HARNESSING SOLAR ENERGY

Why?
How?
When?

A course for ElderU
by Gerry Pageau, P.Eng.

Lesson 2

This course will teach how Solar Systems are built so you can decide what options you want, how much to do yourself and what to contract out.

Output of 5.75 kW Solar Array on Sunshine Coast (Lower Rd & Hwy 101)

Solar Power Produced by Month			
	Month	**kWh Produced**	
	Jan-2015	175.7	
	Feb-2015	339.0	
	Mar-2015	513.8	
	Apr-2015	808.0	
	May-2015	1052.0	
	Jun-2015	1069.5	
	Jul-2015	1039.9	
	Aug-2015	884.8	
	Sep-2015	712.2	
	Oct-2015	449.2	
	Nov-2015	278.0	
	Dec-2015	102.9	
	Total	**7425.1**	**kWh/yr**
System peak power		5.75	kW peak
		1291	**kWh/yr per kW peak**

Heating Fuel Energy and Cost

Fuel	50 GJ of Energy Per Year				100 GJ of Energy Per Year			
	Low efficiency	Tonnes of CO2	High Efficiency	Tonnes of CO2	Low efficiency	Tonnes of CO2	High Efficiency	Tonnes of CO2
Oil	$1,976.44	5.67	$1,317.63	3.78	$3,952.88	11.34	$2,635.25	7.56
Electricity	$1,321.64	7.54	$1,255.56	7.17	$2,643.27	15.09	$2,511.11	14.33
Natural Gas	$1,086.36	4.73	$628.95	2.74	$2,172.73	9.45	$1,257.89	5.47
GSHP	$627.78	3.59	$418.52	2.39	$1,255.56	7.17	$837.04	4.78

www.fallsbrookcentre.ca

On Sunshine Coast, to produce 100 GJ of energy per year, a 22 kW solar array would be needed. $60k - $70k

Overview of Green Technologies

- Bioenergy
- Run of River Hydro
- Generating electricity with wind turbine
- Ground Source Heat Pump
- Solar Thermal Applications
  - Home hot water heating
  - Pool water heating
- Generating electricity with solar PV array

Freiburg, Germany

Many homes here produce more energy than they consume.

How do you compare?

- The typical Canadian household consumes ~8000 kWh per year (Pembina Institute)
- The average Canadian household consumes 10,880 kWh per year (NRCan Office of Energy Efficiency 2003 Survey)
- Useful figures for quick calculations:
  1 kW average power consumption is about
  25 kWh/day , 750 kWh/mo. , 9000 kWh/year
- The average US household consumes 10,654 kWh per year (USDOE 2001)
- To become net zero the average household would need an 8 kW solar array on Sunshine Coast.

10 kW – 40 panels

More than enough to supply the average household.

Electrical nomenclature

The **volt** (abbreviated **V**) is the Standard International (SI) unit of electric potential or electromotive force. A potential of one **volt** appears across a resistance of one ohm when a current of one ampere flows through that resistance. You can picture voltage as water behind a dam. The higher the elevation the higher the potential.

The **ampere** (SI unit symbol: A), often shortened to "**amp**", is the SI unit of electric **current**. Basically it measures the electron flow moving past a specific point in one second. You can picture amps as water flowing from a dam. The higher the flow, the higher the current.

Electrical nomenclature

Watt: the **power** in an electric circuit in which the potential difference is one volt and the current one ampere. The **watt** (abbreviated W) is the (SI) standard unit of power (energy per unit time), the equivalent of one joule per second. The **watt** is used to specify the rate at which electrical energy is dissipated. You can picture power as the amount of water flowing combined with the pressure of that water. A small amount of water under high pressure can have the same amount of power as a large amount of water at low pressure. 14 HP = 10 kW = peak output of a 40 panel array

Kilowatt Hour: (kWh) the amount of **energy** consumed. It is 1,000 watts of power expended for a duration of 1 hour.

Electrical nomenclature

Watts per square meter (W/m^2) The amount of solar energy reaching the solar cell.

- Typical Sunshine Coast (sea level) peak is about 1000 W/m^2 on clear summer day around noon.
- On cloudy, rainy winter day it may only be in 100-200 W/m^2 range at noon.
- If panel is not at optimum orientation (directly pointing into the sun), then it will receive less energy.
- If panel is dirty or shaded even less energy will reach the cell.
- The cell efficiency is typically in 15-20% range so solar cells are far less efficient than thermal collectors which can reach 80%. That is why thermal HW heating is so much better than using PV to heat water.

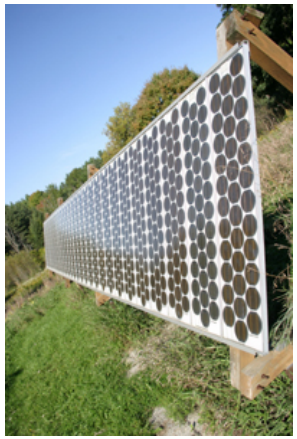
DC vs. AC

- In DC circuits the direction of current flow does not change with time.
- In AC circuits the direction changes at 60 Hz (cycles per second) in North America.
- Large generators generate AC power.
- Converting from AC to DC is easier than from DC to AC
- AC has an advantage in distributing power due to the ease of changing voltages with a transformer and easier switching.
- Power is the product of voltage × current ($P = VI$).
  - For a given power, a low voltage requires a higher current and a higher voltage requires a lower current.
- Since metal conducting wires have a certain resistance, some power will be wasted as heat in the wires. This power loss is given by $P = I^2R$
  - The higher the current, the heavier the wire needed, that is why long distance transmission is done at very high voltage.

Solar PV Terminology

< Cell

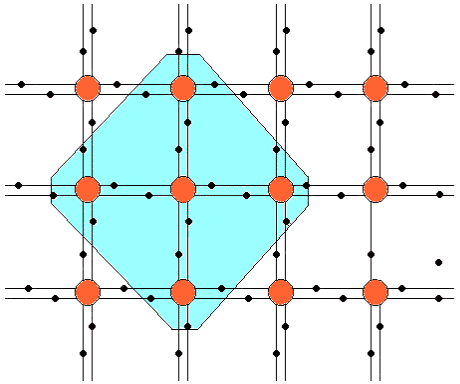
Module >

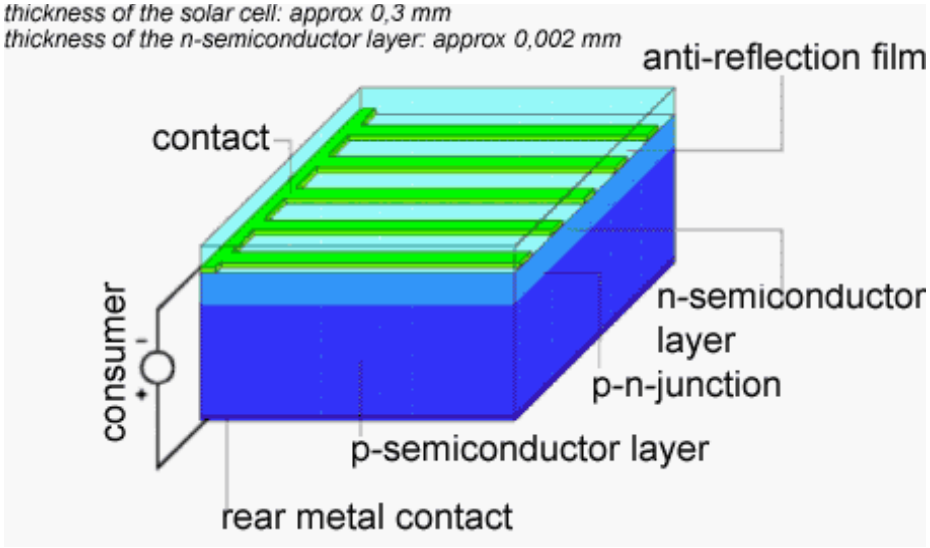


< String

Array >

Solar Photovoltaic Cell





- Photons in sunlight hit the solar cell and are absorbed by semiconducting materials, such as silicon.
- Electrons (negatively charged) are knocked loose from their atoms, allowing them to flow through the material to produce electricity. The complementary positive charges that are also created (like bubbles) are called holes and flow in the direction opposite of the electrons in a silicon solar module.

PV Cell Types

Single Crystal (**Monocrystaline**)

- Single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most *c-Si* panels have uncovered gaps at the corners of four cells

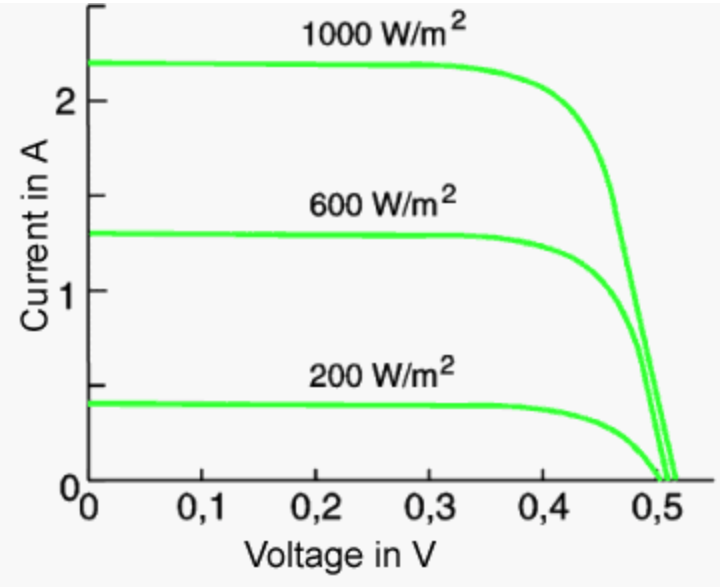
Multi Crystal (**Polycrystaline**)

- made from cast square ingots - large blocks of molten silicon carefully cooled and solidified. These cells are less expensive to produce than single crystal cells but are less efficient.

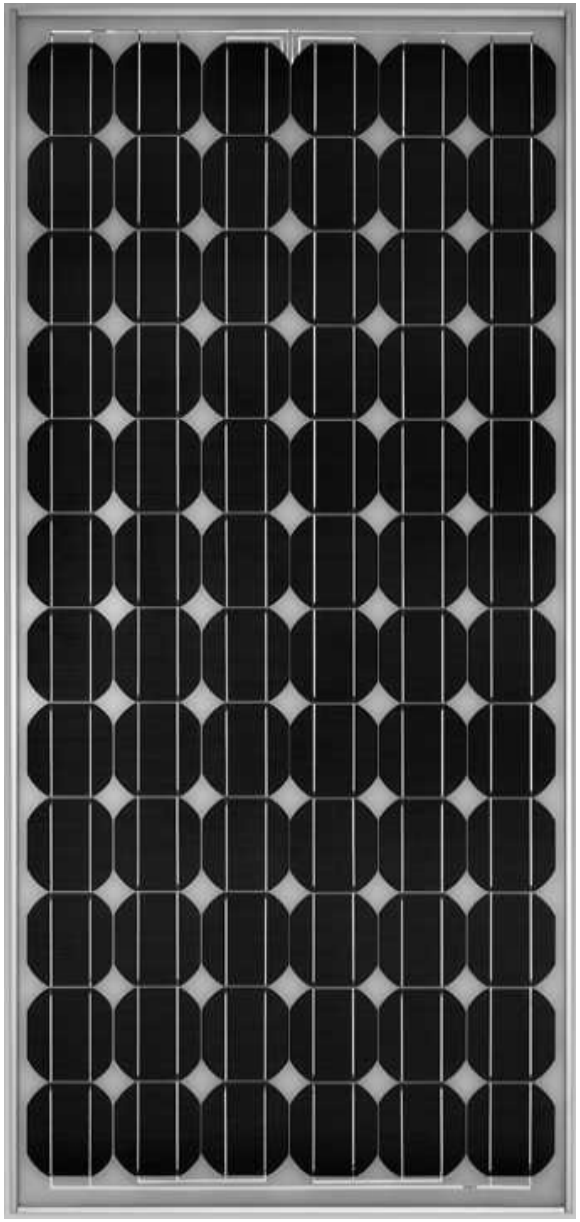
Thin Film (**Amorphous**)

- The various *thin-film* technologies currently being developed reduce the amount (or mass) of **light absorbing material** required in creating a *solar cell*. This can lead to reduced processing costs from that of bulk materials (in the case of silicon thin films) but also tends to reduce *energy conversion efficiency*, although many multi-layer thin films have efficiencies above those of bulk silicon wafers.

Solar Insolation, shading, and temperature impact cell output



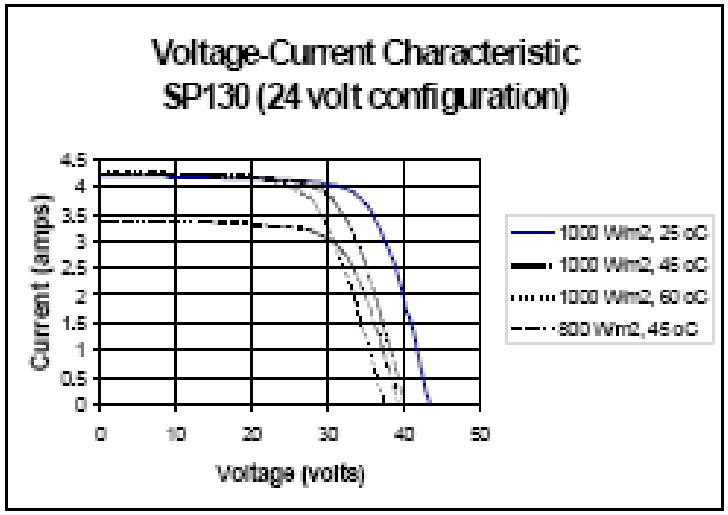
- Shading causes the corner of the curve to become less square.
- Higher temperature shifts the curve left.



Solar module

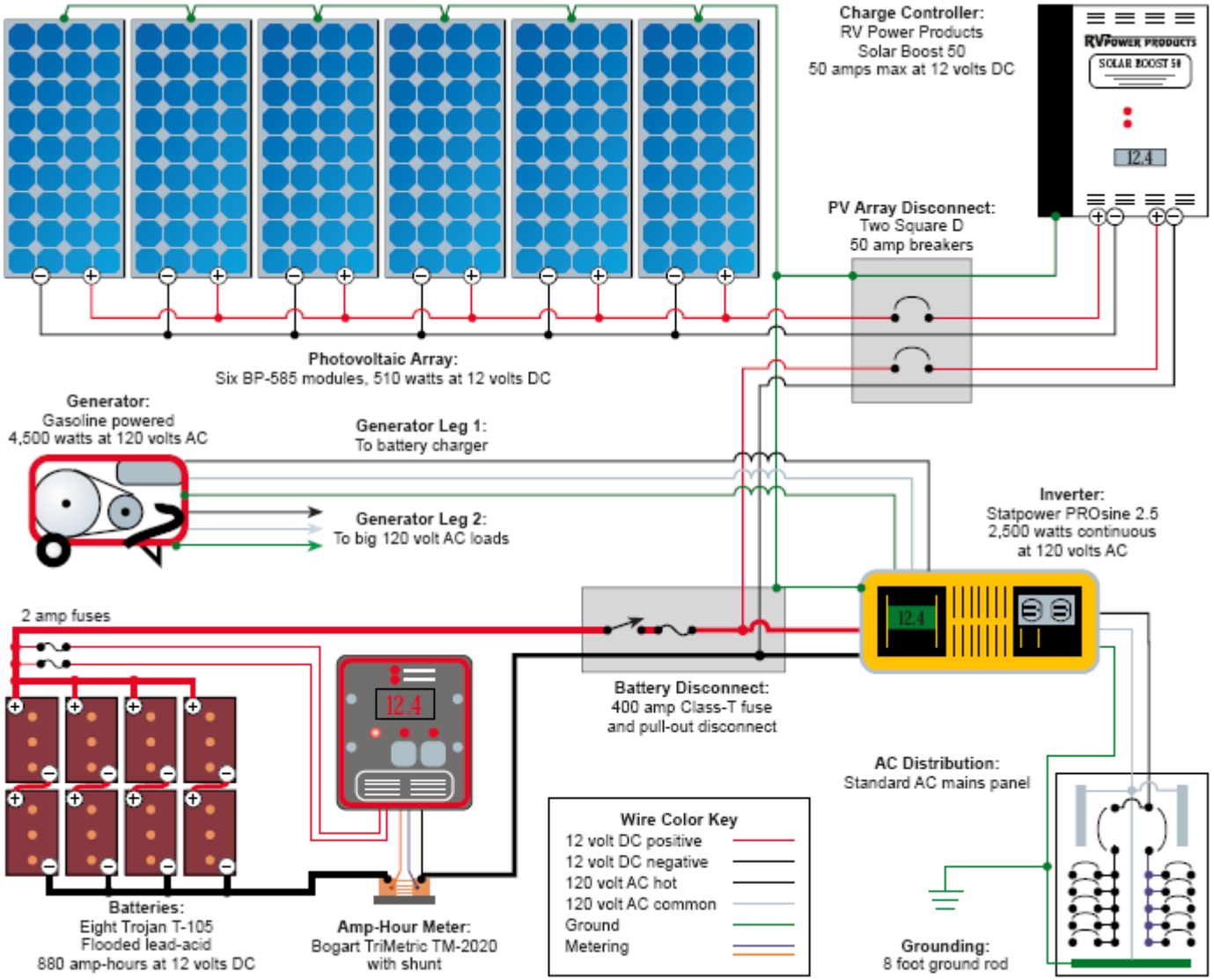
Model:	**SP130**
Rated power:	**130 Watts**
Limited warranty:	**25 Years**

- Module voltage 24 volts
- Single crystalline PowerMax® solar cells, textured for maximum output ratios
- Rugged weather-proof design
- Utility, large project and BIPV applications



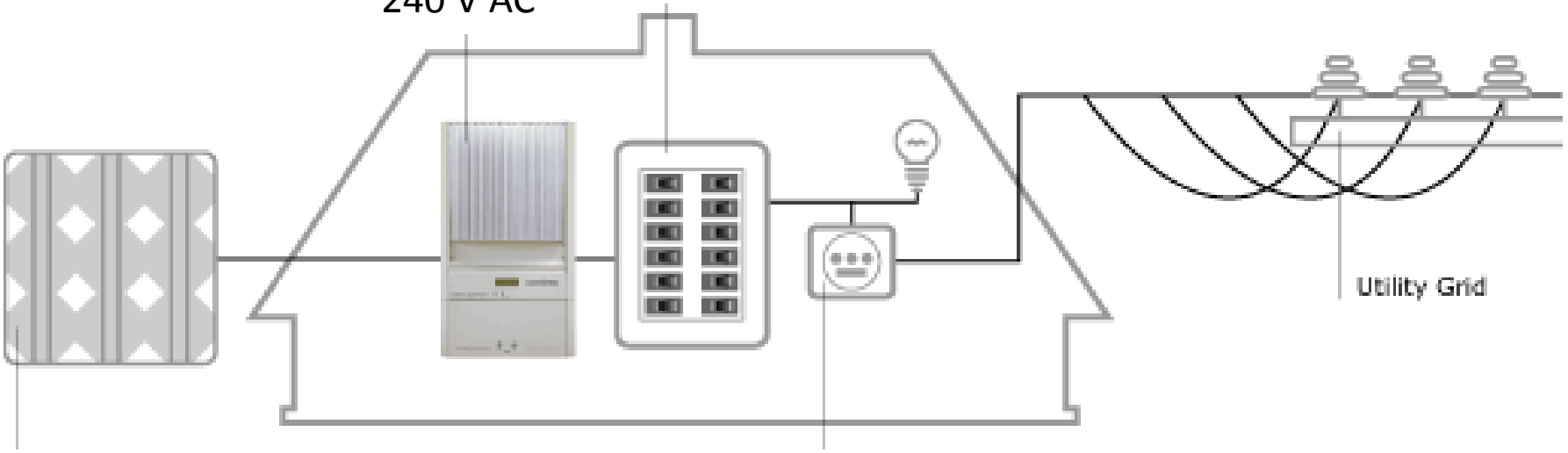
Solar module SP130

Electrical parameters		(24 V)
Maximum power rating P_{max}	[W_p][1)]	130
Rated current I_{MPP}	[A]	3.95
Rated voltage V_{MPP}	[V]	33.0
Short circuit current I_{SC}	[A]	4.5
Open circuit voltage V_{OC}	[V]	42.8


Charge Controller:
RV Power Products
Solar Boost 50
50 amps max at 12 volts DC
RV POWER PRODUCTS
SOLAR BOOST 50
12.4
PV Array Disconnect:
Two Square D
50 amp breakers
Photovoltaic Array:
Six BP-585 modules, 510 watts at 12 volts DC
Generator:
Gasoline powered
4,500 watts at 120 volts AC
Generator Leg 1:
To battery charger
Generator Leg 2:
To big 120 volt AC loads
Inverter:
Statpower PROsine 2.5
2,500 watts continuous
at 120 volts AC
12.4
2 amp fuses
12.4
Battery Disconnect:
400 amp Class-T fuse
and pull-out disconnect
AC Distribution:
Standard AC mains panel
Wire Color Key
12 volt DC positive
12 volt DC negative
120 volt AC hot
120 volt AC common
Ground
Metering
Batteries:
Eight Trojan T-105
Flooded lead-acid
880 amp-hours at 12 volts DC
Amp-Hour Meter:
Bogart TriMetric TM-2020
with shunt
Grounding:
8 foot ground rod

Inverter converts DC to 240 V AC

Main Utility Service Panel distributes 120 V AC and 240 V AC to house circuits



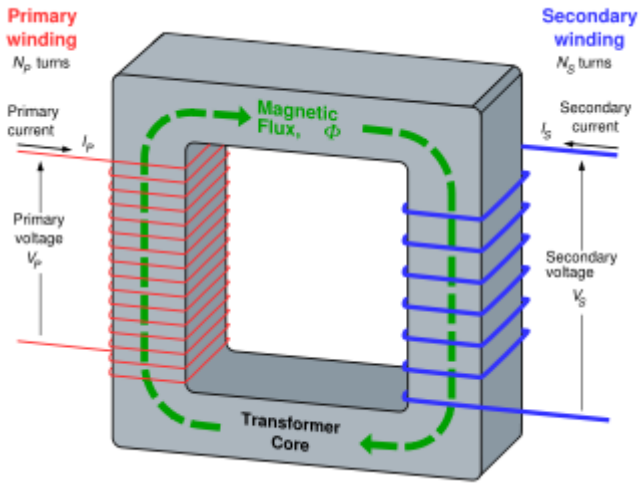
Solar cell puts out 0.5 V DC
Solar panel 12 to 40 V DC
String up to 600V DC

Conventional meter measures energy consumption **from** grid.
Smart meter can also measure energy sent **to** grid

Other Components

- Transformers (changing from one voltage to another)
- Rectifiers (converting from AC to DC)
- Batteries (for grid interactive systems)
- Disconnect/Transfer Switches
- Meters (performance monitoring)

Transformers



Lead Acid Deep Cycle Batteries

- RV, golf carts, renewable energy, and marine (plate thickness)
- Flooded – Sulphuric acid and water electrolyte
- Gel/AGM (Absorbed Glass Mat)
- Typical efficiency in a lead-acid battery is 85-95%
- Expected life of batteries used in deep cycle applications: Starting: 3-12 months, Marine: 1-6 years, Golf cart: 2-6 years, AGM deep cycle: 4-7 years, Gelled deep cycle: 2-5 years, Deep cycle (L-16 type etc): 4-8 years

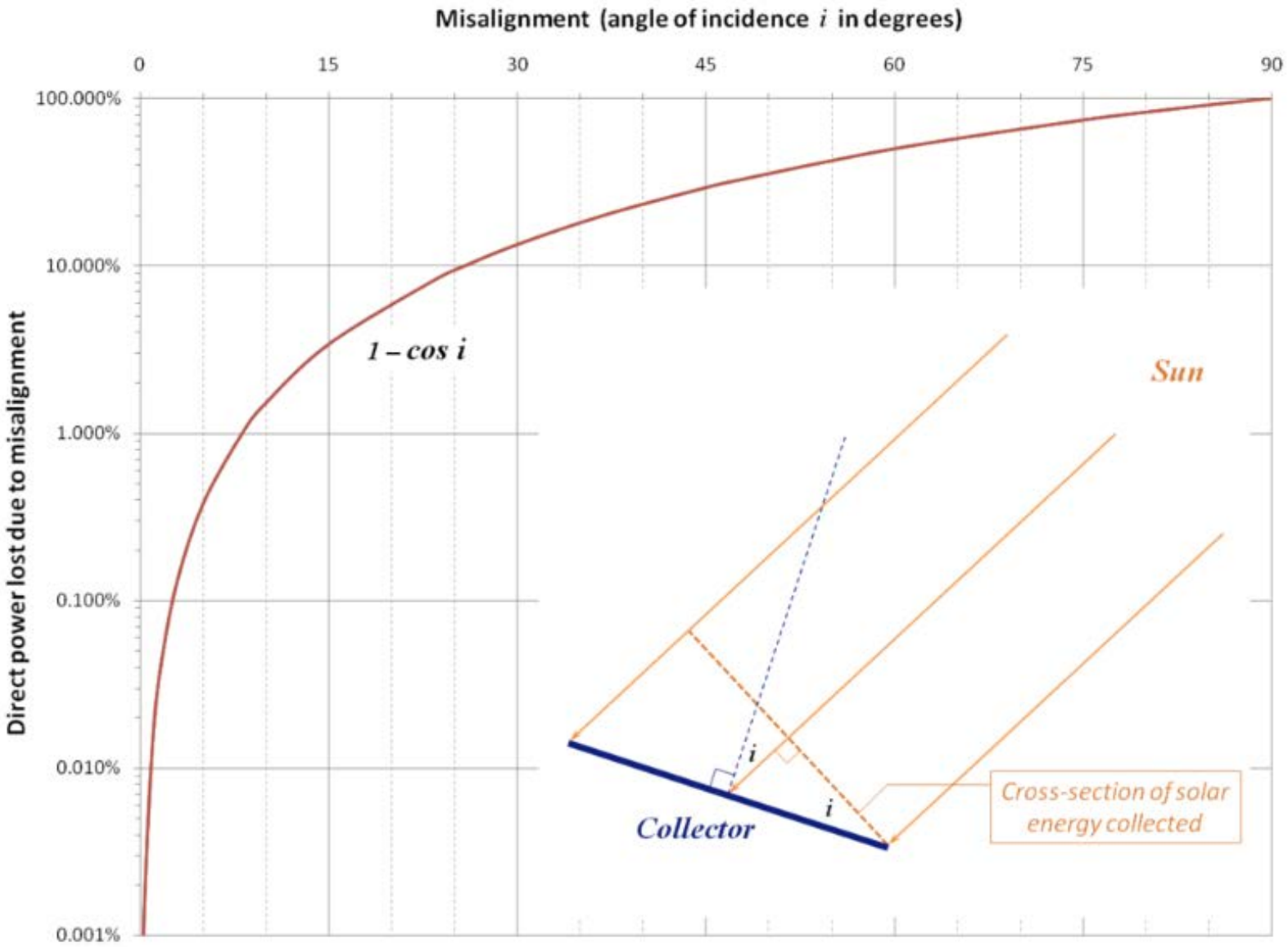
  – http://www.windsun.com/Batteries/Battery_FAQ.htm

What is the potential of your site?

For best performance:

- The panels should be in full sun all day, every day of the year.
- The panels should point directly at the sun
- The panels should be perpendicular to the incoming solar rays.

So a tracking array in location with no shade will provide maximum output from your panels.


Misalignment (angle of incidence i in degrees)
0
15
30
45
60
75
90
100.000%
10.000%
1.000%
0.100%
0.010%
0.001%
Direct power lost due to misalignment
1 – cos i
Sun
i
i
Collector
Cross-section of solar energy collected

Two axis PV Solar Tracker

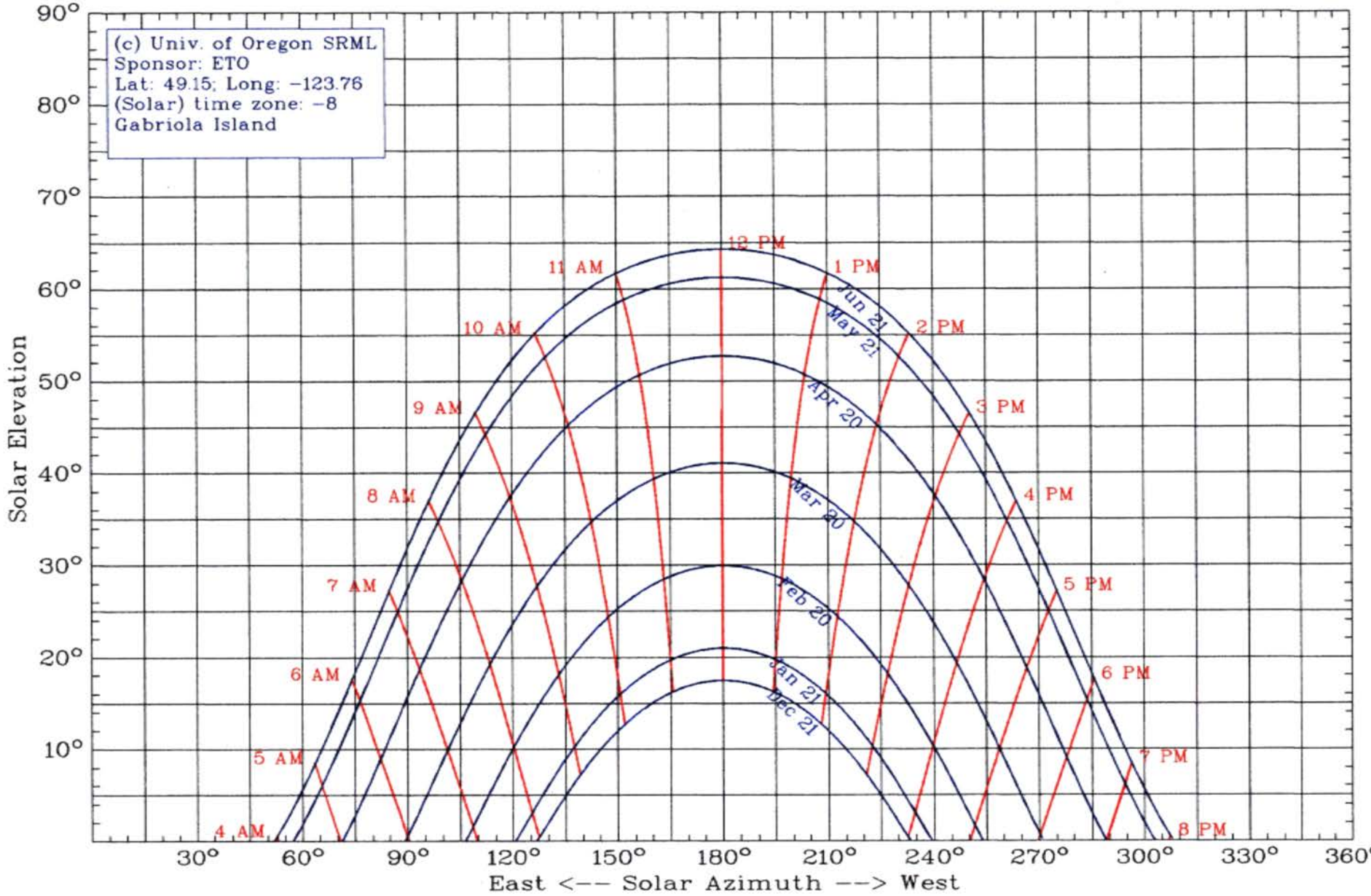
https://en.wikipedia.org/wiki/Solar_tracker

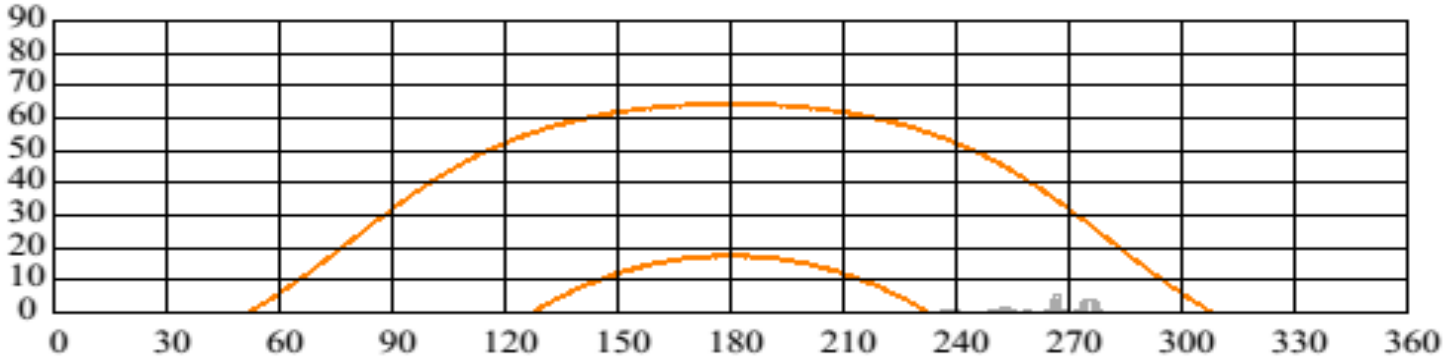
How to maximize panel efficiency.

- A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees to either side, and thus, will lose 75% of the energy in the morning and evening.
- The Sun also moves through 46 degrees north and south during a year. The same set of panels set at the midpoint between the two local extremes will thus see the Sun move 23 degrees on either side, causing losses of 8.3%. A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker.

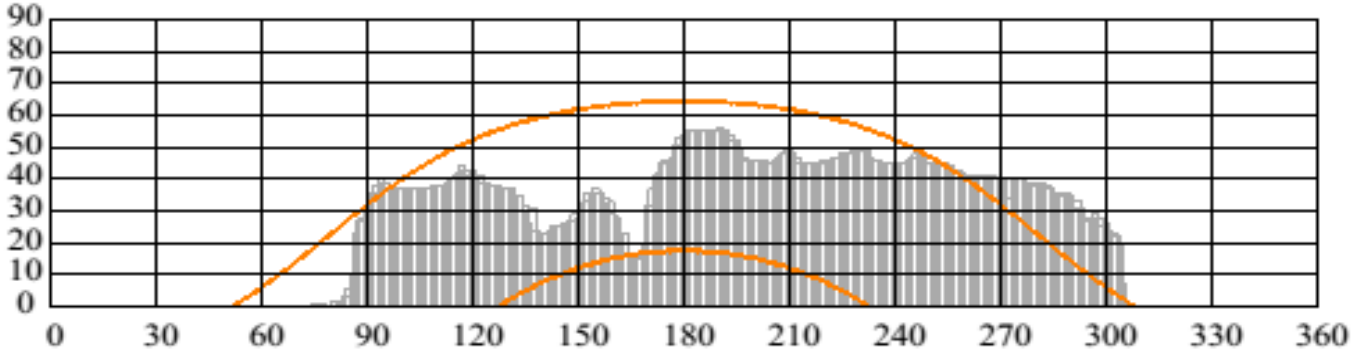
Is tracking worth doing?

- There is 24-32% improvement between a fixed array and single-axis tracker.
- There is a further 4% improvement by going to dual axis tracker.
- When considering capital cost of tracking devices and their ongoing maintenance, it is almost always better to simply add a few panels to fixed array.


(c) Univ. of Oregon SRML
Sponsor: ETO
Lat: 49.15; Long: -123.76
(Solar) time zone: -8
Gabriola Island
Solar Elevation
90°
80°
70°
60°
50°
40°
30°
20°
10°
12 PM
11 AM
1 PM
10 AM
2 PM
9 AM
3 PM
8 AM
4 PM
7 AM
5 PM
6 AM
6 PM
5 AM
7 PM
4 AM
8 PM
Jun 21
May 21
Apr 20
Mar 20
Feb 20
Jan 21
Dec 21
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
360°
East <-- Solar Azimuth --> West



	Solar Energy Actual Tilt: 49 Actual Az:179 No Shade kWh/m sq/day	Solar Energy Actual Tilt: 49 Actual Az:179 Shade kWh/m sq/day	Shade Derating % Captured
January	1.4	1.4	100 %
February	2.8	2.8	100 %
March	3.5	3.5	100 %
April	5.3	5.3	100 %
May	5.6	5.6	100 %
June	5.4	5.4	100 %
July	6.2	6.2	100 %
August	5.8	5.8	100 %
September	5.2	5.2	100 %
October	2.8	2.8	100 %
November	1.7	1.7	100 %
December	1.3	1.3	100 %
Total Annual	3.9	3.9	100 %



	Solar Energy Actual Tilt: 49 Actual Az:179 No Shade kWh/m sq/day	Solar Energy Actual Tilt: 49 Actual Az:179 Shade kWh/m sq/day	Shade Derating % Captured
January	1.4	0.1	6 %
February	2.8	0.2	8 %
March	3.5	0.8	23 %
April	5.3	2.1	41 %
May	5.6	3.9	70 %
June	5.4	4.3	80 %
July	6.2	4.9	79 %
August	5.8	3.2	56 %
September	5.2	1.5	29 %
October	2.8	0.5	18 %
November	1.7	0.1	7 %
December	1.3	0.1	5 %
Total Annual	3.9	1.8	47 %

Net Metering (NM) at BC Hydro

BC hydro
FOR GENERATIONS

- Started in 2004
- Tariff Rate Schedule 1289
- Eligibility:
  - Residential and small commercial customers
  - Up to 100 kW
  - Clean and renewable energy source
- Open application window – come when you are ready
- Simple process, no cost to interconnect to the grid*
- Requires full load displacement before payment (annual basis)
- Annual excess electricity is paid at a rate of 9.99 cents/kWh
- Technical requirements = DGTR/100
- Electricity flow is measured by Smart Meter

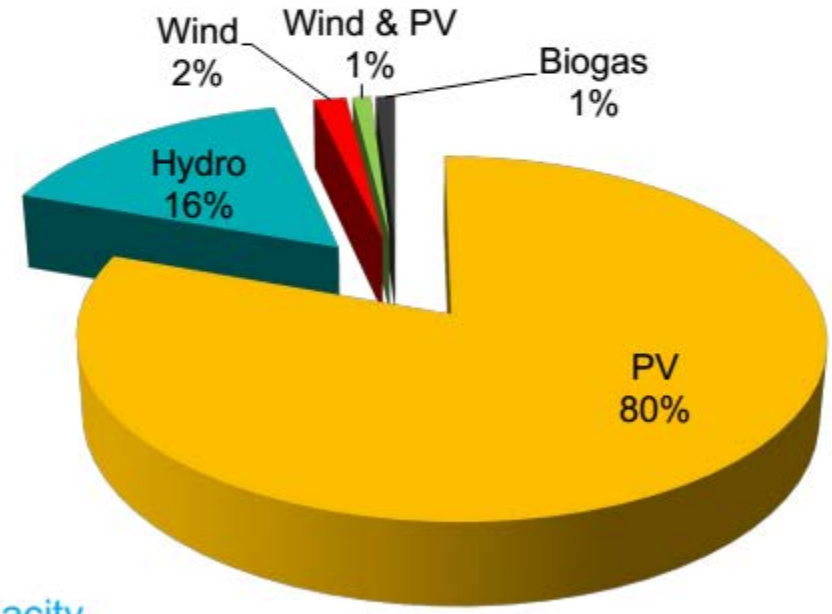
BC Hydro Net Metering in numbers

BC hydro
FOR GENERATIONS

As of November 2014:

371 NM customers – 2 MW installed capacity:

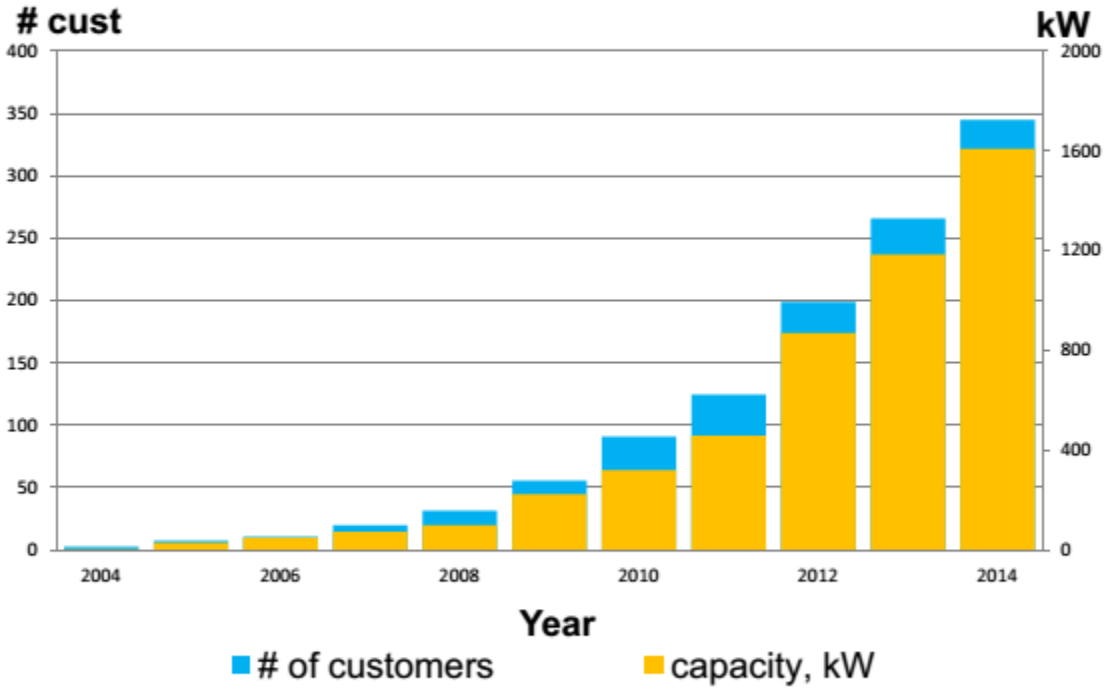
- 345 solar PV
- 12 Hydro
- 9 Wind
- 4 Wind & PV
- 1 Biogas



By Installed Capacity

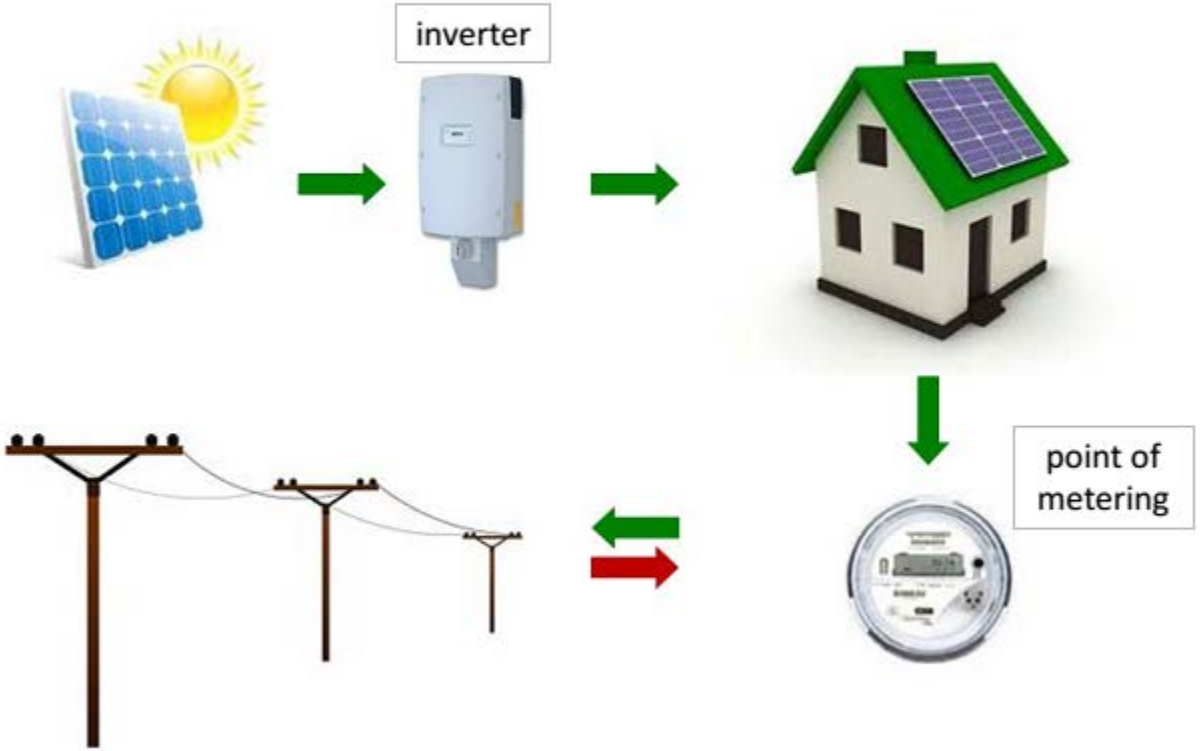
Solar PV Growth in BC

BC hydro
FOR GENERATIONS



What is Net Metering?

BC hydro
FOR GENERATIONS



Smart Meters

BC hydro
FOR GENERATIONS

ELECTRICITY CONSUMPTION

When '01' appears in the top left corner, the smart meter shows your total electricity consumption since the meter was installed - measured in kilowatt hours.

A kilowatt hour is a unit of electrical consumption equal to the amount of electricity needed to burn ten 100-watt light bulbs for one hour.

ELECTRICITY GENERATION

When '02' appears in the top left corner, the smart meter shows the net amount of electricity generated at your home or business if you have small generating units such as solar panels.

BC Hydro able to offer programs, enabling you and your community to generate power for your own use and sell excess electricity back to the BC Hydro.

http://www.bchydro.com/energy-in-bc/projects/smart_metering_infrastructure_program.html#how meters work

NM Billing

BC hydro
FOR GENERATIONS

- Inflow (net consumption)
- Outflow (net generation)
- Billed on net of inflow and outflow:
  - If *inflow* > *outflow* -> charged for *inflow* – *outflow*
  - If *outflow* > *inflow* -> bill $0, *outflow* – *inflow* -> credit to Customer Generation account

NM Billing – Net Inflow

BC hydro
FOR GENERATIONS

BC hydro

Prepared For
JOHN SOLARIS
111 WELLKNOWN ST
VICTORIA BC V8Z 1P3

Billing Date	Account Number
Oct 09, 2014	XXXXXXX
Pay By	**Please Pay**
Oct 31, 2014	**$99.16**

Invoice Number:
XXXXXXXXXX

Meter Reading Information

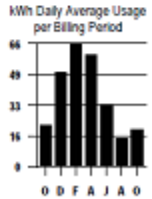
Electric:

Meter #	1234567
Aug 08	16000
Oct 07	17228
61 days	1228

Electric Outflow:

Meter #	1234567
Aug 08	1100
Oct 07	1257
61 days	157

Next meter reading on or about Dec 04



Daily Average Comparison

Oct 2013	22 kWh
Oct 2014	20 kWh

Previous Bill

Balance payable from your previous bill	68.59
Thank you for your payment Aug 14, 2014	68.59CR
Balance from your previous bill	**$0.00**

BC Hydro **Electric Charges**

Aug 08 to Oct 07 (Residential Conservation Rate 1101)	
Basic Charge: 61 days @ $0.16640 /day	10.15*
Energy charge:	
Step 1: 1061 kW.h @ $0.07520 /kW.h	79.79*
Rate Rider at 5.0%	4.50*
* GST	4.72
	$99.16

Customer Generation Account (Net Metering Rate 1289)
Previous Balance: 10 kWh Current Balance: 0 kWh

Taxes

The following is a summary of taxes billed to your account since your last invoice:

GST at 5 % on 94.44	4.72

Balance payable	**$99.16**

Thank you for keeping your account up to date.

NM Billing – Net Outflow

BC hydro
FOR GENERATIONS

BC hydro

Prepared For
JOHN SOLARIS
111 WELLKNOWN ST
VICTORIA BC V8Z 1P3

Billing Date	Account Number
Oct 09, 2014	XXXXXXX
Pay By	**Please Pay**
Oct 31, 2014	**$11.18**

Invoice Number:
XXXXXXXXXX

Meter Reading Information

Electric:

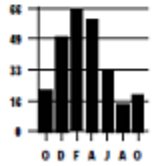
Meter #	1234567
Aug 08	16000
Oct 07	16000
61 days	0

Electric Outflow:

Meter #	1234567
Aug 08	1100
Oct 07	1257
61 days	157

Next meter reading on or about Dec 04

kWh Daily Average Usage per Billing Period



Daily Average Comparison

Oct 2013	22 kWh
Oct 2014	20 kWh

Previous Bill

Balance payable from your previous bill	68.59
Thank you for your payment Aug 14, 2014	68.59CR
Balance from your previous bill	**$0.00**

BC Hydro **Electric Charges**

Aug 08 to Oct 07 (Residential Conservation Rate 1101)	
Basic Charge: 61 days @ $0.16640 /day	10.15*
Energy charge:	
Step 1: 0 kW.h @ $0.07520 /kW.h	0.00*
Rate Rider at 5.0%	0.50*
* GST	0.53
	$11.18

Customer Generation Account (Net Metering Rate 1289)
Previous Balance: 10 kWh Current Balance: 167 kWh

Taxes

The following is a summary of taxes billed to your account since your last invoice:

GST at 5 % on 10.65	0.53

Balance payable	**$11.18**

Thank you for keeping your account up to date.

NM on MyHydro

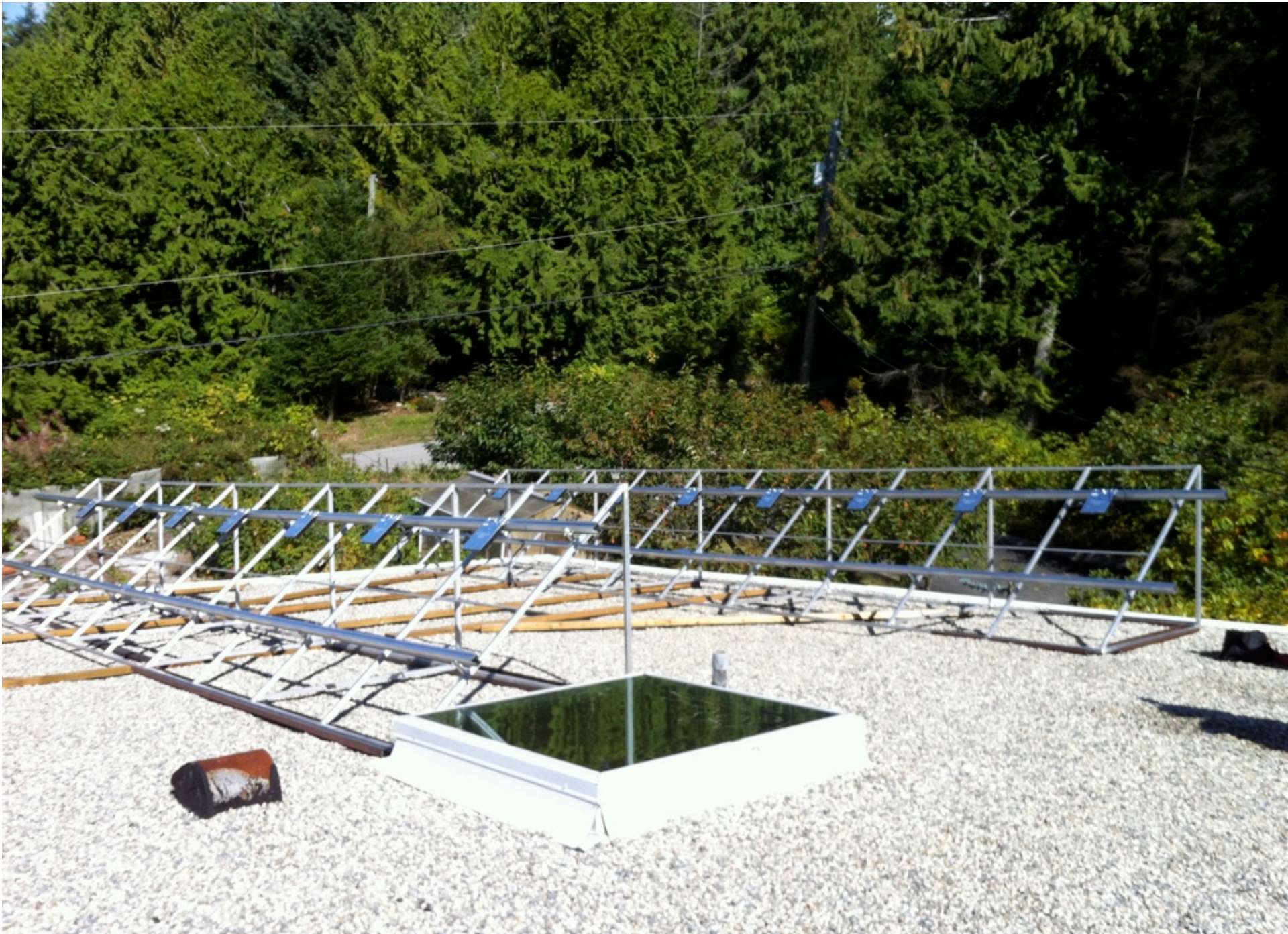
BC hydro
FOR GENERATIONS

https://www.bchydro.com/accounts-billing/customer-service-residential/understand-electricity-consumption-residential/understand-your-net-consumption.html

Recent Changes to NM

BC hydro
FOR GENERATIONS

- ✓ Increased maximum size of generators eligible under NM to 100 kW
  - Requires professional design and installation
  - P.Eng seal requirement
  - Incremental costs




Residential
Solar Power:
- good for the environment
- good investment where return
grows as energy cost rises


PROTECT YOUR ASS