Accurately Predicting and Optimizing Yield Factors which impact Financial Efficacy of Solar Arrays

A White Paper on behalf of potential purchasers of PhotoVoltaic Arrays

Thomas Cleland, B.Sc Eng, LE, ET, EET
Thomas.Cleland@HybridynePower.ca

Co-Authored by
Richard J Leverton BSc.

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1 Executive Summary

This paper is written in terms that apply primarily to Ontario, Canada, but virtually all of the information will be of use in most jurisdictions.

The first question which invariably comes up in the early stages of considering a Solar Array (for example, one to supply electricity to the grid under Ontario's Feed In Tariff (FIT) program), is that of " how much will it earn ? and how long will it take to pay back the investment ".

Unfortunately, the Renewable Energy Industry has attempted to answer these questions in 'end user' terms and as a result, often supplies misleading information. Thus, the term " Sun Hours " is much in vogue, and much of the prediction of yield is explained ONLY on Sun Hours, without taking into consideration the other factors which also contribute to the calculation of yield.

This paper will discuss all the factors involved and give the prospective purchaser or financier an accurate and meaningful methodology for anticipating how much a proposed solar array should earn.

2 Some Terminology :

1. **Insolation** – "Insolation is the amount of solar energy hitting a surface over time. It is usually referred to as megajoules per square metre, peak sun hours, or kilowatt hours per square metre. One megajoule per square metre divided by 3.6 equals one kilowatt hour per square metre. To determine power output for your situation, insert the insolation values for your area, and multiply by the power rating of your array."
   Source : Natural Resources Canada
2. **Sun Hours** – again, according to Natural Resources Canada, Sun Hours is just a measure of Insolation – how much sunlight is hitting the ground at your location during an average day.
3. **Raw Energy** – the Renewable Energy Resource being captured . That is, the amount of sunlight reaching a solar panel's location, usually expressed as Insolation - the amount of solar energy received on a given area over time measured in watts or kilowatt-hours per square meter (kWh/m2).
4. **Collection Technology** or Collection Device – the mechanical/electrical device which captures 'raw' energy (wind, sun, water movement)
5. **Unrefined Electricity** – the electricity as produced by the Collection Device(s) – normally in a form which cannot be directly sold to the grid or used by consumers
6. **Nameplate Ratin**g – the advertised output of the Collection device under "perfect" conditions. This is usually a measure of Unrefined Electricity
   a. a wind turbine might be advertised as 1 MegaWatt or 5 Kilowatt
   b. a solar panel might be described as 170 Watts peak
   c. a biogas turbine might be rated at 300 Kilowatts peak
7. **Usable Electricity** – electricity converted to a format which can be used (sold)
   a. For an Energy Park©, selling electricity to the grid, this will be defined as 60 Hertz (cycles per second) (in North America) at a particular voltage, say 27,600, or 4800.
   b. For use in a factory or other building, this will be defined again at 50 or 60 Hertz, and at a particular voltage, for example 120/240, 120/208 , 240/380 277/480, 600/347 etc.
8. **Conversion/Inversion** – the process of converting Unrefined Electricity into Usable Electricity
9. **Capacity Factor** – the means of predicting and then measuring how efficiently (or completely) the Raw Energy was converted into Usable Electricity. Also known as "Capacity Factor.
10. Harvest or **Yield** – the number of KiloWattHours (kWh) of electricity generated per year. Since electricity is sold in units of KiloWattHours, **this is the ONLY measurement of a system which has any validity in financial terms**.
11. **MPPT** – **M**aximum Power **P**oint **T**racking is a process by which the input side of the inverter periodically samples the connected PV array, to determine its capability to deliver current. This sampling is coupled with the array's capability to produce Voltage potential.
12. **MTBF – M**ean **T**ime **B**efore **F**ailure – the number of hours or years a component (for example an inverter) is designed to operate before it needs to be replaced
13. **MTTR– M**ean **T**ime **T**o **R**epair – the amount of time in minutes or hours required to repair a fault or failure

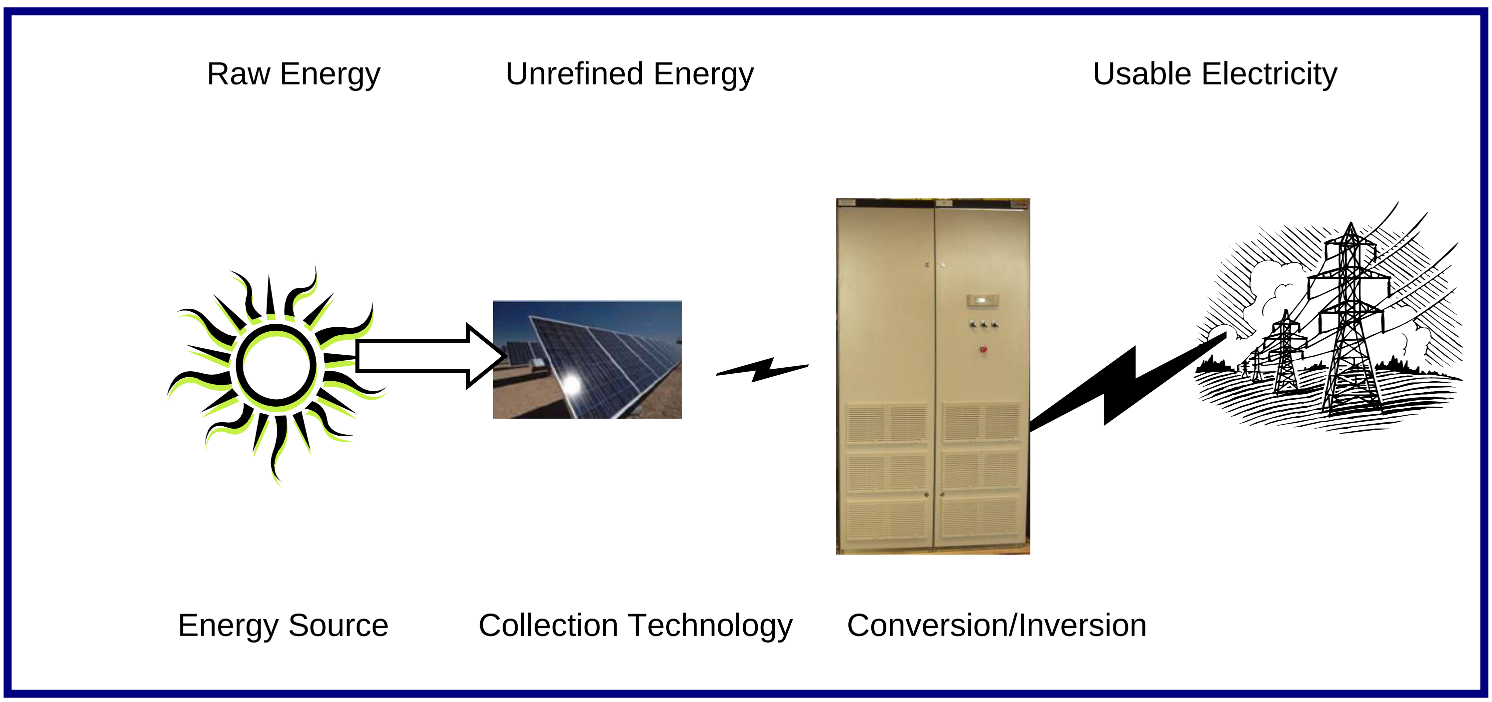
3 Factors driving Yield

Just as a car is more than just an engine and a house is more than just a furnace, a Renewable Energy system is more than just a solar panel. The Renewable Energy System has a single purpose (to generate electricity) but has many components with many independent functions. To maximize the profit (" the Yield ") of any Renewable Energy System, one must be cognizant of the *Renewable Energy System Equation.*

This Equation is a completion of earlier relationships which dealt with only Wind power. With the advent of modern Hybrid systems, the full relationship between all forms of Renewable Energy and the output electricity yield needs to be explored and explained.

We will not discuss the Equation in this document – it has been previously explained in a White Paper entitled ***The Renewable Energy System Equation , document number WMKWHPR0001.***
Suffice it to say that the Equation is part of the calculations determining Yield.

Yield is the product of the raw " Nameplate Rating " of the array multiplied by the Capacity Factor (discussed in the next section).



3.1 θ_N - Capacity Factor

The Capacity Factor of a Collection Device is expressed as a *percentage or multiplication factor less than 1, to be applied to* R_N *(the Nameplate Rating of the device)* . The factors that come into play to determine this percentage are :

- different for each technology
- all related to the utilization of the resource (wind, solar, etc)
- all related to losses in the system, (magnetic, mechanical, junction-resistance, IR heat etc.)
- the efficacy of the conversion electronics (in the case of PV, that would be the inverter)

Thus, Capacity Factor expresses the expected yield of the device in use, where Nameplate Rating only expresses a theoretical maximum.

It must be made perfectly clear that when purchasing Renewable Energy equipment / system, the wise purchaser will only deal with Capacity Factor (effective yield) , and use that factor to calculate the number of KiloWatt hours per year and will not be misled by claims related to Nameplate Rating only.

The Utility-Scale Wind Power industry has been rating its turbines with a Capacity Factor for many years. A given turbine may have a Capacity Factor of 0.25. That means that on the average, it will deliver 25% of its Nameplate Rating over the whole year.

Capacity Factor can also be related to PhotoVoltaics as follows.

Capacity Factor (θ_N) for PV is a site-specific multiplier, and is derived from:

- average solar Insolation at a particular location - not something that can be changed
- illumination at a specific time of day - not changable
- panel efficiency (now in the 20% range) - maximized by manufacturer
- orientation of the panels - can be optimized by the installer
- Thermal degradation - can be mitigated by panel product choice
- **conversion and delivery losses** - something that **can be reduced**

For most currently available PhotoVoltaic Solar panels now in use, with conventional inverters and no mechanical tracking system, the Capacity Factor is usually about .125 - .135 (0.13 seems to be the average). This factor is latitude dependent, since the capacity factor is always dependent on the insolation at that latitude.

Remembering the Energy Equation, then, the Annual Yield or Energy Harvest of a 170 Watt solar panel would be calculated as :

Yield = Nameplate * Capacity Factor * Hours per Year
= .170W * 0.13CF * 8760hrs
= 193.596 KiloWattHours per year

Recently however there has been a move to expressing an array's output based on annual output per KW installed. In this case the output would be calculated as :

kWh / kW installed = 1kW of Array Nameplate * Capacity Factor * Hours per Year
= 1000W * 0.13CF * 8760hrs
= 1138.8 KiloWattHours per year

Therefore, the purchaser of any PV array, when calculating his expected earnings, should keep several things in mind :

1. those earnings will be paid at so many dollars per KiloWattHour, not so much per Watt installed
2. use the installer's Capacity Factor to determine yield. If your installer doesn't know what his Capacity Factor is, perhaps you need to find a more knowledgeable installer/developer

3.2 Factors Determining Capacity Factor

Capacity Factor (how much energy and income you can expect from a solar array) is driven by the following factors :

3.2.1 Insolation

The insolation at a particular location is outside the control of the owner or the installer of the array. It is determined mostly by latitude (how far from the Equator the array is), and also by local climactic conditions like cloud cover , humidity and suspended particulate pollution. This White Paper is being written as a response to the unfortunate perception that insolation (Sun Hours) is the only contributing factor. As you will see, that is not the case.

3.2.2 Yield of the Conversion/Inversion process

Another unfortunate result of the drive to 'simplify' the yield calculation process is the implicit assumption that " all inverters are the same ", and therefore there is no need to differentiate between inverters when deciding how much yield you can expect from a solar array.

Alas, this oversimplification is fatally flawed. Some inverters are much better than others in all of the characteristics that effect the economics of a solar array :

1. efficiency – The term efficiency as it relates to PV inverters is often confused with "efficacy". An inverter can be very efficient without being very effective, however it goes hand in hand that an inverter that is very effective, is also efficient.
   Efficiency can be defined as "how much does a machine lose" in energy, when doing its job. Efficiency is expressed as a percentage and is only related to losses. To put this in perspective, because this always comes down to money …
   - If you put a product worth $1M / yr into a device, and that device has an overall efficiency of 96.04%, then you will lose $39,600 / yr
   - On the other hand, if the device is 97.21% efficient, then the loss is only $27,900.00 which is a delta or savings difference of $11,700.

   See the discussion about Efficiency in the next section.

2. efficacy – would be defined as how well or effectively does the machine do THE job with ALL of the available energy presented to it. What makes that machine effective or ineffective ? If there is "X" energy available to be converted, how much of it can the machine get at ? This is always going to be something less than 100%
   See the discussion about Efficacy two sections down.

3. Voltage Window – as it refers to inverters is the device's "voltage opportunity" window. That is, if a device can convert power and MPPT from 300 – 600VDC presented to it from an

array, then its Voltage Window is 300V or 50% of the possible 600VDC. Similarly if a device can operate from 90 – 600VDC then it's Voltage Window is 510V or 85% of the possible 600VDC. Obviously a device that has a larger or broader Voltage Window is going to be more effective throughout the available Voltage opportunity . See section 3.2.8 for an example.

4. MTBF – Obviously, the longer a device lasts, the less it costs in replacements over the whole life of the system. MTBF is calculated differently by different manufacturers. Most Utility scale inverters have a real lifespan of 10 – 12 years , not because they can't last longer, or can't be made to last longer, but simply because the environments they are installed in are hostile (too hot or too cold, and too damp). A 10 – 12 year MTBF is 87660 hrs – (or 22 yrs for a PV inverter that only operates 12 hrs per day average). The manufacturer may have calculated more, but this would be in ideal conditions, for example 200,000 hrs (40 years, for a PV inverter operating 12 hrs per day average).
5. MTTR – the longer a component takes to repair, the longer the array or part of it is down, and the more it costs in lost revenue and hourly repair fees. Look for inverters with 'hot swappable' components or power drawers, where the whole or major component unit can be swapped out in 15 minutes or less.

Simply put, even if one Converter/Inverter may cost (let's say) 10% more than another, if it delivers (let's say) 30% more electricity per year and lasts longer before needing to be replaced, then that better Converter/Inverter is a much better investment. And often the ROI on that incremental investment would be in the order of months.

3.2.3 Efficiency of the Conversion/Inversion process

Efficiency is a simple mathematical calculation
P_{in} / P_{out} X 100 = Efficiency in % - where P_{in} is power input , P_{out} is power output

For more complex systems , where there is more than one component connected in series to perform an overall task, the formula is :
Overall Round Trip Efficiency = Eff of Dev #1 x Eff of Dev # 2

For example
The inverter is connected to a transformer to deliver the power to the grid at the appropriate grid voltage. An inverter output section has an efficiency of 98%, and the transformer has an efficiency of 98% as well, therefore the efficiency of the system is .98 x .98 = .9604 or 96.04 %

Obviously a little more or less in either case means a lot to the overall outcome.
If both efficiencies are a little higher … then : 0.984 X 0.988 = .9721 or 97.21 %

In the case of an inverter system efficiency can make a big difference per MW of energy produced from PV panels. The product "in" is the energy from the panels, and you only get paid on the energy that is coming <u>out</u> of the other end (grid connection).

If an array would make $5M per year (if the inverter were 100% efficient), that 1.17% difference in efficiency (from 96.04% to 97.21% means the array earns an extra $58,500 per year.

Thus

- if you had to spend an extra $200,000 during the construction of the project to get a transformer output system that was ***only 1.17%*** more efficient than a competitor's cheaper offering, the ROI on the difference in cost is $200,000 CapEx / $58,500/yr = 3.41 years
- if we look at a 20 year life of the project after this incremental difference is paid for, that transformer will earn the owner $ 970,515.00 extra (16.59 yrs remaining x $ 58,500), and that's just for an efficiency increase of 1.17 % in only one component .

So efficiency is a major factor, but there are even bigger considerations !

3.2.4 Efficacy of the Conversion/Inversion process

Again, Efficacy is defined as would be how well or effectively the machine does THE job with ALL of the available energy presented to it.

To relate efficacy of PV inverters with PV arrays, let's use an example :

- Assume a 1Mw array using 18% efficiency panels

  Note: the term efficiency in this context means that based on 1000 Watts/Sq M of sunlight on the earth's surface, (at 25 degrees C and zero angle of incidence) the panel will capture 18% of it, or 180 watts / panel.

  Or

  Of all of the possible sun on the ground where there are panels correctly installed, the array can capture 18% of it.

- However
  - Let's remember that it is only 1000 watts per sq meter for a few hours around noon on a cloudless day.
  - There are cloudy days, snowy days, rainy days, and all of the time between noon and morning and noon and evening when the intensity is not 1000 Watts/Sq M, but instead something often much less.
- An effective inverter system should be able to convert 97%+ of the energy produced from the panels at high noon, or 970 KW for that hour or 970 kWh.
  - Sounds great in principal, but in Canada , for example, how many days are ideal like that ?
  - The question is not how **efficient** the inverter is in the ideal case (almost any inverter makes the grade at high noon) the question really is how **effective** is it under cloud, snow, rain, evening and morning.

A Silicon PV panel generates Voltage potential and a corresponding availability of current when exposed to sunlight. As the sunlight or intensity of light is increased or decreased, the panels output voltage increases and decreases proportionately with irradiation.

A single panel typically does not produce enough power (or rather Voltage and Current) to warrant connection to a single inverter. But, there are micro-inverters on the market today that do just that, and micro-inverters are a different discussion which applies to small scale arrays only.

In general then, PV panels are connected in strings. Strings are created to series-connect the voltage potential to get it to a level where it makes sense to the input of an inverter.

Max String Voltage $= P_1V + P_2V + P_3V + P_NV$ (where $_N$ is some number of panels required) .

However there are limitations to the string voltages.

- In North America Underwriters laboratory (UL), Canadian Standards Association and the IEEE (Institute of Electronic and Electrical Engineers) have determined that this maximum level is 600VDC
- In Europe the governing bodies there have determined that theirs is 1000VDC
- This means that inverters and arrays built in these areas must follow these respective and very different guidelines.

Simply put, the moment the PV panel or string of panels is exposed to sunlight, or even ambient daylight (dawn), it produces some PV (Photo Voltaic) potential. This continues to increase in lock-step with irradiation as the day approaches Noon, and then of course it wanes as the day moves towards evening. Also, as clouds pass over the panels the irradiation (and thus the potential) will go up and down in lockstep as well.

If an inverter were 100% ***effective*** it would be able to begin harvesting useable electricity from the moment the panels begin to produce potential, (at dawn) until they stop (at night).
However no-one has yet made an inverter that is 100% effective or 100% efficient.

But just how effective (or ineffective) are they, and how effective can they be ? Please read down to the last point of the following paragraph.

Because the PV market matured in Europe, there are some technical issues that most people do not comprehend when selecting an inverter.

- In Europe the maximum string voltage is 1000VDC, in North America it is 600VDC. Most of the Inverters currently available were developed for deployment in the richest PV marketplace over the past 20 years - Europe
  - Most of these inverters (Siemens, SMA, Satcon, Xantrex etc.) were designed to work within that 1000VDC parameter. So in their European iterations they turn on at or about 450V and then MPPT (Maximum Power Point Track, see definition) from 500 - 900V.
- When the North American market started to emerge as a possible player, do you think any of these manufacturers went back to the drawing board and completely redesigned a brand-new product, after having built them for 25 years ? Absolutely not - they adapted the European technology to try to work here in this 600VDC limited market.
- **95% of the inverters operating in this market have a voltage window of 285 - 550VDC, with MPPT from 300 - 500VDC, max 600VDC**
- Bottom line, when it is cloudy, raining, partial snow coverage, the string voltages are mostly below 300VDC, and these inverters (all of them) are simply OFF. At that point we can forget about the efficiency discussion - they are "OFF" , that is **0% efficiency**.

So how much of the available energy is being wasted by this flawed philosophy ? It can be calculated relatively easily, without going to first principals, and recalculating all losses, efficiencies etc. We can simply go back to some industry accepted standards, and use examples.

If we go back to the <u>Capacity Factor</u> discussion, and we assume that most inverter/array systems are operating at a 14% CF:

- CF is calculated over a 24 hour period, so for PV and for the purposes of this discussion, we need to consider only the 12 hour daylight day
- Thus, in a 12 hour period, the array is 28% effective overall.
  - o That is, 100 – 28 = 72% of the available energy is being wasted. Not all wasted by the inverter mind you, but a good portion to be sure. And it's not all being wasted in inefficiency, it is largely being wasted by lack of effectiveness or lack of efficacy in dealing with less than ideal circumstances.

Where are these losses coming from? We'll discuss each loss in the following sections.

3.2.5 The “Enhanced” Inverter

Briefly, before we discuss the elements that contribute to losses, let’s imagine an inverter that mitigates much of the effect of those losses. An enhanced inverter is simply one that has a broader DC voltage input window, while maintaining reasonable efficiency throughout that conversion process (reasonable being greater than 90%).

If the North American max DC voltage is 600V, then any inverters which are working within the 285VDC to 600VDC range are by definition ignoring everything below 285VDC.

The conditions under which voltage below 285 VDC occurs, will be discussed in some detail below.

In my opinion those conditions represent better than 50% of the available annual energy from any array at the latitude of Central Ontario Canada.

1. Because mathematically this is obviously true on a single clear day of irradiance vs energy production
2. Because there are a lot of ‘poor weather’ days, and all mornings and evenings when the array produces below 285 VDC.
3. Because there are many hot days when the array produces below 285 VDC.

My estimate of 50% will vary from area to area. For example in southern latitudes, where the weather tends to be clear, an enhanced inverter may only represent a 30% opportunity for gain.

Now, let’s look at the factors which contribute to the losses and the opportunity for gain.

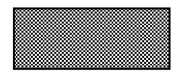
3.2.6 Orientation (Tilt) of the Solar Panels

Solar panels receive the most light (and thus generate the most electricity) when they are mounted perpendicular to the path of the sunlight. The angle at which the light strikes the panel is called Incident Angle.

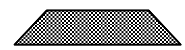
Thus at the equator, PV panels can be mounted horizontally (flat, like a table) and receive maximum illumination/solar-irradiation. Conversely, as one goes farther away from the equator, (North or South) the sun is lower and lower in the sky, and the panels need to be tilted progressively higher to ‘see’ the sunlight ‘flat on’.

It may not be obvious why the incident angle needs to be as close to perpendicular as possible. Let’s conduct an experiment :

1. pick up a rectangular object (like a notebook or sheet of stiff paper)
2. close one eye (our binocular vision can compensate the way a ‘dumb’ solar panel cannot
3. hold the object at arms length
4. angle the object so it is at right angles to the line of sight – not surprisingly, it looks like a rectangle.



5. now, tilt the object so the top is farther away than the bottom. Now it looks ‘smaller’. We know that it’s the same size, but because of the angle of view, the apparent area is reduced.



That’s exactly what happens when a solar panel is mounted at too shallow an angle – insolation is measured in Watts per **Square Meter**, and when the apparent size of a PV panel is reduced, the energy gathered is reduced.

Most of the solar arrays in North America at the time of writing (late 2010) are mounted in the American SouthWest (Arizona, Nevada, New Mexico, California) at a latitude of 30 to 35 degrees north. Consequently, in those locations it is entirely appropriate to mount solar panels at 20-30 degrees from the horizontal. See Figure 2 below.

However, in Ontario (Toronto’s Latitude is 44 degrees), the sun is lower at all times of the year, more so in the fall, winter , and spring. Therefore at this latitude, the optimum angle is near 45 degrees. See Figure 1 to the right .

Figure 1

Our Beta Test Facility has two identical arrays connected to two identical Conversion/Inversion devices. One is mounted flat, the other array is mounted at 45 degrees. Day in and Day out, <u>the correctly mounted array delivers about 20% more electricity.</u>

We’ll talk later about the effect ambient temperature has on yield, and the effect that a more effective Converter/Inverter can have, but while we’re talking only about orientation, it needs to be stressed that in order to maximize yield :

1. the correct angle is about the same as the latitude
2. the panel should be angled to match the sun angle NOT at midsummer, but at early- Fall / late-Spring (due to lower ambient temp, see discussion below)
3. see the section about the Conversion/Inversion process to understand why gathering energy in the Spring/Fall is economically worthwhile

A separate point about orienting the panels correctly is not directly about the yield, but does greatly affect the economics of the whole project.

Figure 2

Many of the panel installers who operate on the model successful in the American Southwest place the panels almost flat, and very near the surface as shown in the photograph to the right . While this works well in a dry climate with no snow, in Ontario's climate, the following problems arise :

1. Water – many rooftops in Ontario are designed (by the Construction Code as it relates to Municipal Storm water retention) to retain rain/storm water so that large amounts of rain from a cloudburst (in built-up industrial centers, where there is a lot of asphalt and very little grass to absorb some water and stem the flow) don't rush down to and overwhelm the storm drains simultaneously. That is, the roofs are designed to hold / retain several inches of water which drains off (through storm drain restrictors) over the next hour or so. Imagine the effect of several inches of water on the panels and the wiring of the array shown above. Most Electrical connections are water resistant but not submersible. Water resistant means that the connections will not be adversely affected by splashed water, whereas submersion is a completely different thing. Maintenance and repair are line items in the financial picture of any array, and submersion will have a quantifiable detrimental effect on performance and longevity.
2. Snow – while show is uncommon in Arizona, it is a fact of life in Ontario.
   - An almost flat array like the one in Figure 2 above will be unable to shed most of the snow load, and even if the snow does slide off on this low angle, it cannot go anywhere due to the proximity to the roof, thus creating a snow / ice dam, which will freeze overnight (every night) and become progressively thicker and more difficult to remove over the winter. An array like the one above can be covered in snow for months and will generate little or no power during that time – even though we know that there are many bright sunny (and cold, see temperature discussion below) days during the winter.
   - Suppose we were able to convince the PV panels to 'defrost' themselves. That would require three things :
     1. make the panels 'slippery'
        - snow and ice are ***translucent*** and opaque coverings, meaning that ***light does get through***. You only have to get in your car after a snow storm to witness this - it will be gloomy (like a cloudy day) but some light does get through
        - Under these conditions the panels (through the Snow and Ice) will produce some voltage, potential (in fact PV panels even react to moonlight, there are just no inverters sensitive enough to this low level of energy to do any real work)
        - IF the inverter is able to turn on at that low voltage, **SOME** current starts to flow
        - The internal impedance of the panels, combined with the current flow to (or demanded by) the inverter creates a bit of heat, which melts a boundary layer of the snow to make a slippery layer of water, and the snow can slide off (if the panel is angled correctly)

- ***But this only happens if the inverter can turn on and let a bit of current flow from the panel*** at that low level of irradiation
- If current cannot flow the panel stays dormant, and the problem compounds itself, with additional layers of snow and ice
- This aspect is entirely about the inverter ! It does not matter how good your panel is - if the current cannot flow the panel cannot de-ice itself. This is a definite side effect of ***Inverter efficacy.***

2. let gravity do its job
   - if the panel is at the correct angle, the snow can slide. If it is mounted too flat, gravity can't pull the snow off
3. have someplace for the snow to go
   - if the panel is mounted too close to the surface, the snow has no place to slide to – it will just accumulate

- Once the panel is clear, it's back to business as usual !

3. Shadowing – if panels are mounted at too shallow an angle and not spaced far enough apart, then low angle sunlight (morning, evening, Fall, Winter, Spring) will be blocked by the Southernmost rows of panels, and those behind them (to the North) will be in the shade. Shadowed PV panels produce little or no energy.
4. Roof Repairs – a well-designed solar array will generate electricity for at least 40 years. Virtually no roof surface will go that long without needing replacement and/or repair. A flat-mounted array like Figure 2 above will need to be totally removed while the roof is being repaired, and then replaced. Three unnecessary costs are involved :
   - Removing the array and storing it (presumably off the roof , or on some area of the roof that is not being used, which may not be stressed for the point loads associated with denser weight storage circumstances) while the repair is taking place
   - The loss of revenue while the array is out-of-service for the roof repair – since repairs are normally done in the summer, that means a significant percentage of the annual yield will be lost
   - Replacing and rewiring the array after the repair has been completed.

   On the other hand, an array mounted on an assembly ABOVE the roof surface does not have to be disturbed for any roof repairs.

3.2.7 Ambient Temperature

PhotoVoltaic (PV) Solar Panels are highly susceptible to high temperatures. If you look at the specifications for any decent PV panel, you'll see a number called "*Maximum Power Temperature Coefficient*" and NOCT. This number states how less efficient the panel will become with each increasing degree of heat above 25 degrees celsius . Thus, a panel will be much more efficient on a cool day than a hot one (like the middle of summer). It is therefore highly desirable to angle the panel to also gather energy during lower ambient temperature periods, (the Spring and Fall) rather than just the summer, which often has high ambient temperatures. Remember, that during the summer, the solar intensity is higher anyway, so tilting the panel to capture maximum illumination at the peak of summer is unnecessary.

A second issue relates back to tilt angle. A flat (or worse yet, enclosed) panel like those in Figure 2 above, will not shed heat easily. A properly tilted panel with an open mounting structure will have an easier convection flow of heat off the back surface and will consequently be cooler overall and generate more electricity (and last longer, as high ambient and trapped heat can do long term mechanical damage).

In general, therefore, it is best to :

- Mount PV panels at the correct angle
- Mount PV panels on open racking
- Select PV panels that have a lower Power / Temperature Coefficient

3.2.8 Environmental Conditions

- **Weather**
  - **Clouds , snow and rain** are far more prevalent in Canada and the Northern US than the clear sunny days of the southern US Midwest or South America
  - while the climate for PV power generation in Southern and Central Canada is similar to that experienced in Germany, the Maximum voltage here is set to North American standards (that is, 50% less)
  - Snow is a double factor :
    - Snow in the air reduces insolation so the PV panels generate less energy
    - Snow allowed to gather on the panels (because they are at too shallow an inclination and/or are too close to the mounting surface) will eventually block the sun even on clear days
    - A poor inverter will not 'turn on' until the string voltage reaches 300VDC, so under these conditions, no electricity will be produced during poor weather conditions
      - If an ***enhanced inverter*** can turn on when the string voltage reaches 70 - 90VDC and MPPT from 100VDC - 585VDC, this inverter is going to harvest much more energy under these 'marginal' conditions.

Mornings and Afternoons

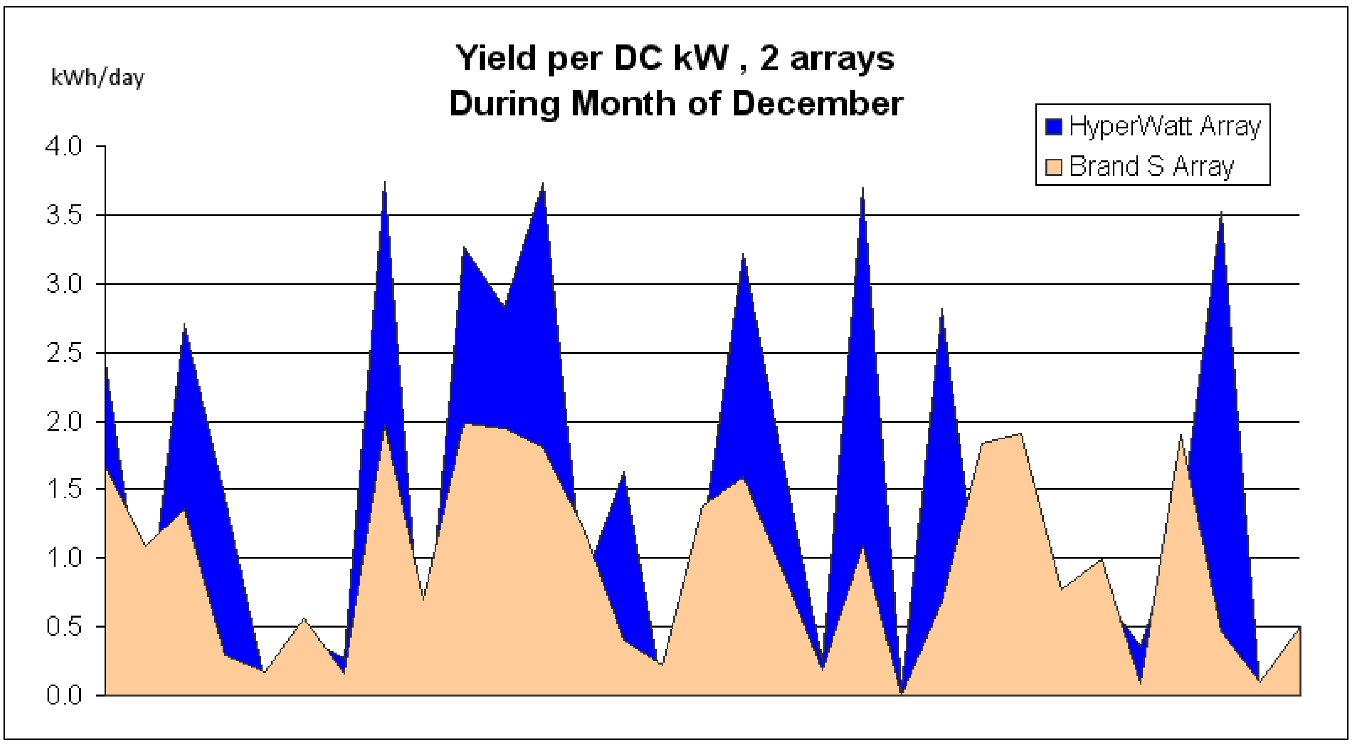
- Obviously, early in the morning and later in the afternoon, there is less insolation reaching the panels
  - The sun is lower in the sky, so the incident angle is more oblique. An oblique angle (as we discussed earlier) causes less energy to impinge on a PV panel. This problem is exacerbated when the PV panels are incorrectly mounted at too shallow an angle.
  - Because the sunlight has to penetrate more of the atmosphere at an oblique angle, the light reaching the PV panels is 'weaker'
  - It bears repeating that even though the illumination intensity is higher in summer, it is fairly good in fall and spring, with lower overall ambient temp.
- Less insolation means the voltage generated by the string of PV panels will be lower
- An inverter that is not effective will not turn on until the string voltage reaches 300VDC, so no electricity will be generated during early mornings (from dawn to perhaps 10AM) or late afternoons (from perhaps 2-3 PM to dusk)
- if an ***enhanced inverter*** can turn on when the string voltage reaches 70 - 90VDC and MPPT from 100VDC - 585VDC, this inverter is going to harvest a lot more energy over the full duration of the day.

So how important are these environmental factors ? If you look at Ontario's conditions (length of days, sun angle, rain, snow, temperatures), the disadvantages of an inverter which only operates at high voltages will result in lost production opportunity of **over 30%/yr.**

As proof, consider the following graph :

- Two similar arrays, geographically nearby
- One connected to an enhanced inverter, the other to a conventional inverter
- The data is from actual monitored observations during December 2011

Over the period from September 2011 thru January 2012, the enhanced inverter (blue trace) delivered 41% more electricity per DC kW of the array, primarily because of its wider voltage window. Over the monitoring period, the enhanced inverter delivered **1201** kWh per kW per year, while the conventional inverter only delivered **961** kWh per kW per year.



3.2.9 Nameplate rating of the Solar Panels

One of the least understood factors in the process of determining the electrical and financial yield of an array is the Nameplate Rating of the PV panels themselves.

Each PV panel is given a rating which indicates how much electricity it is expected to yield under 'perfect' conditions (maximum insolation, right angle incidence of the light, relatively low ambient temperature = 25 degrees C). For example , a given panel might be rated at 200 Watts. That is the amount of electricity which can be expected from that new panel at high noon on the brightest day of the year @ 25 degrees C. Unfortunately, those perfect conditions rarely occur over the course of a real outdoor year (especially in Ontario, Canada)

Moreover, our tests on many panels from various manufacturers have revealed that the Nameplate Rating for some panels is quite misleading. We simply arranged a series of panels from different manufacturers at exactly the same angle on the same roof, connected to the same monitoring equipment, and recorded how much electricity they generated per day. The results were quite surprising :

- One well-known branded panel, rated at 240 watts, never delivered more than 170 watts under any conditions
- Most brands delivered significantly less than their Nameplate Ratings
- Most brands performed very poorly in low light conditions (some cloud, early or late in the day)
- Only two brands consistently delivered electricity at their Nameplate Rating, (although one slightly better than the other) and also performed well in the less than perfect weather conditions we expect here in Ontario.

Unfortunately, in the attempt to simplify the calculation process for customers, vendors often over-simplify the yield and simply multiply the Nameplate Rating of the array by the Sun Hours, with some nominal deduction for conversion and wire losses.. On the face of it, that's easy to understand, but it does NOT take into consideration the possible inaccuracy of the Nameplate Rating nor all the other factors that have a much greater impact on the annual yield (tilt angle, ambient temperature, Conversion/Inversion).

3.2.10 Quality of the Solar Panels

In addition to the Nameplate Rating of PV panels, there are other considerations when selecting a panel for your array.

1. does the panel actually deliver what its Nameplate Rating suggests ?
2. has each PV panel been independently tested and rated, or has the same rating been applied to all the panels in a 'batch' ? We found only three brands that "flash" test and rate each panel independently, all of the time.
3. how long will the panel last ? All PV panels manufacturers warrant that their products will deliver a certain percentage of their 'as new' rated performance after and over a number of years. For example, most manufacturer will tell you that their panels will still be 100% effective after 5 years, and perhaps 80% effective after 25 years. The better the panel, the more it will still be delivering 20 or 40 years into the future.

3.3 How Capacity Factor Affects System Output

As we have seen above, an Enhanced Inverter can increase the Capacity Factor of the array from 14% to 19% or beyond. Now, that extra 4% in CF may not look like much, but consider the following …

- A system with a 14% (28% daily usage based on a 12 hour day) Capacity Factor is wasting 72% of the available energy.
- A system with a 19% (38% daily usage based on a 12 hour day) Capacity Factor will only waste 100% – 38% = 62% of the available energy - this is fully 37% more production than the 14% CF system.
- Now this 19% CF presumes that you are using a good panel (with a decent temp coefficient) at the right incline. BUT even if you are using poor panels at a poor angle, if the inverter turns on sooner, that array is going to perform *better* than the alternative of simply being OFF.
- If you use good panels, correct incline (not just for the latitude but for the climate) , good height from the ground and an ***enhanced inverter***, you can forget about settling for a CF of 14% and entertain a CF of 19% !

3.4 Why do PV Arrays Underperform ?

1. poor connections create high impedance and high voltage drop at the panel. This is something an array ***cannot recover from***, and low-voltage-low-current losses in series are additive
2. bad angle - the recommended angle is equal to the latitude of the installation. Incidentally, programs like NRCAN's Retscreen or NREL's PV-watts DO recommend the correct angle, but DO NOT associate a greate enough loss penalty to panels installed at the incorrect angle.
3. shading issues (e.g. from trees or rows of PV panels mounted too closely together)
4. dirty panels – air pollution, bird droppings, leaves, etc. By the way, a properly angled panel can clean itself of debris with rain or snow, but if the panel is too flat, the natural cleaning process is hindered or completely impaired.
5. improper string configurations (not enough panels per string)
6. poor inverter technology – for example any of the above-mentioned styles originating from or designed for the European market generally perform poorly here compared to an enhanced inverter
7. Are you really is using an excellent high quality panel ? (did you test them ? or have them tested ? or are you taking the panel manufacturer's word for it ?) We don't mean every panel, though the manufacturer should have flash-tested every one when they come off the assembly line - we mean (particularly on very large arrays) random quality control sampling of the product destined for the field prior to installation

    - For example

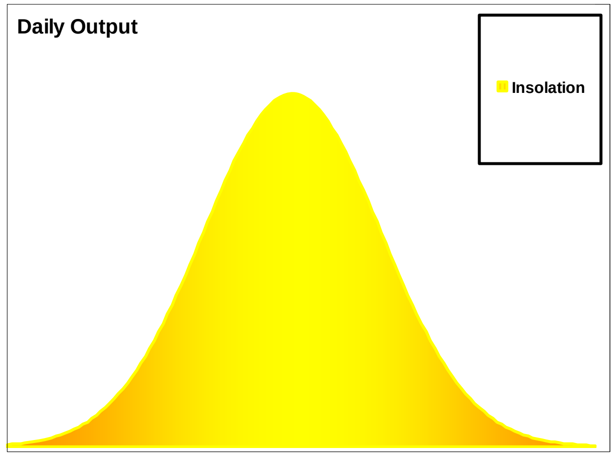
        - we have tested brand-name panels rated at 270Watts (in 1000W/sq meter- 25 degrees C), that cannot produce more than 190W in 1080 W/sq meter sunshine, and 25 degrees C
        - these are panels right off of the shelf at random.
        - ***This means that the panel is producing 30% LESS VOLTAGE*** and current than specified. On a cloudy day (or a hot day), a string of those panels does not have a chance of making the standard inverter 'start up' – no power will be produced.

4 Steps to Improving Yield

Given that the owner of the array wants the highest possible yield out of the facility, let's examine what can be done to achieve the best possible yield of a typical array.

4.1 Insolation

Actually, there's nothing that can be done to improve Insolation (Sun Hours) at any given location . Insolation is just a matter of geography, and looks like this over a 'typical' day .

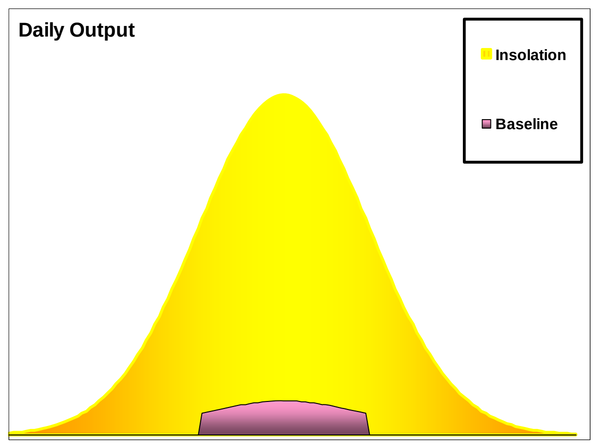


4.2 Baseline

Before we start improving, let's look at the yield of a typical " SunBelt " array transplanted to Ontario. We'll consider this the ***Baseline*** before we start improving on it.

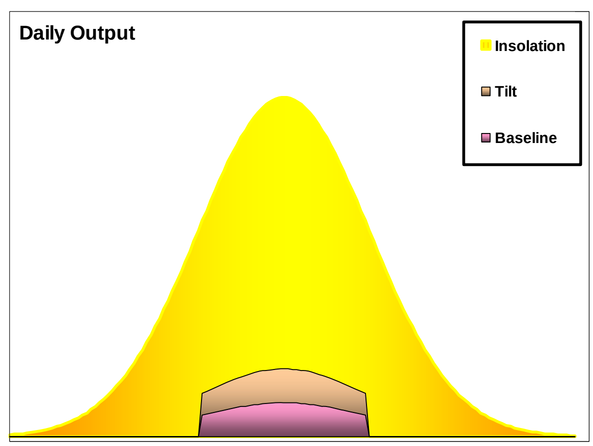
Because NO array ever gathers 100% of the available energy, notice that the yield curve is much lower than the insolation curve. This would be typical of an 11-12% Capacity Factor array

Also, since NO array ever gathers energy during 100% of the illumination day, the yield starts sometime during the midmorning, and ends in the middle of the afternoon or early evening.



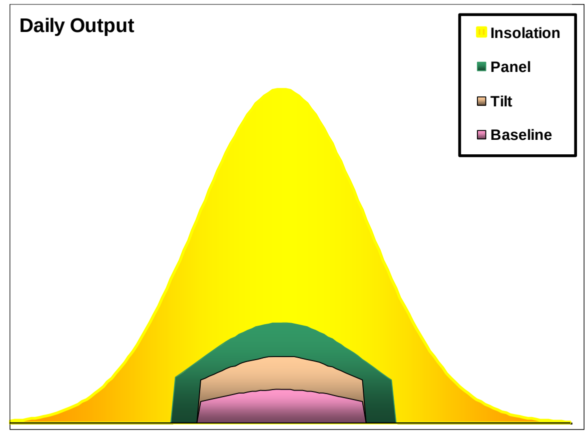
4.3 Tilt Angle of panels

The typical " Southwestern USA " array is erected at a shallow angle (like Figure 2), but if we tilt the array at the correct angle for Ontario (~ 45 degrees) we immediately see an increase in yield. This increase is driven by more illumination striking the panel directly ***and*** by the panel running cooler as heat convects more easily off the back side. This improved angle will be even more productive if the Conversion/Inversion process can take advantage of lower light levels during dull days or during Spring and Fall's shorter days.



4.4 Choice of Panels

Choosing the correct PV panel to use can have a significant effect on yield. Remembering that in Ontario the array owner is paid for KiloWattHours (yield) and not Watts (Nameplate), buying the cheapest panel is not productive in the long run.

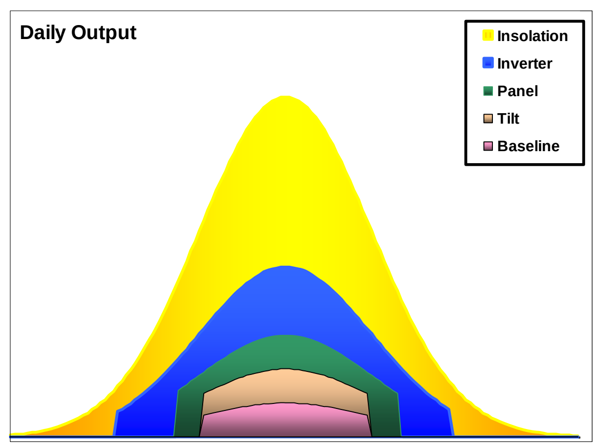


Notice that the yield curve is now higher and wider. Better panels deliver more electricity in all light conditions – the 'good' part of the day around noon, and the poorer parts of the day with less illumination as well. This is now a typical 13-14% Capacity Factor array

A third factor not shown here is that better panels last longer, delivering the same or nearly the same yield for more years.

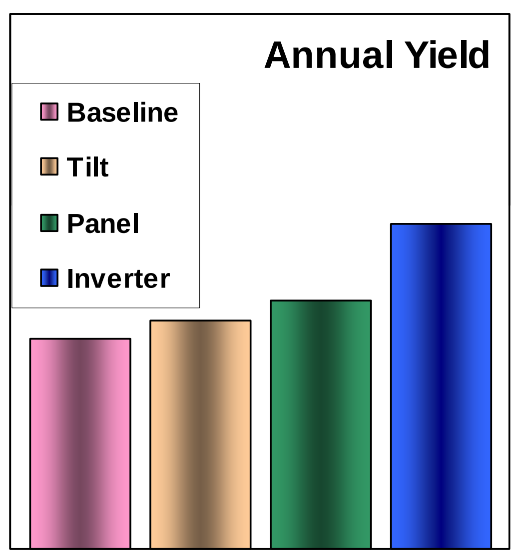
4.5 Conversion/Inversion Process

Perhaps the biggest improvement is realized by the use of a Conversion/Inversion Technology that delivers a higher percentage of yield over even wider illumination ranges.



A good CIT will 'turn on' earlier in the morning and turn off later in the afternoon, and deliver higher percentage efficiency over the whole range. Now this is a typical a 17-19% Capacity Factor array

Moreover, if an Inverter can handle lower light levels, it can operate effectively during more days of the year. We have found that a better Inverter easily delivers an extra 30% yield over the course of a year.



5 Summary/Conclusion

The wise investor or developer will use the correct measurements when evaluating a proposed Solar Array – Capacity Factor is much more revealing than partial and over simplified measurements like " Sun Hours " or Nameplate Rating, which lead to kWh per kW installed. These numbers are meaningless if all of the factors are not taken into account.

The wise investor / developer will insist that the Solar Array is built to match the geography of the location – selecting angle and mounting technologies that take into consideration the angle of the sun and the rain and snow of the area.

The wise investor will insist that panels purchased actually deliver what their Nameplate ratings promise, and will choose panels that deliver higher output under the same conditions.

The wise investor will insist on an Inverter that delivers the highest possible yield, rather than the lowest priced option.

Glossary of terms and definitions

- ***60 Hz*** – 60 cycles per second (alternating current)
- ***AC*** – Alternating current – as distributed by the grid and used by most electrical devices
- ***DC*** – Direct Current – as provided by batteries (and PV Panels)
- ***Array*** – a group of PV Panels all mounted and connected to an inverter.
- ***Brand S*** – a specific manufacturer/supplier of inverters which has an Ontario Office. We are reluctant to supply the real name of the company because of the perceived damage to their reputation by the poor performance of their product in the results monitored as a subject of this document
- ***HPE*** – Hybridyne Power Electronics Inc.
- ***HyperWatt*** – the 'brand name' of a line of high-capacity inverters marketed and supplied by Hybridyne Power Electronics Inc.
- ***kW*** – KiloWatts – 1,000 Watts of power
- ***kWh*** – KiloWattHours – 1 KWH is 1 KW delivered continuously for one hour – electricity is typically purchased and sold by the KHW
- ***mW*** – MegaWatts – 1,000,000 Watts of power
- ***Inverter*** – a device that converts DC energy (as from a PV solar panel) into AC power suitable for sale to the grid
- ***LCOE*** – Levelized Cost of Energy (or Electricity) – the cost per kWh to generate electricity over the life of the equipment
- ***Monitored or Monitoring*** – the recording on a regular basis (for example, once a minute) of the values of input or output signals from a device - in this case the output kW and kWh from two inverters
- ***MTBF*** – Mean Time Before Failure – an expression of reliability of equipment – expressed as the average number of hours of service before the equipment has significant failure
- ***NamePlate Rating*** – the manufacturer's assertion of how many watts the PV panel will deliver when exposed to 1000 kW of incident light per square meter.
- ***PPA*** – Power Purchase Agreement – the agreement by which electricity generators sell electricity to the local grid – in Ontario, one set of PPA's is defined under the FIT Program of the Ontario Power Authority.
- ***PV Panel*** – PhotoVoltaic Panel – the solar panels that generate electricity from sunlight
- ***PVWatts*** - a piece of 'predictor' software provided by the National Renewable Energy Laboratory
- ***RetScreen*** – a piece of 'predictor' software provided by National Resources Canada
- ***ROI*** – Return on Investment - an accounting term expressing the amount (or rate) of the financial return on the investment of any piece of equipment
- ***Usage Factor or Capacity Factor*** - a number (usually expressed as a percentage of, or decimal equivalent less than 1 of Nameplate Rating) which expresses how much actual energy is delivered by a Renewable Energy Generator (wind turbine or solar panel) as opposed to the theoretical (nameplate) yield. Thus, a 10 KW wind turbine with a .25 usage factor delivers a yearly average of 2.5KW per hour, every hour all year, where a 10 KW wind turbine with a .50 usage factor delivers a yearly average of 5KW per hr every hour all year under the same conditions. For a more complete explanation, please see *The Renewable Energy System Equation* mentioned in the Addenda Section 12.