MUNICIPAL ENERGY GENERATION PROGRAM

Solar PV Basics – Technology, Installation & Cost

September 2024

This document provides municipalities with information to install solar PV on their facilities, reduce permitting and tax barriers to solar PV in communities, and engage community members on the benefits of producing power.

Municipal Climate Change Action Centre

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1.0 INTRODUCTION

As the cost of installing solar photovoltaic (PV) systems falls, many municipalities across Alberta are looking to "go solar" for the benefit of municipal residents, businesses, non-profits, and public institutions.

This document will help municipalities who are looking to install solar by providing them with the technical understanding and information needed to make informed decisions regarding solar PV and its development in their communities. It describes the current state of solar PV technology, its benefits to all electricity users and municipalities, how it integrates into Alberta's electricity system, and what you can expect to pay in Alberta for various types and sizes of systems.

1.1 Solar PV Technology and System Sizes

Solar PV is a renewable energy technology that converts energy from the sun into electricity. Solar PV technology can be mounted on building rooftops, walls, facades, or on frames and poles on the ground[1]. Solar PV is different than solar thermal technology, which transfers solar energy to water for water or building space heating.

Solar PV projects may be categorized by how much electricity they generate (size) and whether they are connected directly to the electricity transmission and distribution system, to an electrical panel in a building behind its electric utility meter, or to battery storage system ("off grid").

1. Large Scale Generation: Also called utility scale ("solar farms") have a generating capacity greater than 5MW and are typically connected to the transmission grid like traditional fossil-fuel generation systems. An example of a utility scale PV project is the Travers Solar Project which is capable of producing 465 MW of power.
2. Large Scale Micro Generation: Have a generating capacity from 150 kW to 4.99 MW. An example of a large-scale micro generation PV project is the Town of Raymonds Ridge Water Services Commission building which has a capacity of 288 kW.
3. Small Scale Micro Generation: Have a generating capacity up to 149 kW. An example of a small-scale micro generation PV project is the City of Edmonton's Leefield Community League which has a capacity of 5.23 kW.
4. Off Grid System's: Are not connected to the electrical gird and utilize energy storage systems like batteries to store excess electricity that is produced for later use.

Micro-generation solar PV projects, also called 'behind-the-meter' systems, can be small enough to fit on a residential roof, or larger for a larger municipal or commercial building. The electricity generated from the solar PV system is first used to power any demand in the home or building, and any excess electricity is exported to the grid. Electricity is also supplied from the grid to meet demand that cannot be provided from the solar PV system. In effect, the electricity grid acts as a battery for the solar PV system. The current Alberta regulation limits solar PV size based on the last twelve months of consumption, or the projected load if it is a new or upgrading service. Micro-generation cannot exceed 5 MW.

This toolkit focuses on small and large micro generation systems, as these are the most common and versatile. While much of the technological information is similar for all systems, the details for the utility scale systems and off-grid system types are out of scope within this resource.

[1] Proposals to integrate solar PV into other surfaces including roads, pedestrian and bicycle pathways are newer and technologically unproven. These should not be prioritized over rooftop and community ground-mount projects which are solidly understood and currently significantly cheaper.

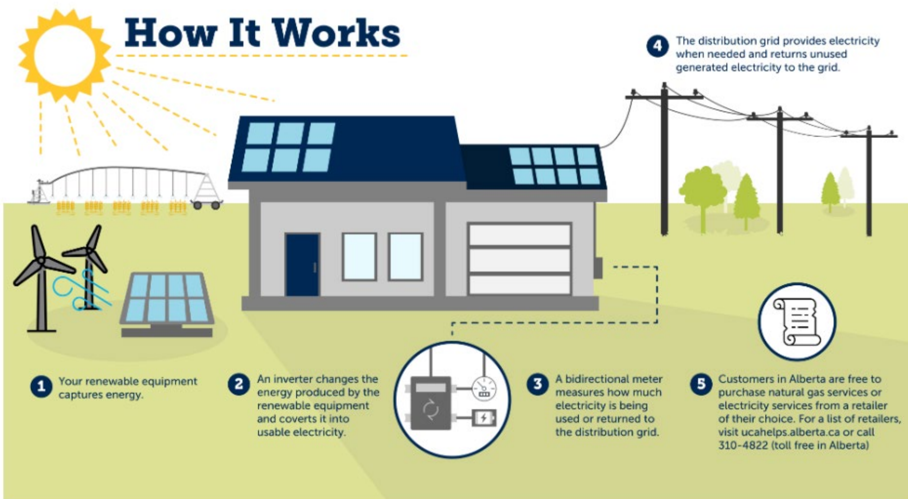

Figure 1: How solar PV systems work. Picture Source: https://www.fortisalberta.com/customer-service/get-connected/generation/micro-generation

1.2 Introduction to Electricity and Photovoltaics (PV) Basics

Electricity powers nearly everything we use including cell phones, TVs, and lights. Historically in Alberta, electricity has been generated in large power plants that burn coal, natural gas, or other fossil fuels. The electricity produced is then transmitted over the transmission grid — long wires connected to transfer stations ("sub-stations") — and then distributed over the distribution grid — smaller wires and transformers — directly to customers, including homes and businesses, for consumption.

Solar PV systems do not burn fossil fuels and can generate electricity very close to where it is used without needing transmission wires. Solar PV systems use the "photovoltaic" effect to convert sunlight[2] directly into electricity. PV modules are made of silicon semiconductors, the same material used in today's computers[3]. These absorb sunlight and transfer that energy to electrons inside the semiconductor material, generating electricity.

1.3 Energy vs. Power

- **Power** is the rate (or instantaneous amount) of electricity use. It is measured in kilowatts (kW) and watts (W). One million watts of power, one megawatt (MW), is enough to power 1,275 Alberta homes[4].
- **Energy** is the amount of electricity used in an hour and is measured in kilowatt-hours (kWh). A utility bill shows how much electricity you use as kilowatt-hours. An average Alberta home uses just under 600 kWh of electricity each month[5], which can be easily generated by a 6kW solar PV system of 22 or fewer PV modules.

2 Sunlight can directly power a solar PV module but scattered ("diffuse") light may also help generate power. This means that even shaded modules will generate some electricity.

3 Silicon material in solar PV generators also use very small additions of "doping" materials to direct the flow of electricity across the semiconductor.

4 A typical Alberta home uses 6,889 kWh of electricity per year. This is equivalent to 786 watts continuously per home. 1,275 homes powered continuously would require just over one MW of power generation.

5 Statistics Canada. "Household energy consumption, Canada and provinces. 2015.https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=2510006001

2.0 SOLAR PV SYSTEMS – HOW THEY WORK AND KEY COMPONENTS

Solar PV systems consist of an array of PV modules, also called "solar panels", inverters, cabling, and racking. The solar modules use many smaller solar cells which collect energy from sunlight and convert it into usable electrical current. When several PV modules are connected, they generate enough electricity to power a small home, but the electric current needs to be prepared for consumption.

Inverters ensure that the electricity from sunlight is compatible with the electricity grid and building electrical system. PV modules are securely attached to buildings or the ground with racking. See Figure 2 for the components of a solar PV system.

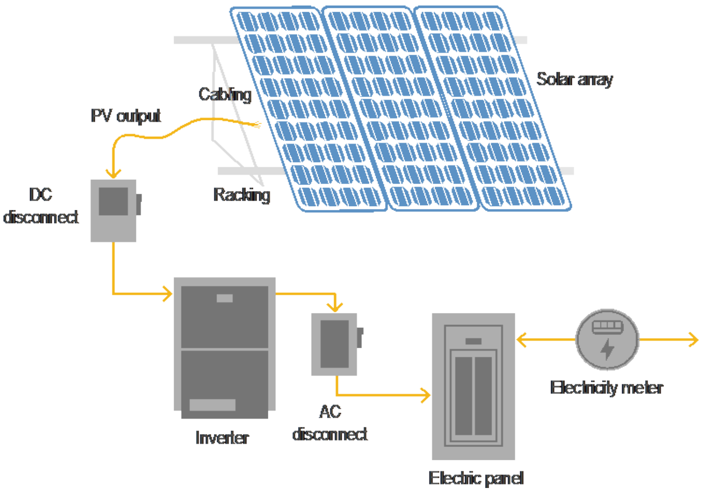

Figure 2: Components of PV solar array system.

2.1 PV Cells, Modules, and Arrays

A solar module, or "panel", typically consists of 60 or 72 single solar cells. Each module is approximately 1 by 1.6 to 1.9 meters in area and 4 cm thick in thickness. A 60-cell module produces approximately 280 to 300 watts while a 72-cell module produces approximately 335 to 450 watts. When installed in Alberta, a 300-watt module generates enough electricity in one hour to power a 40" LED TV for 9 hours[6].

Modules are built to withstand extreme temperatures and weather. For protection, the solar cells are sandwiched between a transparent protective front sheet and durable backing inside a fitted aluminum frame for mounting to a supporting structure. And to ensure the PV module is never overloaded by electricity, each includes a "bypass" that effectively removes the module from the module array. These features ensure solar PV systems operate successfully in all environments, including arctic[7] and desert[8] climates.

One PV module contains many smaller solar cells; each cell is a package of semiconductor material in a single wafer about 12 cm across, protected by an anti-reflective coating, and with metal contacts for power delivery. Crystalline silicon (c-Si) is the most common type of solar cell material.

6 Assuming a TV that has a 33W power rating. Some of that 9 hours of electricity would need to be stored in a battery, because an average Alberta day — including winter and summer months — has less than 8 hours of sunlight.

7 Pembina Institute, *Solar PV Case Study: Colville Lake, Northwest Territories* (2015). http://www.bullfrogpower.com/wp-content/uploads/2015/09/Colville_Lake-Solar.pdf

8 International Energy Agency, *Energy from the Desert: Very Large Scale PV Power Plants for Shifting to Renewable Energy Future* (2015). www.iea-pvps.org/index.php?id=9&eID=dam_frontend_push&docID=2398

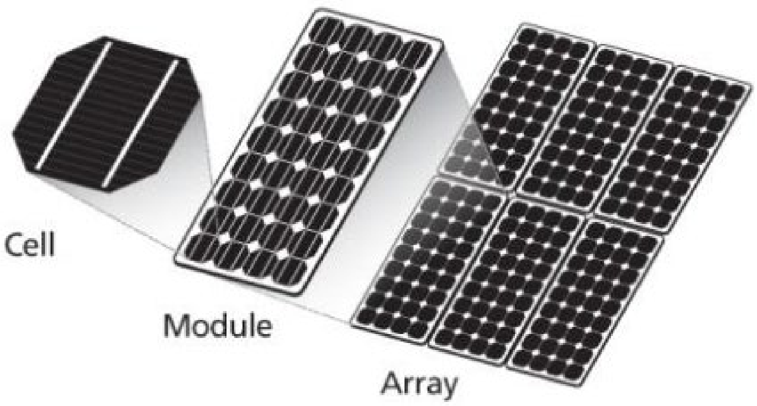

Figure 3: PV cell, module, and array. Source: https://www.researchgate.net/figure/Solar-panel-figuration-cell-module-array_fig1_270706722

The most common solar cells are poly-crystalline material made from large molten blocks of material, cooled, and solidified. This is a mature technology with the largest market share, low prices, and a good manufacturer warranty. Efficiency of these module types is up to 20%[9]. See Figure 4 for example photos.

Less common are cells using mono-crystalline silicon, which use one seed crystal to grow a single crystal structure. These cells can convert up to 25% of the sun's energy into electricity but are very expensive to produce — although their cost has dropped more than 30% over the last few years[10]. They are best for areas of limited space where efficiency is key. They also have a more consistent, darker appearance, if aesthetics is a consideration.

"Thin film" cells use less silicon and are cheaper to manufacture but are only 10–15% efficient, meaning more modules are needed to generate the same electricity as mono- or multi-crystalline cell modules. In addition, the cost of mounting equipment and cabling is also higher. They are more flexible and may be suited for installation in certain applications where flexibility is key. They also have a darker, more homogenous appearance.

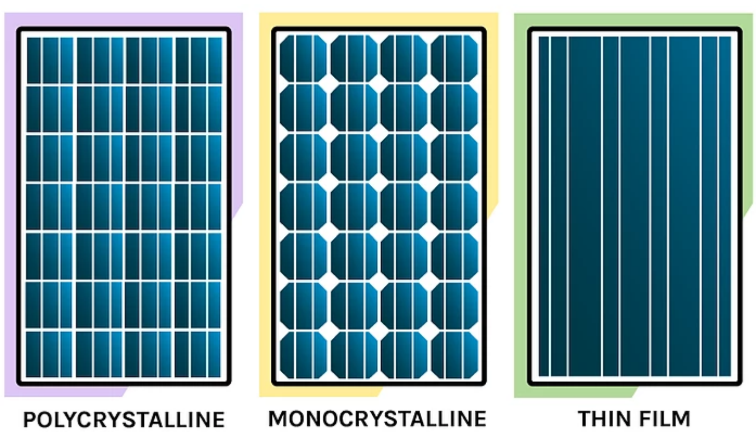

Figure 4: PV cell types. Source: https://getsolar.ai/blog/types-of-solar-panels/

9 A typical Canadian Solar module of this type has a module efficiency of up to 18%. Solar Quotes, *Canadian Solar* (2016). https://www.solarquotes.com.au/panels/canadian-solar-review.html; Canadian Solar, *CS6K-275|280|285 M* (2016). http://www.canadiansolar.com/fileadmin/user_upload/downloads/datasheets/v5.5/na/Canadian_Solar-Datasheet-CS6K-M- v5.52na.pdf

10 Mike Munsell, "Solar Module Prices Reached 57 Cents per Watt in 2015, Will Continue to Fall Through 2020, GreenTech Media, March 10, 2016. https://www.greentechmedia.com/articles/read/solar-pv-module-price-reach-57-cents-per-watt-in-2015- continue-to-fall-thro

2.2 Inverters

Because solar PV modules generate electricity at a lower voltage and as direct current (DC), it is necessary to connect them together in an array and convert their output from DC to AC power using inverters. After the electricity passes through the inverter it can be utilized in homes and businesses.

Some energy is lost during this conversion. When combined with losses from cabling and fuses, the total loss can vary from 1% to 12% of the total electricity output from the array. The highest efficiency inverters minimize this loss.

Different types of inverters are used depending on how the modules are connected. One configuration is to connect the PV modules in series to form strings, and to use a string inverter designed to handle much higher voltages and power output. The number of modules in each string depends on the input voltage requirement of the DC-AC inverter.

2.2.1 Systems with String Inverters

Arrays with string-level inverters can use optimizers that detect partial shading of a string of modules. These can exclude shaded modules from the string. While this ensures non-shaded modules operate at maximum efficiency, it excludes power output from only partially shaded modules. An alternative solution is to install one MPP optimizer per module in a string. This way each module operates at maximum power regardless of other modules in the same string[11]

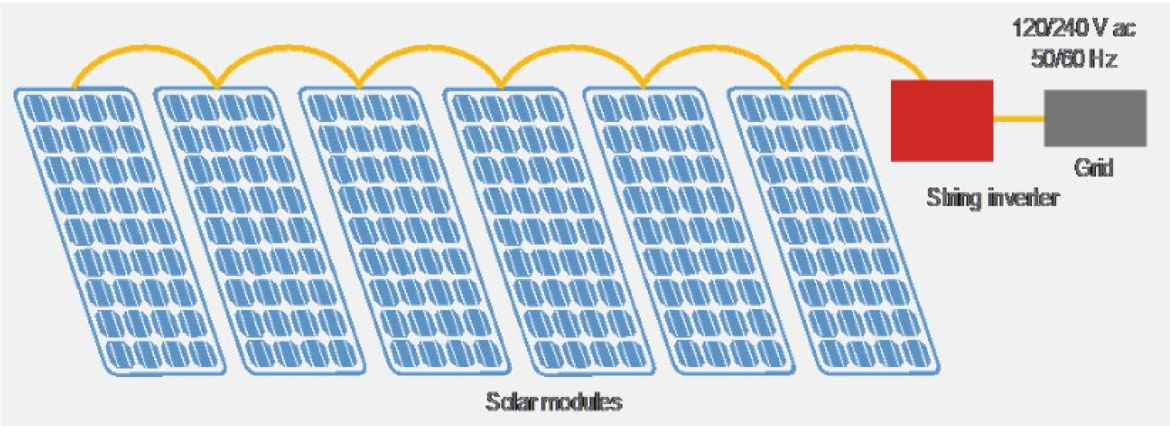

Figure 5: PV solar system connected to a string inverter.

[11] Solar Edge, *Performance of PV Typologies under Shaded Conditions* (2013). http://www.solaredge.com/sites/default/files/performance_of_pv_topologies_under_shaded_conditions.pdf

2.2.2 Systems with Micro-Inverters

Arrays may also use micro-inverters to invert current from each individual module. These inverters are quite small and are mounted directly behind the module. This avoids the effects of shading on the array (see below). In this configuration, each inverter is optimized to the voltage and power output of its module. It is possible to connect up to 18 modules and micro-inverters to one trunk line, which reduces cabling complexity and cost.

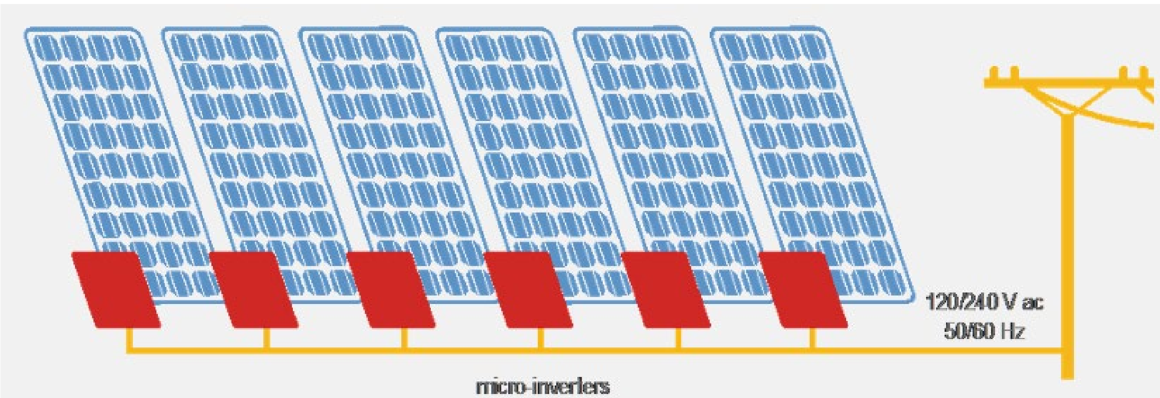

Figure 6: PV solar system connected to a micro-inverter.

2.2.3 Systems with Central Inverters

A third approach uses central inverters, where all modules are connected to a single DC-AC inverter. Typically, only large ground-mount systems use these inverters, and in locations where there is no concern about shading of the solar array.

2.3 Shading of Solar Arrays

When clouds, nearby trees, or buildings obstruct sunlight to a module, the electricity generated through the affected PV modules is reduced which can reduce power output for all other modules on the same string. It is possible to avoid this issue by:

1. *Strategic placement of strings* - Smart alignment of the modules so that modules are subjected to shadows mostly simultaneously. [12]
2. *Maximum power point (MPP) tracking – S*tring inverters can ensure highest possible power output even when modules are partially shaded.[13]
3. *Using micro-inverters* - Arrays using micro-inverters avoid the problem of shading altogether. Since each module's output is directly converted to AC power, they operate independently and shading on one module has no impact on the performance of other modules.

[12] SolarEdge, *Technical Note: Bypass Diode Effects in Shaded Conditions* (2010). http://www.solaredge.com/sites/default/files/se_technical_bypass_diode_effect_in_shading.pdf

[13] Texas Instruments, Introduction to Photovoltaic Systems Maximum Power Point Tracking (2010). http://www.ti.com/lit/an/slva446/slva446.pdf; Samlex Solar, *Solar Panel Characteristics: Current, Voltage and Power Curves of a Solar (PV) Panel* (2016). http://www.samlexsolar.com/learning-center/solar-panels-characteristics.aspx

2.4 Balancing the System

Balancing the solar PV system refers to all the components other than the modules that need to be connected and properly tested to ensure efficient and safe operation of the solar array. This includes inverters, optimizers, electrical cabling, disconnection equipment and supporting structures (mounting or racking).

1. *Cabling* - The amount and complexity of cabling depends on the type of inverters used. Micro-inverters reduce cable clutter because all modules are connected into one AC trunk line. Arrays with string inverters use more cable to connect PV modules in strings, and then to inverters. Larger systems may use string "combiners" that can connect several module strings into one cable; these are typically isolated in a separate electrical box.[14]

Figure 7: Solar PV system cabling and combiner box Photo: Green Sun Rising

2. *Disconnects* — A complete solar PV system must include circuit disconnections at the DC and AC sides. The DC disconnect is installed to cut off power from solar modules to the inverter during installation and maintenance. The AC disconnect is used to isolate the system from the grid in case of maintenance or emergency activities performed by the electric utility. The disconnect also facilitates electrical inspection and safe installation of the solar PV system. The utility must always authorize solar PV connection to their electric grid.

14 Clean Energy States Alliance, *Solar Photovoltaic (PV) Fire Safety Training* (2015), 42. http://www.cesa.org/assets/2015- Files/CESA-PV-Fire-Safety-Training-Slides.pdf

3. *Electric panels* — These are typically not considered part of the solar PV system, but are where inverter output, flowing through an AC *disconnect*, is tied to the building's electrical system. In some cases, separate solar PV generation meters can be installed to measure total solar output; these are often combined with a data acquisition system that reports generation and system status to owners and operators in real time through a website or smartphone app.

Figure 8: Solar PV system disconnects and electrical panels Photo: SkyFire Energy.

4. *Labelling and rapid shutdown* — A rapid shutdown feature allows firefighters to rapidly stop the flow of electric current through cabling and equipment connected to PV modules. This reduces the risk of severe electric shock when cutting into roofs and walls for venting. Labelling is also required to provide accurate information about the solar PV system and electric shock risks.[20]
5. *Mounting (racking)* — PV systems may be mounted on building walls (facades) or roofs, or directly on the ground. The racking and attachments should be designed and installed to withstand the weight of the PV modules, as well as uplift caused by wind and weather (e.g. intermittent snow).

Figure 9: Rapid shutdown device (left) and DC disconnect with appropriate labeling (right) Photo: SkyFire Energy and Green Sun Rising

2.5 Solar PV Efficiency and Capacity Factors

Efficiency defines how much useful electricity is generated from the primary fuel. Maximum efficiency is limited by both physical laws and optimization of the electricity generators. Natural gas power plants using the newest technology are up to 60% efficient — up to 60% of the gas is converted into electricity, while the remaining 40% or more is wasted as heat. The efficiency of solar cells is much lower than this — but the fuel is free and abundant. Typical commercially available solar PV technology is 17 to 20% efficient.

The efficiency of converting sunlight into electric current using solar PV technology depends on how well the silicon material absorbs sunlight. Like all power generation technologies, laws of physics limit the maximum efficiency that can be achieved for a given system: not all sunlight can be absorbed by the solar cell material.

Today's solar cells achieve the highest energy conversion efficiencies when using the purest silicon materials and by layering several different semiconductor materials to capture more wavelengths of light.[15] Tradeoffs must be considered between improved efficiency and the additional cost of manufacturing more complex solar cells. In fact, energy efficiency is not the most important metric when deciding what type of solar cells to use in a solar PV system. Ultimately, the price per unit of generated electricity and the space available for installing modules are deciding criteria.

[15] Visible light is only a small part of the sun's full solar spectrum. Parts of sunlight, called "photons", have different energy levels corresponding to parts of the full spectrum.

The capacity factor describes how much power is generated over the course of a year on average. The amount of energy generated by technology is always less than the theoretical maximum output of working at full capacity every hour of the year — because the sun does not always shine, and power plants need to be switched off for maintenance. A 1,000-kW solar PV system may have a capacity factor of 14%, which means on average it will produce 140 kW of power over the course of a year.

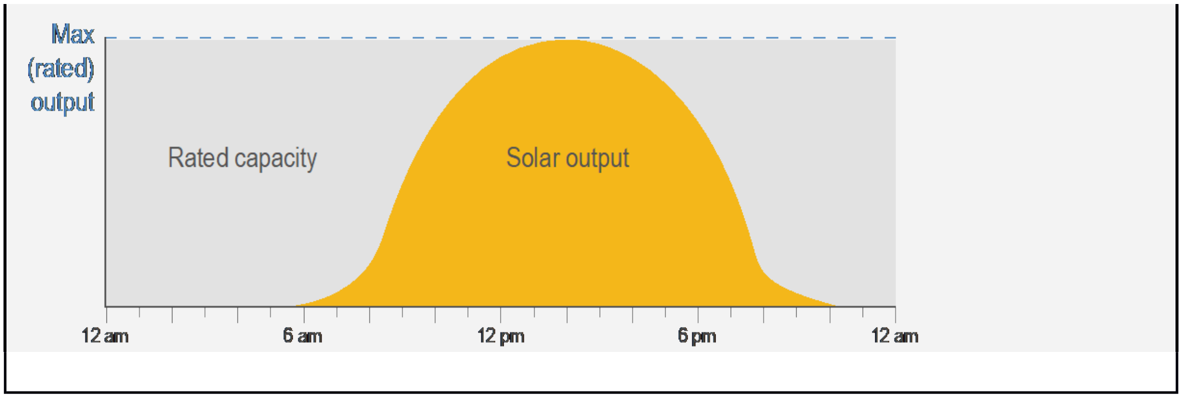

Figure 10: Typical daily solar PV electricity generated and maximum capacity.

3.0 SOLAR PV PROJECT INSTALLATION PROCESS

3.1 Alberta Microgeneration Regulation and Net Metering

Solar PV projects connected under the Microgeneration Regulation are net-metered generator projects where electricity generated is netted against local consumption. A bi-directional electricity meter keeps track of electricity consumption when there is less solar PV system generation and measures any excess electricity flowing to the electric grid. These projects are approved through a Project Notice Form, typically submitted by the installer.

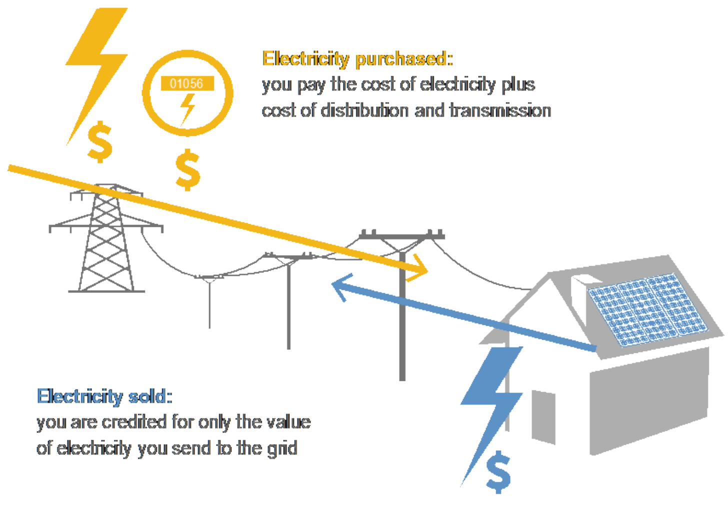

Figure 11: Solar PV production and net metering.

The installation process for applications under the microgeneration regulation follows the following steps. Additional considerations for location, installation, sizing, as well as details on the permitting process, are provided below.

1. *Project feasibility and screening* — Inspect site for potential shadows from trees or nearby structures; determine typical annual energy use from electricity bills; use online calculator (e.g., solar calculator) to give preliminary indication of project economics.
2. *Initial project development* — Refer to Microgen Notice Submission Guideline document to understand the full required process.[16] Contact vendors for preliminary project design and quotes (it is recommended to get at least three quotes); submit expression of interest to funding programs; select vendor and sign contract.
3. *Project development* — The vendor will complete a detailed design of the project; the applicant or vendor will prepare a Generation Project Notice form to provide to the wire service provider (WSP) (note the requirements may vary across providers); the vendor/applicant will apply for all required permits (see permitting). Apply for funding from funding programs.
4. *Construction and energizing* — Vendor begins construction; upon completion of construction, an electrical inspection is completed, and electrical permit is obtained. The WSP is contacted to submit electrical inspection; WSP installs a meter and issues an interconnection agreement; the system is energized. Funding report is submitted to funding program.

3.2 Location Considerations

Determining the best location to install the solar PV system is one of the most important project decisions. This is because the location determines how much sunlight the solar PV system receives, which in turn determines annual electricity generated.

Factors that influence the choice of location include, among others; available roof space, age and material of the roof, pitch, and potential shading — including both present and likely future developments. The best locations experience little shading from nearby buildings, trees, and other obstructions on the horizon, including mountains, hills, bridges, and towers.

Two other important considerations regardless of building are PV module *tilt* and *orientation*:

1. *Tilt* — It is best practice to tilt modules approximately to the degree of latitude.[17] This optimizes module orientation with the height of the sun on the horizon. Tilt may vary depending on available roof area and pitch.
2. *Orientation (also called "azimuth")* — Typically, solar PV systems are oriented south to generate maximum energy. But buildings that see high electricity consumption throughout the day, or particularly in mornings and evenings (e.g. recreation centers) can maximize production by orienting PV modules east and west to capture energy during those periods of the day.

The choice of orientation and tilt is ultimately decided by project economics as well as structural and aesthetic considerations. Figure 12 shows how the orientation and tilt of solar PV systems will affect annual output, compared to maximum output from a tilted roof, oriented south. In winter months the tilted surface will produce less energy than in summer months.

16 Alberta Utilities Commission, *Micro-Generator Application Guideline* (2024). https://www.auc.ab.ca/micro-generation/

17 While a solar PV module will generate the most electricity when tilted at the same angle as the system's latitude, in Alberta this means very high tilt. When installing a large array with multiple rows of modules on a flat roof, higher tilt means bigger spacing requirements to reduce shading. Wider spacing means less room for modules, and lower power output.

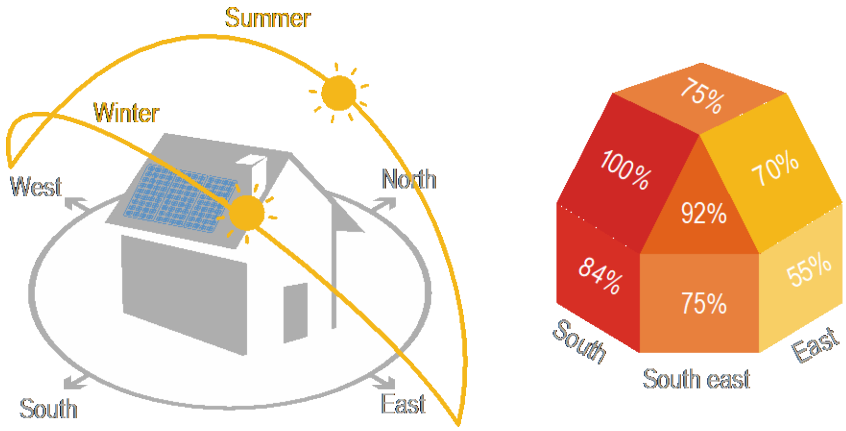

Figure 12: Location of a solar PV system on a building relative to sunlight.

3.3 Building and Roofing Considerations

1. Size, shape, and pitch of roofs — Pitched roofs with angles close to the building's latitude are ideal, but installations can work on roofs of all pitches.[18] Flat roofs are especially useful for larger systems. For these, PV modules are tilted for better positioning towards the sun or to optimize the number of modules that can fit in a given area.[19]
2. Shading — Obstructions may impede access to sunlight, reducing the power output from a solar PV system. The relative positioning of these obstructions to the module array (height and distance) determines their shading impact. Note that trees will grow, and buildings may be built or removed over the lifetime of a solar installation; future impacts should also be estimated. Dust from nearby roadways, animal operations, crop and harvesting facilities may also reduce the light reaching the modules. Other considerations include positioning and size of mechanical equipment, plumbing and stacks.
3. Age and roof material — While solar PV systems may last more than 25 years, the roof may not; and when the roof is replaced, PV modules would need to be temporarily removed. It is important to consider the remaining life expectancy of a roof and ensure that it requires no immediate repairs or replacement before installing a solar PV system. For installation on heavy roofs, structural integrity must always be assessed by a professional engineer to ensure the roof can withstand additional weight of the solar PV system. Also consider roof cleanliness and the possibility of debris, especially on flat roofs, which may reduce solar PV system performance.

3.4 Snow and Cold Weather Impacts

Contrary to common belief, snow has little impact on total electricity production from solar PV over the course of a year. There are two reasons for this: most production occurs during the months of March to October, when there is little to no snow; and snow typically will melt before significantly inhibiting production. Show can also provide a source of reflected light, increasing the production from tilted arrays.

18 EnergySage, "Solar panel installation." https://www.energysage.com/solar/101/solar-panel-installation

19 Charles R. Landau, "Optimum Tilt of Solar Panels," 2015. http://www.solarpaneltilt.com/

20 A sloping heavy roof uses clay or concrete tiles, whereas typical flat roofs use a combination of gravel and tar. Professional engineers will need to assess the combined load of the roof and solar PV system, factoring in wind and snow, before proceeding with solar PV system installation.

The Northern Alberta Institute of Technology (NAIT) installed a reference solar PV system to compare electricity production between snow-covered and clean modules, measuring their performance from 2012 to 2015. Results show snow cover reduces annual electricity production by less than 6%, regardless of tilt. PV modules tilted 45 degrees or more lose less than 2%.[21]

Cold weather is sometimes also cited as a concern — but colder temperatures actually increase module efficiency. At –45°C, a PV system may work up to 30% better than it does at +20°C. Cold temperatures help mitigate some of the losses from snow cover in the wintertime. Figure 13 depicts two photos of a SkyFire Energy solar PV system taken on the same day. All snow has melted from PV modules by the early afternoon.

Figure 13: Snow impacts on solar PV systems.

3.5 Installation considerations

PV modules can be mounted to sloping or flat roofs, using a variety of attachment systems:

1. *Sloped roofs with asphalt shingles* — This is the most common mounting in Alberta, especially for residential homes. Mounting systems are either attached to structural members (rafters and/or pre- manufactured roofing trusses) or to the roof deck and require penetration of shingles. Steel or aluminum flashing, and rubberized grommet seals, cover the points of penetration to prevent moisture from entering.
2. *Sloped roofs with tiles* — Replacement tiles with built-in attachment points for the mounting system can be installed on an existing tiled roof. This method does not require penetration.
3. *Lightweight metal roofs (flat or sloped)* — Seam metal lightweight roofs are perfect for solar PV installation because in many cases clamps are used that fasten to the seams; penetration is not required. Corrugated roofs typically require a bracket that connects to the surface with roofing screws.

21 Northern Alberta Institute of Technology, *Solar Photovoltaic Reference Array Report* (2016), 7. https://empowerenergysolar.ca/wp-content/uploads/2022/11/NAIT_Reference_Array_Report_March_31_2016_revD.pdf

4. *Flat roofs* — Ballasted tilted racking is typically the most common method used for these types of roofs. Heavy flat roofs may not be designed to deal with additional loading. A structural engineer should assess the roof to determine its ability to accept additional weight. Where loading is not a problem, modules may be secured with ballasts such as masonry blocks or gravel. Otherwise, attached mounting is preferable to reduce maintenance and lengthen roof life.[22] Penetration to attach modules is only an option if roof weather-proofing is not compromised.[23]

Figure 14: Solar PV racking on sloped asphalt roof Photo: SkyFire Energy

Figure 15: Solar PV racking on lightweight metal roof Photo: Green Sun Rising

[22] Jeff Spies, "Solar Racking: Ballasted or Mechanically Attached?" *Roofing Contractor,* April 7, 2014. http://www.roofingcontractor.com/articles/90272-solar-racking-ballasted-or-mechanically-attached

[23] Bill Taylor, "To Attach or Ballast? The pros and cons of roof-mounted PV installation options," *North America Clean Energy*, September/October, 2016.

3.6 Roof Warranties and Liabilities

Roofs, especially larger commercial roofs, will be warrantied both for installation and for operation. Solar installers should carefully examine liabilities to ensure that their work does not void the roof's warranty. The best way, especially for installation on relatively new roofs, is to involve the original roofer and manufacturer. Sometimes manufacturers require certified contractors to install the solar PV mounting systems.

3.7 Ground Mounting

Until recently, ground-mounted solar PV systems were installed using custom engineered solutions that involved cutting, drilling and welding in the field. Now, fully engineered options offer "off-the-shelf" mounts that lower costs and reduce building permit barriers.

These engineered solutions include steel or aluminum frames with integrated electrical bonding and grounding. Some manufactured racking also includes features to help manage cabling, and to account for thermal expansion when long strings of modules are installed in one continuous row, as in large arrays. Pole-mounting is an option where space is not limited; it is more expensive but offers optimal pitch and tilt of the PV modules to make best use of available sunlight. This option reduces the risk of module theft and vandalism.

Racked systems must be placed on a solid foundation. Options include driven piles with helical screws, and ballasted systems using concrete footings. The choice depends on the quality of soil and surface roughness and level.

3.8 Sizing Considerations

Once a location and method of installation has been selected, the solar PV system should be sized to maximize project economics. Sizing solar PV systems involves careful consideration of the building or structure where it will be installed. However, the size, orientation and layout of the roof has the biggest impact in determining the maximum size of a solar system.

Solar PV projects may be categorized by how much electricity they generate (size) and whether they are connected to an electrical panel in a building,[34] behind its electric utility meter, or to the distribution grid. Very large, utility-scale solar PV projects are typically connected to the transmission grid like traditional fossil-fuel generation. Micro-generators, also called 'behind-the-meter' systems, are small enough to fit on a residential roof, or large enough to be installed on 10 to 50 acres of land.[25] Larger projects may be connected behind the meter, or directly to the distribution grid.

To reduce shading potential of each row by spacing rows using a "safety factor" — typically a multiple of the PV module height [36]. In Alberta, this factor may be as high as 3.0 to account for a lower angle of the sun against the horizon. Typically, this means 50 watts per m^2 of roof area (5 watts per ft^2).

24 Solar PV systems connected to a building's electrical panel are also called 'behind-the-meter' systems because their electricity production is primarily used to meet building electricity loads.

25 National Renewable Energy Laboratory, *Land-Use Requirements for Solar Power Plants in the United States* (2013), v. http://www.nrel.gov/docs/fy13osti/56290.pdf

26 A solar PV module will generate the most power when tilted to the degree of latitude. However, too high of a tilt angle does not make effective use of roof area.

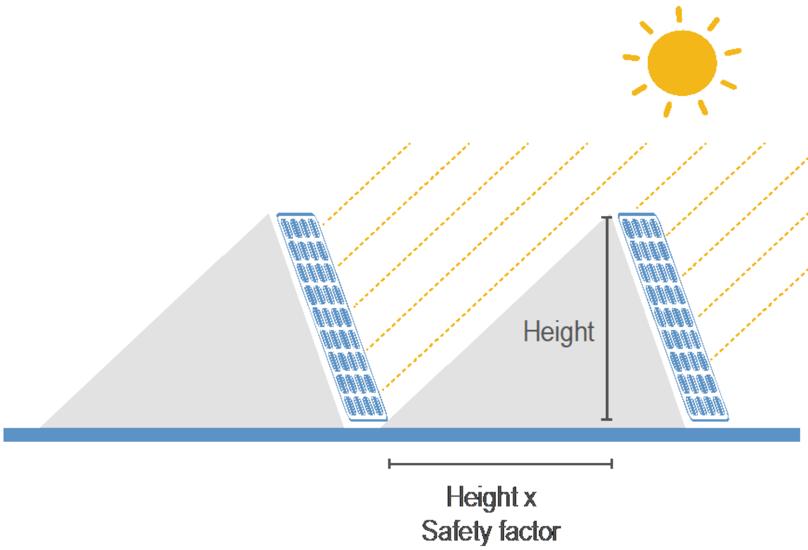

Figure 16: Spacing requirements on flat roofs with tilted racking

Pitched roofs — The pitch and orientation of roofs will vary depending on the property width and age of construction. Typical roofs have 4" rise over each 12" run (4:12), about a 20-degree tilt. While not tilted at the optimal angle, these roofs still generate as much as 95% of the optimal output when oriented south. Roofs of other orientations and lower angles can still accommodate solar PV systems, although with lower output because they receive less sunlight exposure.

Development permits typically restrict placement of solar PV modules flush to, or extending beyond, roof tops ("ridges") and edges ("eaves"). Roof access requirements for fire safety means leaving continuous space from eaves to ridge on each roof slope, typically resulting in access pathways of 0.5 to 1 meter (1.5 to 3 feet). Typically, this means 100 watts per m^2 of roof oriented towards the sun (10 watts per ft^2).

3.9 Permitting

Permits safeguard the wellbeing and safety of Albertans by ensuring conformance of building and electrical systems to provincial codes and standards, such as the Alberta Building Code, the Fire Code and the Canadian Electrical Code.[27] These are designed to be comprehensive, applying to all aspects of buildings and electrical systems, including solar PV. While codes regulate how systems are inspected, municipalities are responsible for that inspection.

There are three types of permits that are relevant for solar PV project development and installation: development, building and electrical permits. While the permit process begins once a site has been identified, in some cases selecting a site is influenced by development and building permit requirements.

27 Electrical systems in Alberta are regulated according to standards developed by the Canadian Standards Association (CSA). Buildings and their attachments are regulated through Alberta codes based on a national building code developed by the National Research Council Canada.

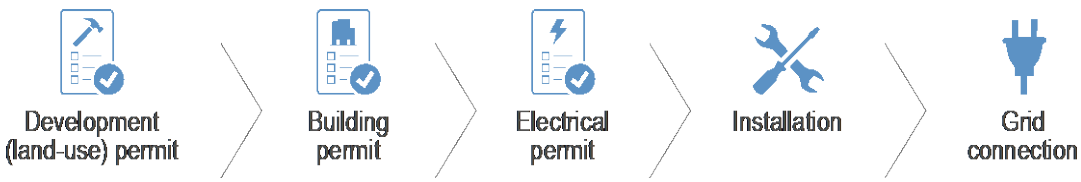

Figure 17: Solar PV project development and permit process

1. Development (land use) permit — A development permit ensures the project fits with the neighborhood, has good aesthetics, and does not unduly impact adjacent properties. Development permits typically require a detailed assessment of these conditions. Depending on the allowable land uses identified for the site by the municipality, there may be different requirements for the permitted installation of a solar PV system. Where these land use requirements are already met, a development permit is not required ("exempted"), though a building permit still is. For complicated installations, such as ground-mounted and building- integrated systems, a development permit is required — often a costly and potentially onerous process.

2. Building permit — A building permit ensures the solar PV system does not alter the structural integrity and fire safety of the building to which it is attached. Ground-mounted projects also require permits for new attachment structures. When a permit is required, the installer "pulls" the permit by submitting required documentation to the municipal (permit) office. Many municipalities don't require installers to get a building permit for the simplest cases, e.g. small residential solar PV. In this case the solar installer must still adhere to the building and fire code, but this activity is self-regulated. When a building permit is required, it must be approved prior to installation.

3. Electrical permit — The electrical permit ensures the solar PV system design conforms to electrical safety codes. It includes documentation requested in the permit application, including a line diagram showing how system components will be connected. Specific details include information about the DC circuit, such as PV module and inverter characteristics, and how the system will be connected to the building's electrical panel and the grid. These details are documented and signed off by a master electrician.[39]

Installation — Once all necessary permits are approved the solar PV system may be installed, but not connected to the building's electrical system or the grid. Rough-in inspections may still be required during construction, but before connection.

[28] While electrical permits are not fully approved until after installation and inspections, construction may begin upon review and approval of the permit application.

Grid connection — Before connecting the system to the building and generating electricity, the installer must apply with the electric utility[29] to "cut and reconnect" the building's electric contact with the grid. A master electrician must co-ordinate this process, which involves the utility disconnecting power to the building, followed by the electrician connecting the solar PV and building electrical systems, and re-connection of the building to the grid upon inspection and approval by the electrical inspector. (The electric utility replaces the existing meter with a bi-directional meter which measures the flow of electricity in both directions.) To expedite the permitting process, the installer should co-ordinate with electrical and building inspectors, and the electric utility, to have all personnel on-site for same-day inspection and the building "cut and reconnect." This practice will benefit the installer most, but the municipality can play an active role in coordination.

4.0 TECHNOLOGY BENEFITS AND IMPACT

4.1 Benefits for Alberta Communities and Their Economies

Both small- and community- scale solar PV projects allow Albertans to participate directly in power generation in a way that isn't feasible with traditional, large, and centralized generation. Citizens and businesses can own or invest in projects and realize the returns. That means more money flows back to the community. These projects also build capacity for further community economic development by training local workers and inspiring entrepreneurship — all ingredients for a sustainable and vibrant Alberta economy. Small and community-scale solar PV projects also create up to 2.8 times as many jobs as large-scale alternatives.[30]

4.2 Benefits for the Electricity System

Solar PV helps build efficient and resilient power grids, with benefits shared among the electricity distribution grid operators and, by extension, all other grid-connected customers. Grid-connected PV system owners generate electricity for their own use, which translates to savings on their electricity bill. They also reduce the need for more expensive generation at peak times — exactly when solar power production is highest — providing savings to grid operators. This is true even in Alberta where the summer demand peak is increasingly larger and growing faster than the winter peak in the south and central regions. This summer demand comes from commercial and residential air conditioning needs on the hottest days of summer. Agricultural irrigation uses large amounts of electricity at these times as well. And areas where air conditioning and irrigation use of electricity in Alberta is highest also have ample space for PV systems. Figure 18 compares winter and summer peak loads in Southern and Central Alberta.

29 Electric utility is also known as the distribution grid owner (wires owner) or operator (wire service provider).

30 Sara Hastings-Simon, "Solar is right where and when you need it," *Pembina Institute,* June 16, 2016. https://www.pembina.org/blog/solar-right-where-and-when-you-need-it

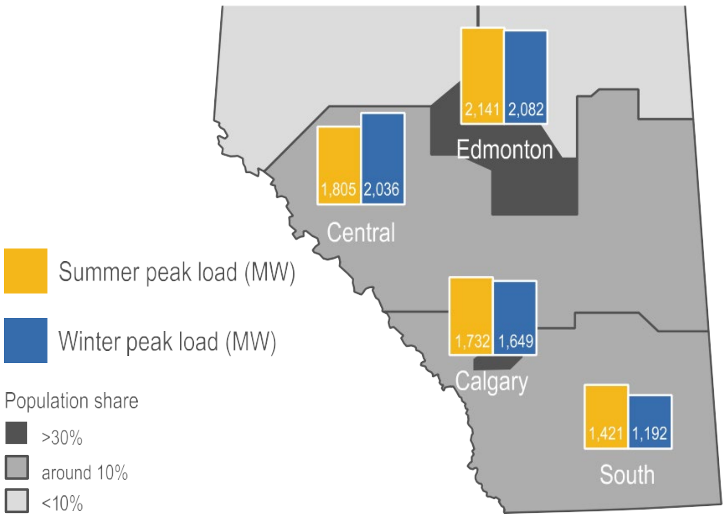

Figure 18: Summer peak demand in Central and Southern Alberta

Power generation at the point of consumption also reduces transmission losses, particularly when electricity travels long distances. Today, these losses are 3% of total energy generation.[31] Local power can reduce the need for additional transmission infrastructure. Local distributed power can also contribute to avoiding possible blackouts at times of system stress by providing more diversified sources of energy generation. An estimate of these benefits shows California could deploy distributed solar and attain annual net savings of $1.4 billion to state residents. These benefits to utilities, customers and system operators also include lower greenhouse gas emissions and net economic returns, including more jobs and business creation.[32]

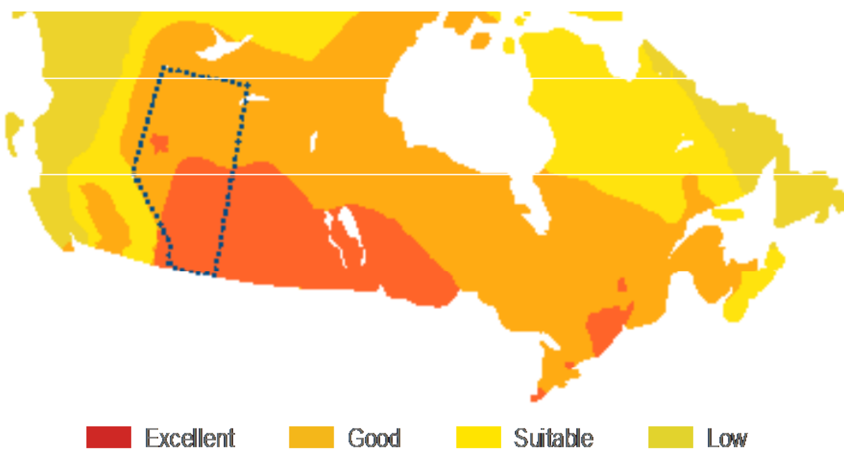

Figure19: Solar access throughout Canada

31 Alberta Electric System Operator, *Current Loss Factors* (2016). http://www.aeso.ca/transmission/10235.html

32 Barend Dronkers and Sara Hastings-Simon, "Renewable energy can power Alberta communities," *Pembina Institute,* July 7, 2016. https://www.pembina.org/blog/renewable-energy-can-power- alberta-communities

Calgary and Edmonton are two of the sunniest major cities in Canada. A solar PV system in Calgary produces 52% more electricity than one installed in Berlin. A typical system could produce more than 1,200 kWh per year for each kW of installed solar PV modules; the amount of electricity an Alberta home uses in two months. Electricity generation from a comparable solar system in Berlin is only about 800 kWh.[33] Alberta's solar PV resource is comparable to the resource available in Rio de Janiero and Rome; Lethbridge and Medicine Hat receive even more sun than Calgary. Solar resources are also fairly consistent across the province with low seasonable and weather-based variability.

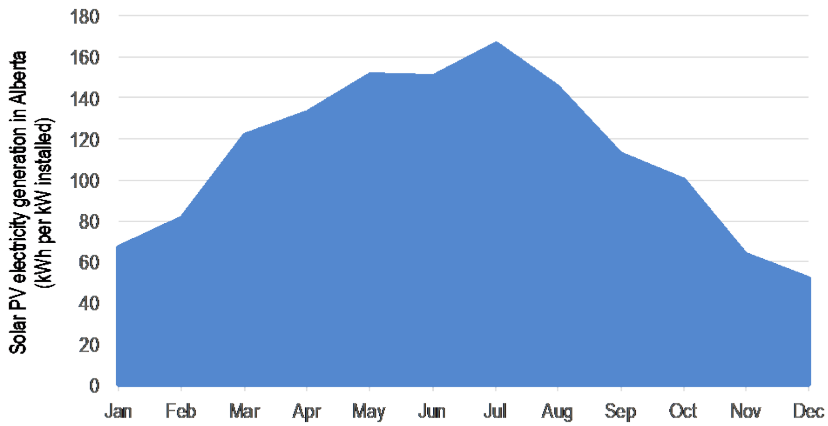

Figure 20: Alberta (Calgary) seasonal variability of solar PV electricity generation. Source: http://pvwatts.nrel.gov/

4.3 Local Property, Built Environment, and Safety Impacts

Glare from solar PV is sometimes cited as a concern among community residents when a new project is developed. However, modules are designed to absorb as much sunlight as possible with anti-reflective coatings, and as a result solar PV systems are less reflective than windows.

The observed impact of solar PV on *property values* is positive — reflecting the value of the electricity produced. Analysis by the U.S. Department of Energy found that homes sold in eight geographically diverse U.S. states between 2002 to 2013 showed market premiums of up to $4 per solar watt installed,[34] or $20,000 to $25,000 for a typical residential solar PV system.

Building-integrated PV (BIPV) embeds the primary system components, PV modules, into building facades, shading devices, roofs and even windows. This largely removes the need for module mounting systems. And for multi-level buildings, BIPV is one way to address the relative decrease in roof space available to power a much larger building by using exterior facades for additional local solar power generation.

33 Green Energy Futures, "19. Sunny solar Alberta," November 7, 2012.
http://www.greenenergyfutures.ca/episode/sunny-solar-alberta

34 Massachusetts Department of Energy Resources, *Questions and Answers: Ground-Mounted Solar Photovoltaic Systems* (2015), 13.
http://www.mass.gov/eea/docs/doer/renewables/solar/solar-pv- guide.pdf; Lawrence Berkeley National Laboratory, *Selling into the sun: Price premium analysis of a multi-state dataset of solar homes* (2015), 29. https://emp.lbl.gov/sites/all/files/lbnl-6942e.pdf

Noise levels are quite limited, especially for small- and community- scale projects. Utility projects using centralized inverters can generate some noise, but this is not usually audible above ambient conditions.[35] Rooftop installs are essentially silent.

Public safety is also cited as a concern due to the risk that additional electrical systems may pose to building occupants and firefighters. Fortunately, these risks can all be mitigated, through preventative measures in system design and installation, and through training of firefighters to work with solar PV on buildings. Building and electrical permitting and approval processes (see Permits, taxes and solar access document) are governed by municipalities and ensure that solar PV is installed according to building, fire safety, and electrical codes and standards.

For concerns around *land use* for ground-mounted solar PV systems, smaller systems of up to 20 MW will use 5 to 8 acres per MW of installed generating capacity. This compares to up to 100 acres per MW for a wind farm; however actual occupied area of turbines is much lower at 1 to 3 acres per turbine. The land use intensity of a coal power plant is less for the actual plant, but much larger when including the surface impacts of mining the coal fuel.[36]

4.4 Global Environmental Impacts and Benefits

Solar PV systems compare very favorably to fossil fuel energy systems across the entire project life cycle[37], including upstream and downstream processes as well as operations. Upstream includes extracting raw materials, manufacturing modules and system components, and installation; downstream includes decommissioning and disposal of system components.

Greenhouse gas emissions — Generating electricity from solar PV in Alberta communities is an important way to help reduce greenhouse gas (GHG) emissions into the Earth's atmosphere. Human activity, especially generating electricity from fossil fuels, causes a rise in atmospheric GHGs. These emissions, measured in units of CO_2e, have increased rapidly in recent decades corresponding with a global change in climate.

Alberta's 2015 electricity consumption was about 80 billion kWh, representing close to 25% of the province's GHG emissions.[38] Replacing 15% of electricity consumption with solar PV would reduce Alberta's annual emissions by 10 million tonnes CO_2e. This is an important contribution to reducing global GHG emissions and helping mitigate human-induced climate change. Owing to the very low emission operation, more than 60% of all GHG emissions from a solar PV system take place during manufacturing. The emissions, about 24 grams of CO_2e per kWh are significantly less than even the most efficient coal plants as shown in Figure 21.[39]

35 *Questions and Answers: Ground-Mounted Solar Photovoltaic Systems*, 13.

36 Ted Nace, "Which has a bigger footprint, a coal plant or a solar farm?" *Grist*, November 18, 2010. http://grist.org/article/2010-11-17-which-has-bigger-footprint-coal-plant-or-solar-farm/

37 Union of Concerned Scientists, "Environmental Impacts of Solar Power," 2013. http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental- impacts-solar-power.html#.WCtsa9yOoac

38 Total GHG emissions from Alberta electricity consumption is based on the provincial internal electricity load (2015) of 80,257 GW. These emissions, about 63 million tonnes CO_2(e), are compared with total provincial emissions of 273.8 reported for 2014.
Sources: Environment Canada, *National Inventory Report 1990-2014. Greenhouse Gas Sources and Sinks in Canada* (2016), Annex 13 Electricity in Canada: Summary and Intensity Tables; Environment Canada,

39 National Renewable Energy Laboratory, *Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics* (2012). http://www.nrel.gov/docs/fy13osti/56487.pdf

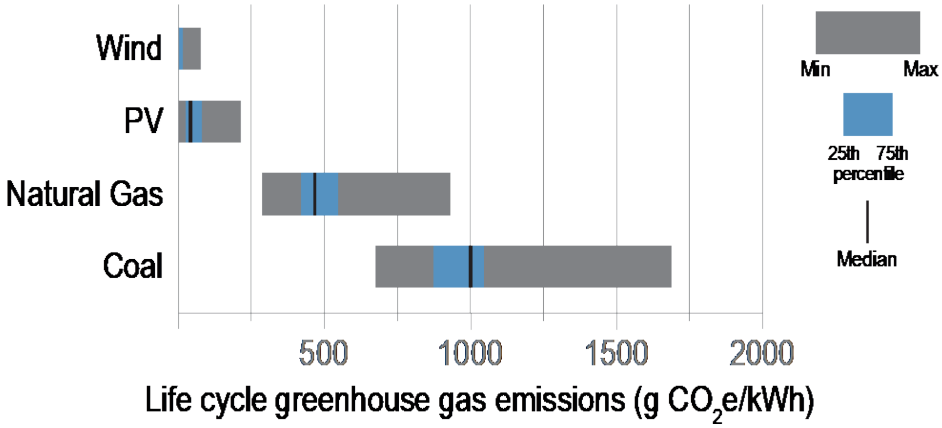

Figure 21: Comparison of life cycle GHG emissions for different types of generators

Water — Manufacture of solar PV system components requires water, but unlike conventional fossil fuel generation, operations do not. The life cycle water use for solar PV is less than 0.4 liters per kWh of electricity generated. This compares to at least 0.8 liters per kWh for gas-fired plants and 1.3 per kWh for coal fired power plants. Solar PV in Alberta would use less than half the water currently consumed per kWh of electricity generated.

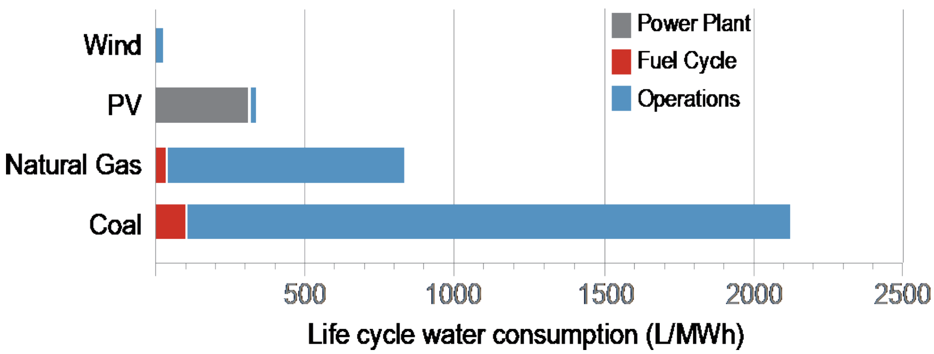

Figure 22: Comparison of life cycle water use for different types of generators.

Hazardous materials — Various hazardous materials are used in the manufacturing process of solar cells. Chemicals including hydrochloric, sulphuric and nitric acids, hydrogen fluoride and acetone are needed to purify the silicon semiconductor material and clean surfaces. Many of these materials are valuable, so they are recycled rather than disposed of.

Other emissions (heavy metals, NO_x and SO_x) — Other emissions from solar PV manufacturing include some heavy metals, nitrogen oxides and sulphur oxides. A 2007 study showed that these emissions are all 90 to 300 times higher for coal-fired power plants with modern particulate controls than for PV technologies studied.

Energy for manufacture and installation — Generating electricity from the sun is free, but some energy was consumed to manufacture the PV modules. The time it takes for an energy system to generate the amount of electricity that was consumed to make and install it is called *energy payback*. Average energy paybacks for typical solar PV range from 0.6 to 1.8 years depending on install location and the type of solar cell materials used.[40] Growing manufacturing efficiency means payback time continues to decline.

5.0 ECONOMICS OF SOLAR PV PROJECTS

5.1 Declining Costs of New Technologies

Declining cost of solar PV means more affordable electricity may be generated locally. But how did prices fall in the first place? Solar PV technology has been around since the 1950s, when the first solar cells were produced by Bell Labs. This cutting-edge technology was later used to power satellites; it is now fully commercialized for power generation at both small and large scales.[41] While the first solar PV systems were less than 4% efficient, some of the latest commercial modules achieve up to 22% efficiency. Meanwhile, the cost to generate electricity from solar PV has fallen more than 90% from 1983 to 2015.[42]

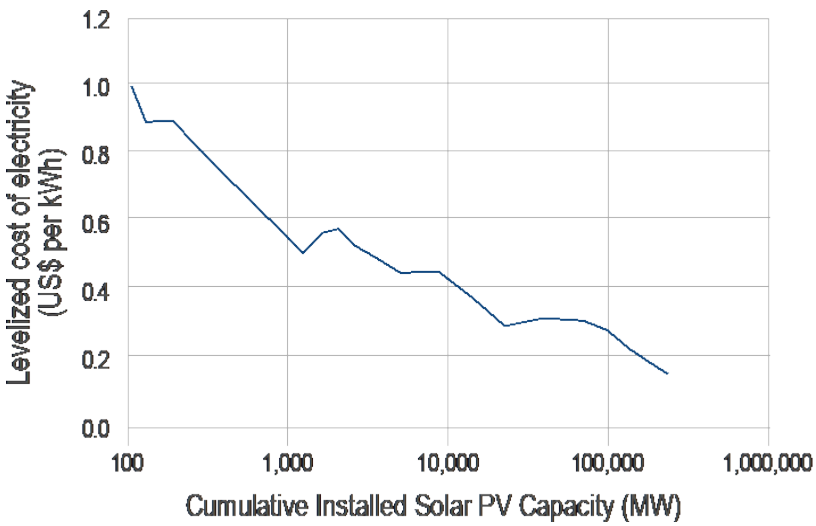

Figure 23: Declining cost of solar PV electricity as installed capacity increases.

[40] Vasilis Fthenakis, *How Long Does it Take for Photovoltaics To Produce the Energy Used?* (Columbia University, 2011). http://www.clca.columbia.edu/236_PE_Magazine_Fthenakis_2_10_12.pdf ; Fraunhofer Institute for Solar Energy Systems, *Photovoltaics Report* (2016). https://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in- englischer-sprache.pdf

[41] U.S. Department of Energy, *The History of Solar*. https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf

While R&D continues and gets a lot of attention, the main driver of these impressive cost reductions is not laboratory research, but simple learning by doing — a phenomenon that applies broadly to all technology innovation. Literature[42] attributes the cost decline to effects like labor efficiency, organizational learning, technology improvements and economies of scale. Price declines for solar PV has been driven by the massive increases in installation around the world. Cost reduction comes from both "hard" costs of technology components, and "soft costs" of sitting, acquiring energy buyers, financing, and construction.

Wright (1936) first observed the relationship between cost and cumulative production by studying the manufacture of aircraft and shipbuilding. This 'learning-by-doing' phenomenon applies broadly across manufacturing and the declining cost of solar is a direct result of cumulative installed solar capacity. Cost reduction comes from both "hard" costs of technology components, and "soft costs" of sitting, acquiring energy buyers, financing, and construction.

5.2 Alberta-Specific Project Costs

The technology, site location, sizing and installation considerations outlined in the previous sections determine the final net cost of the solar system, which consists of the following:

Development
+Materials and construction
+Operation and maintenance
<u>+Grants and financing</u>

= Cost of a solar PV system

1. *Development* — This includes the cost of assessing solar resources, siting, acquiring buyers for renewable electricity, and permit fees. Many of these costs are minimal for projects originating from the customer, such as for small-scale projects. Community-scale projects often experience higher development costs because these need to be sited, and developers need to find local buyers for generated electricity.
2. *Materials and construction* — This includes the cost of equipment (PV modules, inverter, cabling, disconnects, racking, and, if applicable, battery) and construction labor.

   Note that often a solar installer will roll all of the above costs into a total system price, also called "turn- key" price. This would include the cost associated with assessing solar resources and suitability of the site, including roofs and ground.
3. *Operation and maintenance* — Small-scale residential and commercial systems have very minimal maintenance costs as the systems typically require no annual maintenance. The most typical costs come from the need for an inverter replacement after the warranty period of 10-25 years. And increasingly, manufacturers warranties will cover the repair or replacement of components for more than 20 years.[43] The annualized cost of an inverter replacement over the lifetime of the solar PV system is less than $20 per kW of installed equipment per year.

42 Peter Thompson, "Learning by Doing," in Bronwyn Hall and Nathan Rosenberg, eds., *Handbook of Economics of Technical Change* (2008),

43 Sarah Römsch, "Five reasons an extended warranty on inverters pays off," *SMA,* July 9, 2015. http://en.sma-sunny.com/en/five-reasons-an-extended-warranty-on-inverters-pays-off/

End-of-life disposal costs — End-of-life system costs are negligible. While solar PV systems are rated with lifetimes of 25 years, they will continue to produce electricity after that time at slightly lower efficiencies and typically there would be no reason to remove an operating system. For example, the original solar cell from the 1950s is still working at 78% of the initial efficiency. If decommissioning is desired, the components of the system, including glass, aluminum, plastic, copper, and silicon, are highly recyclable.

Among the costs of developing, installing, and maintaining a system, the cost of equipment has dropped most significantly in the last few years. However, the softer costs associated with permitting, engineering, labor etc. remain to be optimized — especially in Alberta. As the solar industry in Alberta matures, these costs are also expected to decrease. Figure 24 summarizes approximate costs for simple PV systems that are installed on the roof without extensive racking (flush-mounted). These numbers are based on estimates obtained from various installers in Alberta.

System size (kW)	Total Costs ($1,000 per kW)	Separated Costs ($1,000 per kW)		
		Development	Construction	Materials
5 to 10	$3.30	$0.36	$0.43	$2.50
10 to 50	$2.80	$0.31	$0.37	$2.14
100 to 200	$2.20	$0.20	$0.30	$1.70

Figure 24: Approximate costs for solar systems (rooftop, flush-mounted) Date source MCCAC[44]

A typical 10 kW solar PV system flush-mounted on a sloped roof cost $30,000 (turn-key) in 2016, but these prices continue to fall, especially as Alberta's solar industry continues to grow. The share of cost belonging to permits, labor, and materials is broken down in Figure 25.

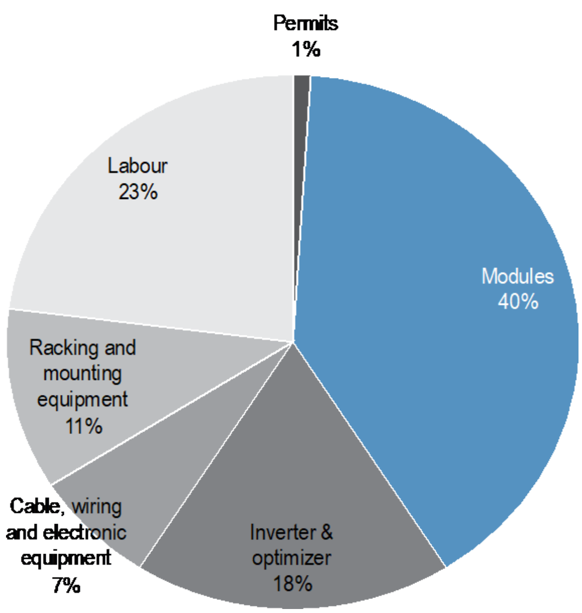

Figure 25: Cost breakdown of typical solar PV project in Alberta

[44] Marc Huot, MCCAC, personal communication, November 28, 2016.

5.3 Alberta-Specific Project Financing and Earnings

The earnings from a solar PV system are a combination of the savings from electricity production, the sale of excess electricity back to the grid, and any production incentives available. Solar projects also benefit from avoiding greenhouse gas emissions, which are increasingly being priced.

Savings on electricity bill
+Earnings from net electricity export to the grid
+Production incentives

= Earnings from a solar PV system

+ Value of avoided greenhouse gas emissions

Savings on electricity bill — Electricity that is generated from the solar PV system and used directly by the consumer is electricity that does not have to be purchased from the utility, so electricity bills will be reduced. The cost savings also includes the value of a solar PV system as a hedge against future electricity price volatility.

Earnings from net export — If the system generates more than the consumption needs of the house/building, that excess energy can be fed back into the grid; solar PV owners are paid for the value of this electricity. The current microgeneration regulation in Alberta allows electric utilities (also called "wire service providers" or "wire owners") to return any earnings (minus the fixed charges such as transmission, distribution and administrative fees) from one month of generation in the bill for the next month. However, only systems sized to meet the electrical consumption needs of the customer are allowed under the current regulation. If this requirement is lifted, a PV system owner could generate a lot more income.

Production incentives — Incentives can be offered to increase the amount of revenue that is earned from each kWh of electricity generated by paying a fixed higher rate or a top-up to the net export rate. In some cases this could include a payment for the renewable attributes of the generation. These include standard offer programs (such as BC Hydro's Standing Offer Program[45]), feed-in tariffs (such as the Town of Banff's Solar Photovoltaic Production Incentive[46]), and establishing utility- or municipal- sponsored REC markets .

Value of avoided greenhouse gas emissions — A price is applied to carbon emissions in Alberta as of 2017. There is therefore an inherent value in producing electricity from emission-free solar PV systems. More generally a cost on carbon emissions can reflect the real costs of inaction on climate change, which would result in increases in other costs such those associated with an increase in extreme weather events. Canada could face annual costs of between $21 billion and $43 billion by the 2050s if action is not taken to mitigate global warming.[47]

However, due to the system used to apply a price on carbon, and the way in which retail electricity prices are set (as an average of instantaneous prices), this value does not translate into a financial payment for solar PV owners. It is possible that in the future mechanisms to recognize this value could be created in the form of offsets/RECs as described above, or through changes to the electricity system pricing.

45 BC Hydro, *Standing Offer Program: Program Rules* (2016). https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/independent-power-producers-calls-for-power/standing- offer/standing-offer-program-rules.pdf

46 Town of Banff, "Solar Power." https://banff.ca/solar

47 Aaron Wherry, "Deputy governor of Bank of Canada warns about climate change, touts pricing carbon," *CBC News*, March 2, 2017. http://www.cbc.ca/news/politics/bank-canada-deputy-climate- change-carbon-1.4007234

6.0 RESEARCH APPROACH & STAKEHOLDERS

Solar PV technology information in this document is based on literature from Canada and the U.S. with input from solar PV design and installation experts from Alberta and other Canadian jurisdictions. Cost information is based entirely on recent Alberta projects. Experts who were consulted include:

- SkyFire Energy: Dave Vonesch, Tim Shulhauser
- HESPV: Ed Knaggs
- Green Sun Rising: Klaus Dohring
- Solas Energy Consulting: Paula McGarrigle

The Canadian Solar Industries Association (CanSIA) was also consulted as an external reviewer.

7.0 CONTACT US

Questions about the toolkit may be directed to:

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