An introduction to Solar Photovoltaic technology and mounting systems

by Daniel Hoviss – Putney Town Energy Coordinator

This document introduces and examines varies kinds of PV systems and the cost benefits vs performance of each. This document is best viewed live, (not printed) to allow hyper links to be viewed.

But first some definitions and explanations

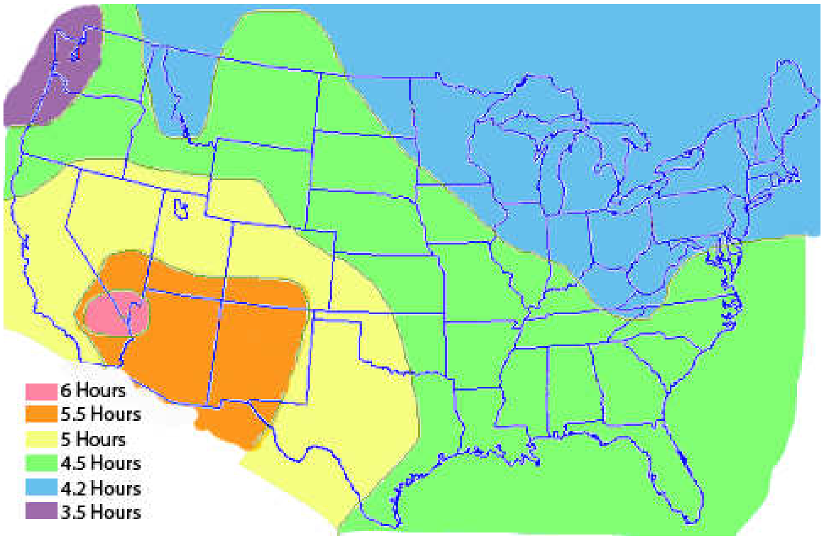
PV or Solar Cells are devices that convert light into electricity. They are usually made from Si (silicon) in various shapes and sizes using various technologies and materials. See **http://en.wikipedia.org/wiki/Solar_cell -** for a very detailed explanation.

The various types of PV in production currently are Crystalline-Si (cut into thin slices from large single crystals), poly-crystalline –Si made from a solid composed of many crystals, and amorphous which is less efficient but also less expensive to produce. http://en.wikipedia.org/wiki/Polycrystalline_silicon - descriptions of the difference between poly and single crystal.

Each type of PV has a specific niche, for instance amorphous PV can be applied to plastic film creating flexible strips that can economically be applied to metal roofing.

PV technology generates electricity by capturing photons which convert energy into a flow of electrons. PV cells range from 10 to 28% in efficiency, while newer more exotic materials have generated over 45% in the lab - they are not commercially available as of 2015. Most PV cells generate the highest amount of electricity when 90' or perpendicular to the sun.

Solar insolation is the amount of sunlight falling on an area, and it is commonly expressed as average irradiance in watts per square meter (W/m2) or kilowatt-hours per square meter per day (kW•h/(m2•day)) (or hours/day).
A good explanation is here:
http://solarinsolation.org/
This irradiance varies throughout the year depending on the seasons. It also varies throughout the day, depending on the position of the sun in the sky, and the weather.



Solar insolation levels are charted across the country like so:

Vt. has a yearly average of only 4.2 peak sun hrs/day. The peak meaning that the sun is at full strength, while this seems to suggest that usable power is only available during that period - that is not the case, it is simply a measure of comparisons for various locations in the US and it includes cloudy days in the average. http://en.wikipedia.org/wiki/Insolation

There are micro climates and other variables that affect the amount of sunshine falling on an area.

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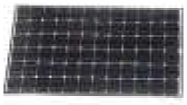
Panels are composed of multiple PV cells all wired together to create more electricity in an easy to handle package. The cells are arraigned between a protective backing and a clear cover.



Arrays are made up of individual panels, all wired together into strings for a specific amount of power. There are different methods of stringing or wiring together all the cells in each array and of connecting array together to ameliorate the negative effect of shading on any one cell or panel so that the complete array can still produce the most power.

MC Connectors

To ensure reliable water proof interconnections for 30 years the industry has adopted a product called MC or multi-contact plug connectors. These cable couplers are fully touch-protected and designed for high voltage and high current-carrying capacity.

Solar inverter or PV inverter is a type of electronic device that can change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances and possibly a utility grid.

MPPT, or maximum power point tracker is an electronic device that optimizes the match between the solar array (PV panels), and the battery bank, utility power, DC motor, or DC pump. Most good inverters now employ MPPT as a way to optimize the energy produced from any PV system. http://pec.putney.net/issue_detail.php?ID=19

MPPT presents the optimal load to the array or panel, to increase efficiencies and obtain the most energy from the panels. MPPT is an algorithm used to calculate and respond to temperature and light changes detected on a solar power system, and to determine how much power to draw from the module.

Traditional Solar Inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows though all panels in the string. But because different panels have different power curves, i.e. different Maximum Power Points (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy.

DC to DC converters are small devices that mount on each PV panel (or nearby on the rails that hold the panel), and provide individual MPPT regulation and remote monitoring.
This allows greater efficiencies because every panel is MPPT optimized, and can be monitored for performance or failure. DC systems still require an inverter.

Micro Inverters are also small devices; they convert the output of each panel into AC. AC wiring is cheaper, and the system is easier to install because the code requirements for DC disconnects and other safety systems are removed or lowered. Some panels have integrated micro inverters and these are called AC panels. Micro Inverters and AC panels offer the following advantages;

- **Increased Productivity**
  MPPT algorithm works at each solar module in an installation and achieves greater than 99.6%

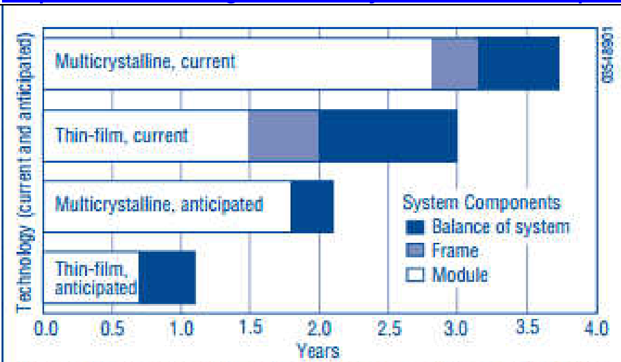
accuracy which enables it to maximize energy harvest at all times, even during variable light conditions. Tests show systems using Micro inverters increase energy harvest by as much as 25% over systems using traditional inverters.

- **More Reliable**
  Traditional centralized inverters implementations create a single point of failure for solar power systems. If the inverter fails, the entire system is disabled. Micro inverters convert power independently at each solar module. If one micro inverter fails, the rest continue to operate as usual. Also, if a micro inverter is damaged or fails, it can be replaced during routine maintenance or when convenient, further reducing maintenance costs.
- **Reduced Operational Costs**
  With the Micro inverter System, installers are no longer limited by string design, marginal designs, co-planarity, and matched modules. The space, heat, and noise associated with a large inverter are eliminated. Micro inverter Systems improve mechanical integration, reduce wiring time, and remove the need for DC switching points.
- **Flexibility**
  Another benefit of the distributed micro inverter design is the potential for installations to be expanded over time. An initial set of solar modules can be installed and additional modules added as needs and budgets grow without requiring the replacement of a large centralized inverter.
- **Remote monitoring**
  Every panel can be monitored for performance or failure.

Here is a link to a well done video;
http://www.5min.com/Video/Photovoltaics-Micro-Inverters-274956482

What is the downside? Micro inverters do cost more money. How much more depends on the project and the number of panels.

Energy Payback for PV modules
The hypothetical energy used to manufacture a given PV cell type is charted and compared against how much it produces to find how long it takes to recoup that energy.

http://www.nrel.gov/docs/fy04osti/35489.pdf	
 *Reaping the environmental benefits of solar energy requires spending energy to make the PV system. But as this graphic shows, the investment is small. Assuming 30-year system life, PV systems will provide a net gain of 26 to 29 years of pollution-free and greenhouse-gas-free electrical generation.*	Energy payback estimates for rooftop PV systems are 4, 3, 2, and 1 years: 4 years for systems using current multicrystalline-silicon PV modules, 3 years for current thin-film modules, 2 years for anticipated multicrystalline modules, and 1 year for anticipated thin-film modules (see Figure 1). With energy paybacks of 1 to 4 years and assumed life expectancies of 30 years, 87% to 97% of the energy that PV systems generate won't be plagued by pollution.

How Much CO2 and Pollution Does PV Avoid?
An average U.S. household uses 830 kilowatt-hours of electricity per month. On average, producing 1000 kWh of electricity with solar power reduces emissions by nearly 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxides, and more than 1,400 pounds of carbon dioxide. During its projected 28 years of clean energy production, a rooftop system with 2-year payback

and meeting half of a household's electricity use would avoid conventional electrical plant emissions of more than half a ton of sulfur dioxide, one-third a ton of nitrogen oxides, and 100 tons of carbon dioxide. PV is clearly a wise energy investment with great environmental benefits!

Standard Types of installations

Stand alone – systems rely on batteries to store solar power, for use later at night. Inverters with charge controllers are required to charge the batteries and keep them happy. Batteries add cost to the installation, and require extra maintenance. This kind of system is often user where the cost of bringing in power is prohibitive. Thee systems often employ a backup generator for extended cloudy days. Sometimes a wind generator is added to the mix depending on location.

Batteryless Grid-tied – systems require no battery and are the most common. They use the electric grid to "store" electricity, for use later when the sun is down. These are less expensive to install because of the simpler inverter and no need for a battery bank or charge controller. The down side is if the grid power goes down, you are also out of power – unless you have a backup generator and critical load center; both add additional cost.

Community solar is a batteryless grid tied system, using larger inverters and many more panels

Battery backed Grid-tied
This is a hybrid system with batteries that can power all or part of your home, for a period of time, while the solar panels or the grid provide the charge to keep the battery system topped up. Incase of a grid outage, this system can switch to battery power. This is the most expensive system type, because of the more complex inverter, and the included or stand alone battery charge controller, and batteries, which usually last 5 – 10 years and then must be replaced.

Types of Arrays

Fixed Array is a system (ground, pole or roof mount) never changes in either tilt or axis. Variations in fixed array implementation can allow for manual seasonal adjustment of tilt to increase performance. A useful option is to specify winter and summer tilt angles (30°and 60° suggested for Vermont) for seasonal adjustment (its generally easy to do) to enhance system performance.

Tracking arrays are designed to follow the sun across the sky to increase the amount of sunshine on the array. Because the earth rotates and the sun moves across the sky, a fixed system is only perpendicular to the sun for a brief period each day.

There are several different types of trackers; Passive vs. Active, Single-axis vs. Dual-Axes, allowing variations in the axis geometry (axis tilt and array tilt). The most popular tracker is the passive single-axis type with rotation around an inclined north-south point.

There are in addition to performance, other reasons to go with one type of system over another, for example;

1. Use a fixed tilt array when the energy requirement is constant year round or peaks in the winter (such as all night lighting). For this situation the higher costs of a tracker is not justified by the minimal *additional* output in the winter, extra output in the summer represents no extra value.

2. Use a tracker when summer loads (or daytime electric loads) are the main concern in sizing the system. Grid tied systems that sell electricity into the grid and most water pumps will benefit even more than the relative higher output in the morning and afternoon as amount of power generated (and sold) at peak load times is increased, the efficiency of a pump also increases at higher power levels.

Pros of Trackers

1. Trackers do produce more electricity per module – up to 50% gains are possible
2. Trackers produce more electricity through the entire day – this is especially valuable where afternoons are longer like in the North East.
3. The tracking array makes more efficient use of inverters, because fixed arrays only use the full output of inverters for a few hours per day while the tracking array provides power to the inverters at near peak levels for a much larger part of the day
4. States that reward for more efficient use of PV may make it more economical (Vermont does **not** reward for performance – only for installed watts)
5. Fewer modules are required for a given power output
6. Land can be cultivated or grazed under and around the tracking array

Cons of tracking devices

1. Trackers add to the cost of a system and are more expensive than ground mounts
2. Active trackers have moving parts, electronics and motors that can fail
3. Passive trackers can also fail due to mechanical problems
4. Passive trackers take some time in the morning to re-aim especially on cold mornings, so you loose about a hour in the am
5. Active Trackers use a very small amount of electricity
6. More land area is used by tracking arrays because of the space required to prevent shading of panels from one another.

Racks and mounts come in all shapes and sizes, and allow the attachment of the panel to the pole, roof or ground mounting system. Modern day racks are almost exclusively made from extruded aluminum for corrosion resistance. The shape of the extrusions allows for fastener systems to make assembly of arrays much faster. Most racks are designed to work with panels, many are specialized and provide specific hardware to work as a system.

Rooftop mounting systems are simple and attractive.

We usually prefer not to mount on roofs because of the potential for leaks, difficulty of maintenance and over heating*. However, a roof mount is generally more secure from theft or damage, and sometimes offers the best access to the sun.

* Not all PV modules are affected by heat.
http://www.pv.kaneka.co.jp/why/index.html

Pole Mounts or top of the pole racks

One type of array mount is the **Top-of-Pole rack.** This type allows for easy seasonal adjustments for tilt angle, it is easy to install, keeps installers off the roofs (with the associated liability issues), and precludes roof penetrations (with leak potential).

As compared to ground mounts, a top-of-pole rack puts panels up into a position less prone to damage from lawnmower-thrown rocks, etc. These allow for tilting to remove snow and cleaning. These require the least obtrusive footing.

Variations on some ground mounts allow for seasonal adjustment or full tracking.

Ground mounts

Tilt-up and fixed array mounts on steel or aluminum frames that are set in concrete. This is an example of a well done ground mount.

So what kind of system should you install? -- It depends.
In the following section we will compare the output and cost of different systems.

Calculations and comparisons
It is important to consider that there are a number of variables that affect the final price of any system. Systems are measured by the installed cost per watt. Rebates and incentives also play a large role in determining the best solution.

The goal of this report is to compare the cost of PV Systems that generate the same amount of delivered annual AC power. It is clear that the tracked array can generate more power and be smaller in wattage (fewer modules) than the fixed mount array. The primary question to be answered is: “Can adding a tracker reduce the system cost while providing a similar amount of power over a non tracked array that contains more modules?” Or to put it a different way; is cheaper to buy more panels for fixed mount than a tracking array?

What I will attempt to prove with the following generalized calculations and examples, is that a dual axis tracking array can be more affordable and a better choice ***where*** full day sunlight and optimal spacing is available.

Rooftop mounts
This comparison does not include building integrated or residential roof mounted systems. Roof mounted arrays often operate at a higher temperature and can suffer up to a 5% loss of power in the summer because of these higher temperatures*. The rooftop of an existing building might not have optimum orientation. The topography, trees and obstructions might also override the ability to provide electric generation. Similarly, new homes that integrate PV’s into the building are beyond the scope of this comparison. The PV Systems described here are all assumed to be pole mounted or ground mount arrays. This allows for an “apples to apples” cost comparison.

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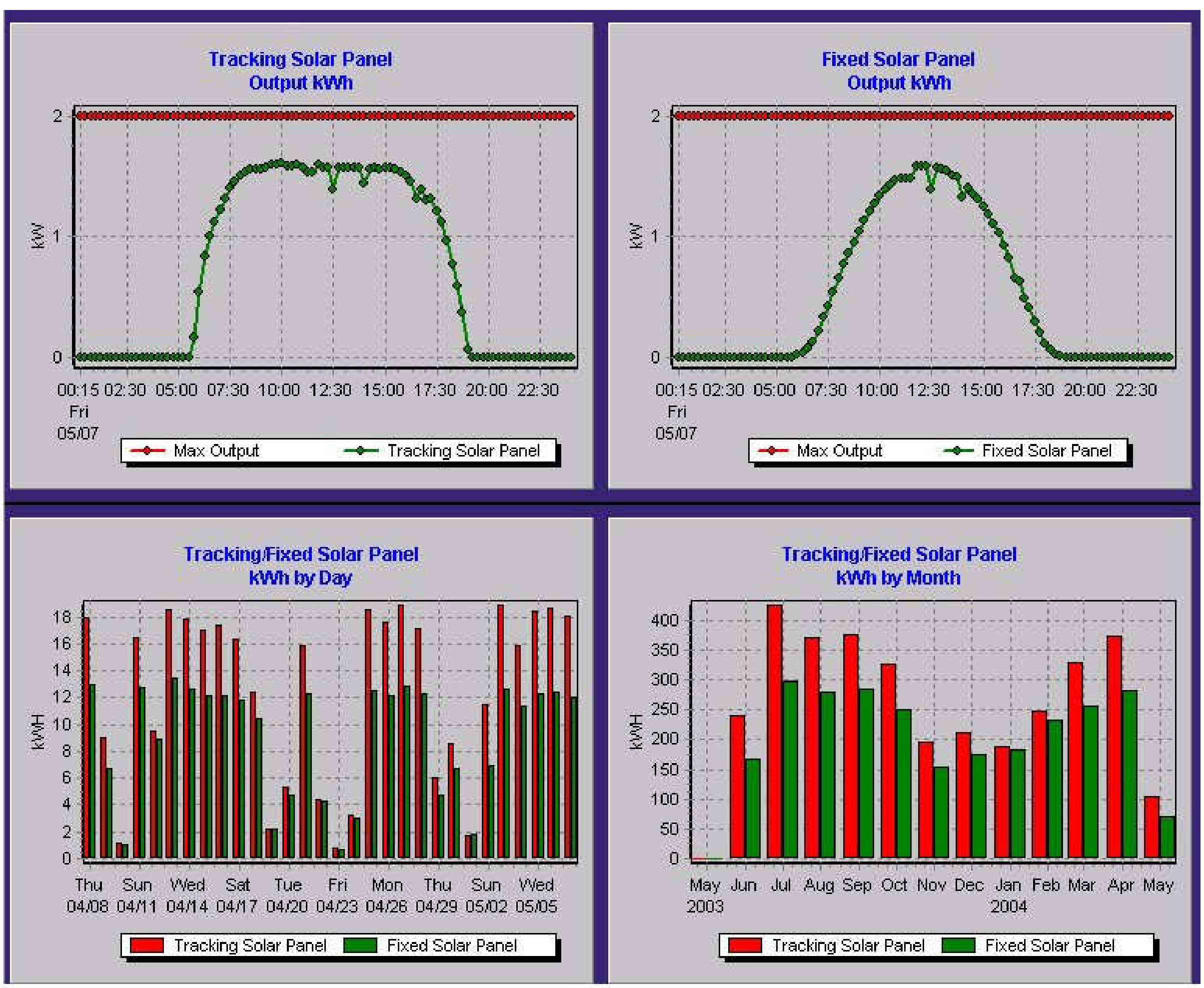
While there are good reasons to use a roof mounted system (no land available, more attractive, less prone to vandalism) – if you need a new roof, and your roof is oriented south, and is of the proper pitch, and you have little or no obstructions, then a roof mounted system may be right for you.

Other variables
The mounting pipes and concrete foundations are roughly similar between fixed and tracking systems so I will not factor that into the cost calculations.

Wiring costs are not included in these calculations, because those depend on the wire run distance and type of inverter system.
Inverters though critical are also not included in this comparison.
Again financing and rebates are not part of this cost comparison and will affect your project, please have look at the following incentives pages:

http://soveren.org/incentives/ and http://pec.putney.net/show_ilinks.php

Chart 1 - IDENTICAL ARRAYS: TRACKED VS FIXED
The tracked array rises up to quickly to full power and stays there on a clear sunny day.
The fixed array only maintains the maximum power for a few hours in the middle of the day.



So if you were to take identically sized modules and test one on a fixed mount and one on a dual axis tracker you would see 30 to 45% more electricity over the course of a year.

Please note that the results above show a fixed system vs a tracking system. The baseline (in this comparison) is a fixed system that allows for seasonal single axis manual adjustment, so the performance gain of a dual axis tracking system over this baseline will be less than that of a comparison between fully automatic dual axis tracking system and a fixed mount (as shown above).

It is well known that if you compare *identical arrays*, one fixed and the other tracked, that the tracked array will annually outperform the fixed array. In the USA the annual improvement can range from 18 to 45 percent depending on the design (dual / single), location and solar resources available at a given location.

Below is Chart 2 - it is a comparison of annual performance of two fixed mount arrays of equal size in KW at different tilt angles. Note the performance of system 2 during Oct – Feb!

	System 1 (Tilt = 35)		System 2 (Tilt = 55)	
Month	4 kW fixed @ 35 Deg.		4 kW fixed @ 55 Deg.	
	AC kWh	Value ($)	AC kWh	Value ($)
JAN	312	$ 28.39	348	$ 31.67
FEB	381	$ 34.67	411	$ 37.40
MAR	436	$ 39.68	438	$ 39.86
APR	433	$ 39.40	399	$ 36.31
MAY	528	$ 48.05	456	$ 41.50
JUN	514	$ 46.77	432	$ 39.31
JUL	519	$ 47.23	440	$ 40.04
AUG	519	$ 47.23	469	$ 42.68
SEP	411	$ 37.40	396	$ 36.04
OCT	363	$ 33.03	374	$ 34.03
NOV	258	$ 23.48	280	$ 25.48
DEC	277	$ 25.21	314	$ 28.57
YEAR	AC kWh	Value ($)	AC kWh	Value ($)
	4952	$ 450.63	4758	$ 432.98

As you can see, **if** you had one fixed (seasonably) adjustable system using the best of both tilt angles above it would produce more.
Below is Chart 3 - this is a comparison of annual performance of a seasonably adjustable fixed mount array vs a dual axis tracking array <u>of smaller size</u> in KW.

	System A (Hybrid Best Tilt)		System B (Dual Axis Tracked)	
Month	4 kW fixed @ Best Tilt		3 kW DA Tracked	
	AC kWh	Value ($)	AC kWh	Value ($)
JAN	348	$ 31.67	298	$ 27.12
FEB	411	$ 37.40	368	$ 33.49
MAR	438	$ 39.86	406	$ 36.95
APR	433	$ 39.40	416	$ 37.86
MAY	528	$ 48.05	546	$ 49.69
JUN	514	$ 46.77	524	$ 47.68
JUL	519	$ 47.23	534	$ 48.59
AUG	519	$ 47.23	520	$ 47.32
SEP	411	$ 37.40	390	$ 35.49
OCT	374	$ 34.03	338	$ 30.76
NOV	280	$ 25.48	243	$ 22.11
DEC	314	$ 28.57	269	$ 24.48
YEAR	AC kWh	Value ($)	AC kWh	Value ($)
	5089	$ 463.09	4852	$ 441.53

Tilt @ 35 for May-Sep
Tilt @ 55 for Oct-Apr

Note the smaller dual tracking system out performs in the fixed system from May to Aug.

What this shows is that you would need to purchase more PV modules for a fixed system to end up with a comparable amount of power. General rules of thumb indicate that (for a good site in a good climate);

- The extra power a tracker produces costs about \$1/watt compared to the \$2 - \$4/watt of PV modules, and is more expensive than standard fixed ground mounts.
- The tracker itself costs from about \$0.75 to \$1.25 per watt of the modules it carries
- Smaller arrays may mean smaller, less expensive inverters and other savings

To compute the approximate net savings from a tracker, subtract the cost of the tracker, the reduced number of PV modules needed, and the appropriate-size inverter from the cost of the larger array, inverter, and stationary rack required *to produce* your target amount of power.

Unfortunately this is not the full story. We have not factored in the types and various efficiencies of different modules or the rebates and incentives.

So are the real benefits worth the costs of adding tracking?

Yes, in some cases under the right conditions and only at the best locations. - It's complicated…

First of all, if the cost of the modules were the same (on a fixed system vs tracked) the decision would be easier, but often the fixed array would be a candidate for less expensive modules, for the very same reasoning – it is "cheaper".

If we consider using an amorphous type of module that is much less expensive per watt, we end up mounting and using many more modules (4 times as many because they are less efficient). The additional cost of installation and mounting hardware can be a factor in the delivered cost per watt.

Here is an example from Minnesota comparing Tracked (crystalline) vs fixed Kaneka (amorphous):

Mono Crystalline = 150W/m^2
Kaneka = 60W/m^2
Tracking factor for MN = 170%
Mono Crystalline cost = \$3/W
Kaneka cost = \$1.20/W

(150W/m^2)/ (60W/m^2) * 170% = 425% greater energy/year
(\$3/W / 425%) / (\$1.20/W / 100%) = 59% energy/cost advantage of crystalline over Kaneka.

This shows that tracked mono crystalline panels have a good advantage over Kaneka panels even with their lower cost. This does not factor in the reduced shipping and mounting costs for the more efficient cells, which would only increase the difference.

However - the amorphous panel strips do work really well on standing seam roofs and are not affected by higher temperatures. So allot depends on the application.

What about rebates?

State rebates and federal tax incentives change the picture, because in Vermont the installed watts are all that matters, not the efficiency. You are not rewarded (with incentives) for choosing more efficient modules or using a tracking system.

Vermont's Renewable Energy Incentive Program, as of 1/22/2015 – with details below;

Vermont State incentives

For a complete listing of all the incentives, rules and regulations for the State of Vermont, please visit the DSIRE Database of State Incentives for Renewable and Efficiency.

There are links at the bottom of this page to download the incentive reservation forms from RERC-VT. You should submit the form as soon as you are committed to installing a system. Incentives are reserved on a first-come first-served basis. For more information on eligibility, please see the SSREIP Terms, Conditions, and Requirement found here.

Overview of Residential Solar PV Incentives

- Federal – 30% tax credit*
- Utility – ~4.3-5.3¢/kWh bonus credit

Overview of Commercial Solar PV Incentives

- Federal – 30% tax credit*
- Federal – 5 year accelerated depreciation with 50% in year one*
- State – 7.2% tax credit*
- Utility – ~4.3-5.3¢/kWh bonus credit

*Please seek professional advice from a qualified tax advisor regarding your eligibility for federal and state tax credits and exemptions.

Federal Solar Incentives

Residential Renewable Energy Tax Credit

- 30% of total installed cost (no cap)
- Effective through 2016
- Credit can be carried forward for up to 15 years, and carried back 1 year

Business Energy Investment Tax Credit

- 30% of total installed cost (no cap)
- Effective through 2016
- Credit can be carried forward for up to 15 years, and carried back 1 year

Modified Accelerated Cost Recovery System (MACRS) + Bonus Depreciation

- Businesses may depreciate 50% of the adjusted basis (85%) of the installation cost in the first year the system is placed in service, and the remaining 50% can be depreciated over a 5 year accelerated depreciation schedule.
- Businesses with gross revenue of less than $1 million may qualify for 100% depreciation in the

first year.

State of Vermont Solar Incentives

Business Tax Credit

- 7.2% of the total system cost

Sales Tax Exemption

- No sales tax for solar

Utility Solar Incentives

Bonus Credit for Net Metered Solar Systems

- 4.3-5.3¢/kWh bonus credit (GMP)
- Valid for 10 years from date of system commissioning
- All VT utilities (bonus credit varies between utilities)
- Enacted in 2011 by the Vermont Legislature in House Bill 56

This exciting bonus credit means that each kWh of electricity generated by your net metered solar system will not only cancel out the cost of a kWh of utility electricity, but also earn you an additional 4.3 to 5.3¢/kWh bonus credit. This makes solar even more effective at saving you money on your power bill. It also means your solar system can be sized to produce less power than you consume and still result in a $0.00 electricity bill.

The bonus solar credit is equal to the difference between the highest utility rate for each utility at the time of the legislation's passage in 2011, and 20¢. For 2015 Green Mountain Power's bonus is between 4.3¢/kWh and 5.3¢/kWh. The bonus credit is fixed at the rate it is when you buy in, and will stay fixed for the duration of the 10 year period, regardless of increases in the utility rate.

Learn more about Green Mountain Power's solar program here.

For incentive info by state, we encourage you to discover this website:
http://www.vpirg.org/cleanenergyguide

Other incentives and Grants:

1. The REAP/RES/EEI Grants Program provides grants for energy audits and renewable energy development assistance. It also provides funds to agricultural producers and rural small businesses to purchase and install renewable energy systems and make energy efficiency improvements.
http://www.rurdev.usda.gov/rbs/busp/9006grant.htm

2. Clean Energy Development Fund Grant / Loan program: The goal of the Fund is to increase the development and deployment of cost-effective and environmentally sustainable electric power resources – primarily with respect to renewable energy resources, and the use of combined heat and power technologies - in Vermont.
http://publicservice.vermont.gov/energy/ee_cleanenergyfund.html - look near the bottom of this link.

3. Property Assessed Clean Energy – Putney Vermont is beginning a pilot PACE program.
This is a loan program that uses existing property as collateral for low interest loans to homeowners and businesses – to enable renewable energy and weatherization projects.

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Incentives:
http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US37F&re=1&ee=1
Expedited Permitting Process for Solar Photovoltaic Systems;
http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=VT13R&currentpageid=3&EE=1&RE=1

VT Small Scale Renewable Energy RERC
http://www.rerc-vt.org/incentives/faq.htm#2b
http://www.rerc-vt.org/incentives/index.htm

Forms
http://www.rerc-vt.org/incentives/forms.htm

More incentives
http://pec.putney.net/show_ilinks.php

Other Resources:
http://www.wattsun.com/pdf/AC%20EnergyComparison-Madison-WI.pdf

www.helmholz.us/smallpowersystems/Intro.pdf

Vertical tracking:
http://www.dhsolar.net/Verticaltracker.htm

Passive Trackers
zomeworks.com/files/pv-trackers/copy_of_Homepower_june2004.pdf
www.powerupco.com/mounts/tracker/ds_tracker.pdf

Active Trackers
http://us.sunpowercorp.com/business/products-services/products/ground-products.php
http://www.solshinex.com/en/our_market.html
www.rimlifegreentech.com/pdf/rimlife_solar_tracker_small.pdf

http://www.arraytechinc.com/download/Array_DuraTrackHZ_Facts.pdf

Tracker calculator:
http://www.arraytechinc.com/duratrackhz-quote.php

Cost comparisons:
http://www.greentechmedia.com/green-light/post/sunpower-how-important-is-pv-efficiency/

www.pipkinelectric.com/pdf/Tracked.pdf

Miscellaneous links:
http://www.hme.ca/presentations/

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