, p. 6.
[203] Eng, S. and Gill, S., *Solar PV Community Action Manual*, Ontario Sustainable Energy Association and Canadian Solar Industries Association, Canada, 2008, p. 40, retrieved September 30th 2009 from <www.ontario-sea.org/Storage.asp?StorageID=445>.
[204] *Ibid*.

# Appendix B: Market Survey of PV Systems in BC

This market survey was initially conducted through a Google search of available online retailers based in British Columbia. This was followed by a search for installers who listed system prices on their websites. Finally, results were assessed verbally by several of the key informants in order to ensure that they reflect true market prices.

There is some variation in PV prices between online retailers and installers. In many cases this variation reflects the warranties associated with the particular products being sold.

| Market Survey - PV Module Prices in British Columbia | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | **Brand/Model** | **Size** | **Price** | **Price/kW** | **Notes** | **Source** | **Website** |
| Multicrystalline Panel | Sharp | 230 W | $920 | $4,000 | | Renewable Future Energy Resources Inc. | http://shop.solarpowernrg.com/Solar-Panels_c2.htm |
| Multicrystalline Panel | Day 4 Energy 48MC | 185 W | $657.50 | $3,500 | 25 year warranty | Renewable Future Energy Resources Inc. | http://shop.solarpowernrg.com/Solar-Panels_c2.htm |
| Multicrystalline Panel | Day 4 Energy 48MC | 185W | $1,350 | $7,300 | | Energy Alternatives Website | http://www.energyalternatives.ca/amazing/items.asp?CartId={8CEVEREST3C4D49-CFB1-4848-8553-B83C94445444}&Cc=110&iTpStatus=0&Tp=&Bc= |
| Multicrystalline Panel | Sharp ND-130UJF130W solar PV module | 130W | $649 | $5,000 | | Energy Alternatives Website | http://www.energyalternatives.ca/amazing/items.asp?CartId={8CEVEREST3C4D49-CFB1-4848-8553-B83C94445444}&Cc=110&iTpStatus=0&Tp=&Bc= |
| Multicrystalline Panel | Sharp NU-235F1 | 235W | $899 | $3,800 | 25 year warranty | We Go Solar Website | http://wegosolar.com/index.php?main_page=index&cPath=35 |
| Multicrystalline Panel | Sharp NE-80EJE | 80W | $399 | $5,000 | | We Go Solar Website | http://wegosolar.com/index.php?main_page=index&cPath=35 |

| Type | Brand/Model | Size | Price | Price/kW | Notes | Source | Website |
|---|---|---|---|---|---|---|---|
| Multicrystalline Panel | Kyocera KD205GX-LPU | 205W | $1,035 | $5,000 | 20 year warranty | AEE Solar Website | http://aeesolar.com/catalog/products/H_ASW_SM_PVM_KYO.htm |
| Multicrystalline Panel | Kyocera KD235GX-LB | 235W | $1,186 | $5,000 | 20 year warranty | AEE Solar Website | http://aeesolar.com/catalog/products/H_ASW_SM_PVM_KYO.htm |
| Multicrystalline Panel | Mitsubishi PV UE125MF5N | 125W | $925 | $7,400 | 10 year warranty for 90% power, 25 year warranty for 80% | AEE Solar Website | http://aeesolar.com/catalog/products/H_ASW_SM_PVM_MIT.htm |
| Multicrystalline Panel | Mitsubishi PV UD190MF5 | 190W | $1,276 | $6,715 | 10 year warranty for 90% power, 25 year warranty for 80% | AEE Solar Website | http://aeesolar.com/catalog/products/H_ASW_SM_PVM_MIT.htm |
| Multicrystalline Panel | SW220-mono | 220W | $1,120 | $5,000 | 10 year warranty for 90% power, 25 year warranty for 80% | AEE Solar Website | http://aeesolar.com/catalog/products/H_ASW_SM_PVM_SWD.htm |
| Multicrystalline Panel w/ inverter | Future Energy 200W AC Solar Panel | 200W | $930 | $4,650 | Built-in Inverter; 12 and 25 year power warranty | | http://shop.solarpowernrg.com/Future-Energy-200-watt-AC-Solar-Panel-AC-Solar-Panel.htm |
| Roof-integrated PV panels (BIPV) | Interlock Solar Roof | 1.8kW | $20,000 (with roof) | $11,000 | | Interlock Roofing Website | http://www.bcsbestroof.com/ |

*Please note that these online retailer prices do not include tax or the cost of delivery, which could significantly affect the prices. In addition, some of these prices are not available for individual consumers.*

| Market Survey – Balance of System Prices | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | **Brand/Model** | **Size** | **Price** | **Price/kW** | **Notes** | **Source** | **Website** |
| Inverter | Enphase MicroInverter M210 | 210 W | $255 | $1,210 | | Renewable Future Energy Resources Inc. | http://shop.solarpowernrg.com/Enphase-MicroInverter-M210-FEIEnphaseM210.htm |
| Inverter | Xantrex GT Grid Intertie Inverter | 2.8kW | $2,285 | $816 | 10 year warranty | Energy Alternatives Website | http://www.energyalternatives.ca/amazing/items.asp?CartId={8CEVEREST3C4D49-CFB1-4848-8553-B83C94445444}&Cc=152&iTpStatus=0&Tp=&Bc= |
| Inverter | Xantrex GT Grid Intertie Inverter | 4kW | $2,995 | $748 | 10 year warranty | Energy Alternatives Website | http://www.energyalternatives.ca/amazing/items.asp?CartId={8CEVEREST3C4D49-CFB1-4848-8553-B83C94445444}&Cc=152&iTpStatus=0&Tp=&Bc= |
| Inverter | Xantrex GT 2.8 | 2.8kW | $2,375 | $848 | | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_XTX_R.htm |
| Inverter | Xantrex GT 4.0 | 4kW | $3,130 | $782 | | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_XTX_R.htm |
| Inverter | Magnum MS2012 | 2kW | $1,599 | $799 | | We Go Solar | http://wegosolar.com/index.php?main_page=product_info&cPath=93&products_id=423 |
| Inverter | Magnum MS4024 | 4kW | $2,089 | $522 | 3 year warranty | We Go Solar | http://wegosolar.com/index.php?main_page=product_info&cPath=93&products_id=72 |
| Inverter | GTFX3048 Grid-Intertie Inverter | 3kW | $2,275 | $758 | 2 year warranty | Energy Alternatives Website | http://www.energyalternatives.ca/amazing/itemdesc.asp?CartId={8CEVEREST3C4D49-CFB1-4848-8553-B83C94445444}&ic=GTFX3048&eq=&Tp= |

| Type | Brand/Model | Size | Price | Price/kW | Notes | Source | Website |
|---|---|---|---|---|---|---|---|
| Inverter | KACO Blueplanet 1502xi | 1.5kW | $2,150 | $1,433 | | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_KAC_R.htm |
| Inverter | KACO Blueplanet 3502xi | 3.5kW | $2,850 | $814 | 10 year warranty | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_KAC_R.htm |
| Inverter | KACO Blueplanet 5002xi | 5kW | $3,550 | $710 | | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_KAC_R.htm |
| Inverter | Solectria PVI 1800 | 1.8kW | $2,510 | $1,394 | 5, 10, or 15 year warranty options | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_SOL_R.htm |
| Inverter | Solectria 4000W | 3.9kW | $3,498 | $896 | 10 year warranty | AEE Solar website | http://aeesolar.com/catalog/products/H_ASW_IN_GT_SOL_R.htm |

*Please note that these online retailer prices do not include tax or the cost of delivery, which could significantly affect the prices. In addition, some of these prices are not available for individual consumers.*

| Market Survey – Complete PV System Prices | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | **Brand/Model** | **Size** | **Price** | **Price/kW** | **Notes** | **Source** | **Website** |
| Complete system, Equipment Only | Renewable Future Energy Resources Inc. | 2.1kW System | $16,175 | $7,700 | Includes mounting structure; excludes tax and shipping costs | Wholesaler website | http://shop.solarpowernrg.com/Future-Energy-Solar-PV-Grid-Tie-Kit-2100-Watts-FEKitPVGridTie2100W.htm |
| Complete system, does not include flashing or conductors | Renewable Future Energy Resources Inc. | 4.4kW | $16,156 | $3,670 | Does not include flashing or conductors; excludes tax and shipping costs | Wholesaler Website | http://shop.solarpowernrg.com/Future-Energy-Solar-PV-Grid-Tie-Kit-2100-Watts-FEKitPVGridTie2100W.htm |
| Installed costs for residential PV system | Resolution Electric | 3kW | $25,000 | $8,300 | | Estimate from installer | www.resolutionelectric.ca |
| Complete system, INCLUDING installation *and* electrical permits | Suddwick Homes | 4.1kW System | $42,000 | $10,240 | Complete install, packaged system | Installer website | http://www.suddwickhomes.ca/solarpackage-pv.html |
| Complete 'flush-mounted' system | Terratek Energy Solutions | Per kW | $8,000-$10,000 | $8,000-$10,000 | | Estimate from installer | www.terratek.ca |

*Please note that these systems may vary in the quality and type of selected components. Installer estimates are approximate and may reflect geographic variations, which can affect the cost of delivery. Please contact the companies directly if you would like a quote or estimate.*

# Bibliography


Association of Canadian Community Colleges, *Government of Canada supports training for solar energy workers*, December 8th 2008, retrieved January 10th 2010 from <http://www.accc.ca/english/publications/media/0812_solar_energy_workers.htm>.

Ayoub, J., and Dignard-Bailey, L., *Photovoltaic technology status and prospects: Canadian annual report 2007*, CanmetENERGY, Natural Resources Canada, retrieved November 20th 2009 from <http://www.canmetenergy.nrcan.gc.ca>.

Ayoub, J., and Dignard-Bailey, L., *Photovoltaic technology status and prospects: Canadian annual report 2008*, CanmetENERGY, Natural Resources Canada, retrieved November 20th 2009 from <http://www.canmetenergy.nrcan.gc.ca>.

Ayoub, J., Dignard-Bailey, L., and Fillion, A., *Photovoltaics for buildings: Opportunities for Canada*, CanmetENERGY, Natural Resources Canada, 2000, retrieved August 1st 2009 from <http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/buildings_communities/buildings/pv_buildings/publications.html?2001-123>

Barringer, F., 'Trees block solar panels, and a feud ends in court,' *New York Times*, published April 7 2008, accessed November 20th 2009 from <http://www.nytimes.com/2008/04/07/science/earth/07redwood.html>

BC Climate Action Toolkit, *DPA guidelines*, Climate Action Toolkit website, accessed March 1st 2010 from <http://www.toolkit.bc.ca/tool/development-permit-area-guidelines>

BC Housing, *Technical bulletin no. 14-08*, issued January 18th 2008, retrieved August 20th 2009 from <http://www.bchousing.org/resources/Programs/ILBC/technical bulletins/TB_14_Energy_Performance.pdf>.

'BC Hydro seeks 33% rate hike over next four years,' *CBC News*, Wednesday March 3rd 2010, retrieved Thursday March 4th 2010 from <http://www.cbc.ca/canada/british-columbia/story/2010/03/03/bc-hydro-rate-increases.html?ref=rss>.

BC Hydro, *BC Hydro annual report 2009*, retrieved March 2nd 2010 from <www.bchydro.com>.

BC Hydro, *Net Metering FAQ*, BC Hydro website, accessed January 30th 2010 from <http://www.bchydro.com/etc/medialib/internet/documents/info/pdf/info_net_metering_faq.Par.0001.File.info_net_metering_faq.pdf>.

BC Hydro, *Net Metering*, BC Hydro website, last modified Feb 8, 2010, accessed February 24th 2010, from <http://www.bchydro.com/planning_regulatory/acquiring_power/net_metering.html>.

BC Hydro, *Peace River Site C Hydro Project Stage 2 - Environmental studies study outline: Preliminary greenhouse gas emissions study, n.d.,* retrieved February 20th 2010 from <www.bchydro.com>.

BC Hydro, *Conservation Research Initiative*, last modified February 24th 2010, accessed March 1st 2010 from <http://www.bchydro.com/powersmart/residential/conservation_research_initiative.html>

BC Hydro, *Electric load forecast 2005/06 to 2025/26, December 2005 Forecast,* Market Forecasting Power Planning and Portfolio Management Distribution Line of Business BC Hydro, retrieved November 13th 2009 from <http://www.bchydro.com/etc/medialib/internet/documents/policies/pdf/policies_2005_electric_load_forecast.Par.0001.File.policies_2005_electric_load_forecast.pdf>.

BC Hydro Customer Service Representative, *Personal communication with the author*, March 26th 2010.

BC Hydro Green & Alternative Energy Division, *Executive report on the green energy study for British Columbia Phase 1: Vancouver Island*, July 2001, retrieved December 20th 2009 from <www.bchydro.com>.

BC Hydro Green & Alternative Energy Division, *Green energy study for British Columbia Phase 2: Mainland*, October 2002, retrieved November 12th 2009 from <www.bchydro.com>.

BC Ministry of Community and Rural Development, *Greenhouse Gas (GHG) emission reduction targets, policies and actions,* Ministry of Community and Rural Development website, accessed January 13th 2010 from <http://www.cd.gov.bc.ca/lgd/greencommunities/targets.htm>.

BC Ministry of Energy, Mines, and Petroleum Resources, *Energy in action*, retrieved September 30th 2009 from <http://www.energyplan.gov.bc.ca/bcep/default.aspx?hash=12>.

BC Ministry of Energy, Mines, and Petroleum Resources, *Energy Plan: A Vision for Clean Energy Leadership*, 2007, retrieved February 20th 2010 from <http://www.energyplan.gov.bc.ca/efficiency/>.

BC Ministry of Energy, Mines, and Petroleum Resources, *For the record: Facts on independent power production*, March 25th 2009, accessed March 1st 2010 from <http://www.gov.bc.ca/fortherecord/independent/in_environment.html?src=/environment/in_environment.html>.

BC Ministry of Energy, Mines, and Petroleum Resources, *Livesmart BC efficiency incentive program: Home improvement incentive brochure*, retrieved February 14th 2010 from <http://www.energyplan.gov.bc.ca/efficiency/>.

BC Ministry of Energy, Mines, and Petroleum Resources, *What is solar energy?*, retrieved November 20th 2009 from <http://www.empr.gov.bc.ca/RET/RenewableEnergyTechnologies/Solar/Pages/default.aspx>.

BC Ministry of the Environment, *Greenhouse gas reduction target act*, January 2008, retrieved September 18th 2009 from <http://www.env.gov.bc.ca/epd/codes/ggrta/>.

BC Ministry of Housing and Social Development, *Greening the BC Building Code: First steps*, BC Housing website, accessed August 29th 2009 from <http://www.housing.gov.bc.ca/building/green/>.

BC Safety Authority, *Electrical program quick reference fee table: Electrical contractor installations,* January 1st 2010, retrieved February 23rd 2010 from <http://www.safetyauthority.ca/?q=feesforms_feeschedules>.

BC Safety Authority, *Electrical program quick reference fee table: Electrical homeowners installations,* January 1st 2010, retrieved February 23rd 2010 from <http://www.safetyauthority.ca/?q=feesforms_feeschedules>.

Becker, G., *et al., An approach to the impact of snow on the yield of grid-connected PV systems*, n.d., retrieved January 30th 2010 from <www.sev-bayern.de/content/snow.pdf>.

Bornstein, S., 'The market value and cost of solar photovoltaic electricity production,' *Center for the Study of Energy Markets Working Paper*, Berkley, January 2008, retrieved January 30th 2010 from <www.ucei.berkeley.edu/PDF/csemwp176.pdf>.

Boubekri, M., 'Solar access legislation, a historical perspective of New York City and Tokyo,' *American Planning Association: Planning and Environmental Law*, May 2005, Vol. 57, No. 51.

Brown, S., and Rowlands, I., 'Nodal pricing in Ontario, Canada: Implications for solar PV electricity,' *Renewable Energy* 34, 2009, pp. 170-178.

Built Green, *2010 Checklist*, accessed February 27th 2009 from <http://www.builtgreencanada.ca/>.

Canada Green Building Council, 'LEED green building rating system,' *Rating System and Addenum for New Construction and Major Renovations Version 1.0*, December 2004, p. 42-44, retrieved January 18th 2010 from <http://www.cagbc.org/leed/systems/neighbourhood_developments/index.php>.

Canada Mortgage and Housing Corporation, *Occupied Housing Type by Structure Type and Tenure, 1991-2006: British Columbia*, retrieved March 1st 2010 from <http://www.cmhc.ca/en/corp/about/cahoob/data/data_007.cfm>.

'Canadian Solar joins ranks of PV Cycle,' *Renewable Energy Focus*, July 27th 2009, retrieved February 3rd 2010 from <http://www.renewableenergyfocus.com/view/2720/canadian-solar-joins-ranks-of-pv-cycle/>.

Cha, A., 'Solar energy firms leave waste behind,' *Washington Post*, Sunday March 9th 2008, accessed September 30th 2008 from <http://www.washingtonpost.com/wpdyn/content/article/2008/03/08/AR2008030802595.html>.

Community Energy Association *Powering our communities: Renewable energy guide for local governments in British Columbia*, 2008, retrieved November 12th 2009 from <http://www.communityenergy.bc.ca/>.

City of Vancouver Development Services Department, *Electrical permit fee schedule*, 2010, retrieved February 23rd 2010 from <http://vancouver.ca/commsvcs/developmentservices/tradespermits/index.htm>.

City of Vancouver, *Pre-piping for roof-mounted Solar Energy generation*, City of Vancouver website, accessed February 13th 2010 from <http://vancouver.ca/commsvcs/cbofficial/greenbuildings/greenhomes/solarenergy.htm>.

Clean Energy Group and Clean Energy States Alliance, *Developing an effective state clean energy program: Clean energy loans*, March 2009, retrieved February 13th 2010 from <www.cleanenergystates.org/publications/CESA_Loan_Programs_March09.pdf>.

Contreras, J., *et. al*. *Photovoltaics Value Analysis*, National Renewable Energy Laboratory, February 2008, retrieved September 30th 2009, from <www.nrel.com>.

Curtright, A., Morgan, M. G., and Keith, D. 'Assessments future pv,' *Environmental Science and Technology*, 2008, Vol. 42, No. 24, pp. 9031-9038.

Denholm, P., *et. al.*, *Break-even cost for residential photovoltaics in the United States: Key drivers and sensitivities*, National Research Energy Laboratory, December 2009, retrieved February 12th 2010 from <www.nrel.gov/docs/fy10osti/46909.pdf>.

Duancey, G., 'HST should have been an ecologically harmonized sales tax,' *BC Sustainable Energy Association,* August 24th 2009, retrieved February 1st 2010 from <http://www.bcsea.org/blog/guy-dauncey/2009/08/24/hst-should-have-been-ecologically-harmonized-sales-tax>.

Encorp Pacific, *Electronics recycling fees*, retrieved September 13th 2009 from <http://www.encorp.ca>.
Eng, S. and Gill, S*., Solar PV Community Action Manual*, Ontario Sustainable Energy Association and Canadian Solar Industries Association, Canada, 2008, retrieved September 30th 2009 from <www.ontario-sea.org/Storage.asp?StorageID=445>.

European Commission, *Global irradiation and solar electricity potential: Germany*, retrieved January 3rd 2010 from <http://re.jrc.ec.europa.eu/pvgis/cmaps/eu_opt/pvgis_solar_optimum_DE.png>.

First Solar, *Refunded collection and recycling program*, accessed January 13th 2010 from <http://www.firstsolar.com/en/recycle_program.php>.

Fortis BC, *Rates*, accessed March 13th 2010 from <http://www.fortisbc.com/about_fortisbc/rates/rates.html>.

Frondel, M., *et. al*., *Economic impacts from the promotion of renewable energy technology: The German experience,* Ruhr University Economic Papers, November 2009, retrieved online February 13th 2010 from <http://repec.rwi-essen.de/files/REP_09_156.pdf>.

Frondel, M., Ritter, N., and Schmidt, M., 'Germany's solar cell promotion: Dark clouds on the horizon,' *Energy Policy* 36, 2008, pp. 4198–4204.

Fthenakis, V., *Could CdTe PV modules pollute the environment?,* National Photovoltaic Environmental Health and Safety Assistance Center, Brookhaven National Laboratory, 2002, retrieved January 3rd 2010 from <www.abound.com>.

Fthenakis, V., 'End-of-life management and recycling of PV modules,' *Energy Policy* 28, 2000, pp. 1051-1058.

Fthenakis, V., 'Life cycle impact analysis of cadmium in CdTe PV production,' *Renewable and Sustainable Energy Reviews* 8, 2004, pp. 303–334.

Fthenakis, V., 'Sustainability of photovoltaics; The case for thin-film solar cells' *Renewable and Sustainable Energy Reviews 13* (2009) p. 2746-2750. Elsevier.

Fthenakis, V., and Alsema, E., 'Photovoltaics energy payback times, greenhouse gas emissions, and external costs: 2004–early 2005 Status,' *Progress in Photovoltaics: Research and Applications 14*, 2006, pp. 275-280.

Fthenakis, V., *et al.,* 'Toxicity of Cadmium Telluride, Copper Indium Diselenide, and Copper Gallium Diselenide,' *Progress in Photovoltaics*, 1999, V. 7, pp. 489-497. Elsevier, www.sciencedirect.com

Fthenakis, V., Kim, H. and Alsema, E., 'Emissions from photovoltaic life cycles,' *Environmental Science & Technology* 42, 2008, pp. 2168–2174.

Hamilton, T., 'Solar panel startup to lease residential rooftops,' *Yourhome.ca*, March 10th 2010, accessed March 13th 2010 from <http://www.yourhome.ca/homes/realestate/article/777492--solar-panel-startup-to-lease-residential-rooftops>.

Hanova, J., Dowlatabadi, H., and Mueller, L., 'Ground source heat pump systems in Canada: Economics and GHG reduction potential,' 2007 in *Discussion Papers, Resources For the Future*, Washington, DC, retrieved January 13th 2010 from <www.rff.org/documents/RFF-DP-07-18.pdf>.

Harrabin, R., 'Solar panel costs set to fall,' BBC, updated Monday November 30th 2009, retrieved January 5th 2010 from <http://news.bbc.co.uk/2/hi/science/nature/8386460.stm>.

Higgins, C., *Personal communication with the author*, February 11th 2010.

Hoberg, G., and Mallon, C., *Electricity trade in British Columbia: Are we a net importer or a net exporter?,* March 17th 2009, retrieved January 13th 2010 from <http://greenpolicyprof.org/wordpress>.

H. Hondo, 'Life cycle GHG emission analysis of power generation systems: Japanese case', *Energy*, Vol. 30, 2005, pp. 2042-2056.

Interlock Roofing, *Solar roof*, retrieved March 13th 2010 from <http://www.bcsbestroof.com/>.

International Energy Association, *Energy Policies of IEA Countries: Germany, 2007 Review*, International Energy Agency, OECD, Paris, retrieved March 13th 2010 from <http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1922>.

Jha, A., 'Solar power from Saharan sun could provide Europe's electricity' *The Guardian*, July 23rd 2008, retrieved March 3rd 2010 from <http://www.guardian.co.uk/environment/2008/jul/23/solarpower.windpower>.

Johnston, W., *Personal communication with the author*, February 17th 2010.

Kalowekamo, J., and Baker, E., 'Estimating the manufacturing cost of purely organic solar cells,' *Solar Energy,* Vol. 83, 2009, pp. 1224-1231.

Kannan, R., *et al.* 'Life cycle assessment study of solar PV systems: An example of a 2.7kW distributed solar PV system in Singapore,' *Solar Energy* 80, 2006, pp. 555–563.

Kato, K., Murata, A., and Sakuta, K., 'An evaluation on the life cycle of photovoltaic energy system considering production energy of off-grade silicon,' *Solar Energy Materials and Solar Cells*, 1997, Vol. 47, pp. 95–100.

Knowles, R., 'The Solar envelope,' *Energy and Buildings,* Vol. 35, Issue 1, January 2003, pp. 15-25.

Kruhlak, R., *A legal review of access to sunlight in sunny Alberta,* Edmonton, 1981, retrieved March 1st 2010 from <http://www.cansia.ca/government-regulatory-issues/archives>.

Landler, M., 'Germany debates subsidies for solar industry,' *New York Times*, May 16th 2008, retrieved March 13th 2010 from <http://www.nytimes.com/2008/05/16/business/worldbusiness/16solar.html?pagewanted=2&_r=3&sq=Solar%20Valley%20Overcast&scp=1>.

Lisell, L., Tetreault, T., and Watson, A., *Solar ready buildings planning guide*, December 2009, retrieved March 10th 2010 from <www.nrel.gov/docs/fy10osti/46078.pdf >.

Lovgren, S., 'Spray-on solar-power cells are true breakthrough,' *National Geographic News*, January 14th 2005, retrieved January 18th 2010 from <http://news.nationalgeographic.com/news/2005/01/0114_050114_solarplastic.html>.

Miller, N. and Ye, Z., *Report on distributed generation penetration study*, August 2003, National Research Energy Laboratory, accesses September 13th 2010 from <www.nrel.gov/docs/fy03osti/34715.pdf>.

Morton, O., 'Solar energy: A new day dawning?,' *Nature* 443, September 7th 2006, pp. 19-22, accessed February 23rd 2010 from <http://www.nature.com/nature/journal/v443/n7107/full/443019a.html>.

Muenster, R., 'Shade happens,' *Renewable Energy World*, February 2nd 2009, accessed March 2nd 2010 from <http://www.renewableenergyworld.com/rea/news/article/2009/02/shade-happens-54551>.

Müller, A., Wambach, K., and Alsema, E., 'Life cycle analysis of a solar module recycling process,' *Materials Research Society*, Warrendale, PA, USA, 2007, retrieved February 26 2010 from <http://www.mrs.org/s_mrs/sec_subscribe.asp?CID=6228&DID=170203&action=detail>.

National Renewable Energy Laboratory, *PV FAQs*, US Department of Energy, Office of Energy Efficiency and Renewable Energy, December 2004, retrieved February 20th 2010 from <www.nrel.gov/docs/fy04osti/35489.pdf>.

National Renewable Energy Laboratory, *NREL energy analysts dig into Feed-in Tariffs*, June 12th 2009, retrieved March 3rd 2010 from <http://www.nrel.gov/features/20090612_fits.html>.

Natural Resources Canada, *Photovltaic Potential and Solar Resource Map of Canada*, accessed November 29th 2009 from <https://glfc.cfsnet.nfis.org/mapserver/pv/index_e.php>.

Odum, H., *Environmental Accounting: Emergy and Environmental Decision Making*, John Wiley & Sons, New York, 2008.

Ontario Power Authority, *What is the Feed-in tariff program*?, Ontario Power Authority website, retrieved February 20th 2010 from <http://fit.powerauthority.on.ca/Page.asp?PageID=1115&SiteNodeID=1052>.

Pearce, J., cited in 'The future of the thin-film solar panel,' *Solar Power Beginner* retrieved February 28th 2010 from <http://www.solarpowerbeginner.com/thin-film-solar-panel.html >.

Pearce, J., *Personal communication with the author*, March 2nd 2010.

Province of British Columbia, *Local Government Act*, Part 26, Section 903: Zoning bylaws, Queen's Printer, Victoria BC, accessed January 3rd 2010 from <www.bclaws.ca>.

Province of British Columbia, *Local Government Act*, Part 26, Section 920: Planning and Land Use Management, Queen's Printer, Victoria BC, accessed January 3rd 2010 from <www.bclaws.ca>.

Province of British Columbia, *Climate action plan*, June 2008, retrieved November 13th 2009 from <http://www.livesmartbc.ca/government/plan.html>.

Province if British Columbia, *Livesmart BC*, accessed November 20th 2009 from <http://www.livesmartbc.ca/>.

'PV CYCLE to initiate solar PV module take-back and recycling programme in 2010,' *Renewable Energy Focus*, 12 October 2009, retrieved February 3rd 2010 from <www.renewableenergyfocus.com>.

Serrano, E., Rus, G., and Garcia-Martinez, J., 'Nanotechnology for sustainable energy,' *Renewable and Sustainable Energy Reviews* 13, 2009, pp. 2373–2384.

Silicon Valley Toxics Coalition, *Towards a just and sustainable solar industry,* January 14th 2009, retrieved March 9th 2010 from <www.svtc.org/>.

Smiley, E., *Green energy study for British Columbia phase 2: Mainland building integrated photovoltaic solar and small-scale wind*, BC Hydro, October 2002, retrieved November 28th 2009 from <http://www.bchydro.com/etc/medialib/internet/documents/environment/pdf/green_energy_study.Par.0001.File.greenenergystudy-summary.pdf>.

Society Promoting Environmental Conservation, *Solar technology tours at SPEC*, SPEC website, accessed February 1st 2010 from < http://www.spec.bc.ca/article/article.php?articleID=488>.

Solar BC, *Solar BC incentives double up: $2000 now available for new buildings and existing homes*, accessed February 3rd, 2010 from < http://www.solarbc.ca/blog/liz-kelly/2010/02/01/solarbc-incentives-double >.

SolarBC, *Solar hot water simplified*, accessed March 3rd 2010 from <http://www.solarbc.ca/learn/solar-hot-water-simplified>.

SolarBC, *Solar in BC's climate*, accessed March 1st 2010 from <http://www.solarbc.ca/learn/solar-in-bcs-climate>.

Solar Buzz, *Solar Energy Costs*, accessed February 23rd 2010 from <http://www.solarbuzz.com/StatsCosts.htm>.

Solar BC, *Incentives and costs*, accessed March 1st 2010 from <http://www.solarbc.ca/learn/incentives-costs>.

Solar Buzz, *Module index retail price per watt peak*, retrieved March 14th 2010 from <http://www.solarbuzz.com/Moduleprices.htm>.

Solar Direct, *Solar Water Heater*, image retrieved Thursday March 4th 2010 from <http://www.solar-water-heater.com/~images/pt-house.gif>.

Stamenic, L., 'Developments with BIPV systems in Canada,' *Asian Journal on Energy and Environment*, Vol. 5, Issue 4, pp. 349-365.

Stonier, J., *Personal Interview with the Author*, March 19th, 2010.

Suddwick Homes, *Solar photovoltaic (PV) packages*, retrieved March 9th 2010 from <http://www.suddwickhomes.ca/solarpackage-pv.html>.

Suna, D., Haas, R., and Lopez Polo, A., *Analysis of pv system's values beyond energy: by country and stakeholder*, International Energy Association, Photovoltaic Power Systems Program, retrieved January 3rd 2010 from <www.iea-pvps.org/products/download/rep10_02.pdf>.

Sustainable Energy Authority Victoria, *Info fact sheet: Siting and solar access*, n.d., retrieved March 3rd from <www.sustainability.vic.gov.au/resources/.../Siting_and_solar_access.pdf>.

Taylor, D., 'On the job with solar PV,' *Environmental Health Perspectives*, 2010, V. 118, p. A19.

Torcellini, P., *et al.* 'Solar technologies and the building envelope,' *ASHRAE Journal*, April 2007, pp. 14-22, retrieved February 13th 2010 from <www.ashrae.org>.

US Department of Energy, Office of Energy Efficiency and Renewable Energy, *Small Solar Electric System Components*, retrieved February 13th 2010 from <http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10790>.
US Department of Energy, *Cell, module, array*, image retrieved November 7th 2009 from <http://www1.eere.energy.gov/solar/pv_systems.html>.

US Department of Energy Efficiency and Renewable Energy, *Get your power from the sun: A consumer's guide*, December 2003, p. 5, retrieved October 20th 2009 from <www.nrel.gov/docs/fy04osti/35297.pdf>.

US Department of Energy, Efficiency and Renewable Energy, *Community solar access*, accessed March 13th 2010 from <http://www.energysavers.gov/renewable_energy/solar/index.cfm/mytopic=50013>.

US Department of Energy: Building America, 'High-performance home technologies: Solar thermal and photovoltaic systems,' *Building America Best Practices Series Volume 6*, June 4th 2007, retrieved August 2008 from <http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/41085.pdf>.

US Department of Energy, *Solar history timeline*, retrieved March 1st 2010 from <http://www1.eere.energy.gov/solar/m/solar_time_1900.html>.

US Department of Energy Office of Building technology, *Passive solar design technology fact sheet,* December 2000, retrieved September 20th 2009 from <http://www.energysavers.gov/your_home/designing_remodeling/index.cfm/mytopic=10250>.

Varun, I., Bhat, K., and Prakash, R., 'LCA of renewable energy for electricity generation,' *Renewable and Sustainable Energy Reviews,* 2009, Vol. 13, pp. 1067–1073.

Weisser, D., *A Guide to Life-Cycle Greenhouse Gas (GHG) Emissions from Electric Supply Technologies*, n.d., International Atomic Energy Association, p. 17., retrieved February 20th 2010 from <http://www.iaea.org/OurWork/ST/NE/Pess/assets/GHG_manuscript_pre-print_versionDanielWeisser.pdf>

Weis, T., and Horne, M., *Residential solar opportunities in Dawson Creek: Solar Hot Water and Electricity Generation Final Report*, Pembina Institute, February 2008, retrieved February 23rd 2009 from <www.planningforpeople.ca/.../Solar%20Potential%20for%20Dawson%20Creek%20-%20Final.pdf>.

Wiser, R., Barbose, G., and Peterman, C., *Tracking the Sun: The installed cost of photovoltaics in the U.S. from 1998-2007*, Lawrence Berkeley National Laboratory, February 2009, retrieved Tuesday March 2nd 2010 from <http://eetd.lbl.gov/ea/emp/reports/lbnl-1516e.pdf>.

Worren, J., 'Ontario FIT program off to a cautious start,' *Renewable Energy World*, October 12th 2009, retrieved March 3rd 2010 from <http://www.renewableenergyworld.com/rea/news/article/2009/10/ontario-fit-program-off-to-a-catious-start>.