TOMPKINS COUNTY PLANNING DEPARTMENT

Solar Energy Generation Potential of Tompkins County

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Executive Summary

This report is intended to be used as a supplement to the Tompkins County Energy Road Map, a comprehensive strategy currently being developed by the Tompkins County Planning Department to reduce the greenhouse gas emissions within the county. The overall goal of this report is to quantify Tompkins County's solar photovoltaic potential.

The solar potential of the county is broken down by sector into commercial, industrial, educational, and residential buildings, shown in **Table 1**. It is easiest to quantify solar potential for commercial/industrial buildings, as they mainly have flat roofs with few obstructions. The cumulative commercial rooftop PV installation potential was calculated to be 86 MW, which could result in an electricity production of nearly 95 million kWh. According to the *Tompkins County Community Greenhouse Gas Emissions Report, 1998-2008*, this potential electricity production could account for around 27% of the electricity demand of commercial and school buildings *(commercial and school buildings are grouped together in the Tompkins County Greenhouse Gas report when calculating electricity usage)*.

Similarly, industrial buildings typically have flat, unobstructed roofs which provide ideal surfaces for solar panels. The cumulative industrial rooftop PV installed capacity potential was determined to be 22 MW, which would result in an electricity production of roughly 24 million kWh, or 17% of demand for the industrial sector.

It is a little more difficult to quantify the energy potential for school buildings, because their roofs tend to have more uneven surfaces and odd contours. Despite this minor challenge, the cumulative school building PV installed capacity potential was calculated to be 40 MW, which would result in an electricity production of approximately 44 million kWh, or 13% of the commercial/school sector's electricity demand.

It is most difficult to calculate PV potential for private homes. Because homes in the county are heterogeneous and do not typically have flat roofs like commercial, industrial, or school buildings, it is much more difficult to calculate their PV potential. To do so, it was assumed that 80% of residential buildings in the county could install a PV system, and rural houses could install bigger systems than urban houses (for a full explanation of these assumptions, see the Residential Potential section on page 32). As such, the cumulative residential PV installation potential was determined to be 124 MW, which could generate approximately 136 million kWh annually, or around 68% of the 2008 residential electricity demand.

Table 1 below shows a breakdown of the PV potential in the county by sector. It should be noted that the calculated PV potentials are merely estimates, although it is reasonable to assume that the total electricity generation potential across all sectors is on the order of hundreds of millions of kWh.

Photovoltaic Potentials by Sector			
	Capacity Potential (MW)	**Energy Potential (million kWh)**	**Percent of Electricity Demand**
Commercial	86	95	27%
Industrial	22	24	17%
Schools	39	43	13%
Residential	124	136	46%
Total	**271**	**298**	**38%**

Table 1: *PV potential by sector. "Percent of Electricity Demand" refers to the energy potential in relation to each sector's 2008 electricity usage as stated in the* Tompkins County Community Greenhouse Gas Emissions Report, 1998-2008**.** *It should be noted that the individual energy potential for commercial and school buildings are described in terms of their ability to account for the demand by both sectors combined in the Greenhouse Gas report. In other words, the 95 million kWh energy potential of commercial buildings alone could account for 27% of both commercial and school building electricity usage.*

Unfortunately, the calculations above are estimates of the county's solar *potential* and do not necessarily represent an accurate prediction of the extent of future investment in solar photovoltaics within the county. The main deterrent against large scale solar energy development in Tompkins County has been the up-front costs associated with purchasing a solar system. However, within the past year or two, the price of solar photovoltaics has dropped precipitously, making solar energy systems more affordable for home and business owners. NYSERDA offers a solar energy financial incentive, along with tax incentives from the state of New York and the federal government. Alternative financing arrangements such as solar leases and power purchase agreements are becoming more popular, and some cities in the US have actually loaned money to residents to purchase and install solar systems, using a special property tax assessment to repay the loan.

Tompkins County itself has already taken steps toward a greener future with two major solar energy projects. The first was the installation of 147 kW of solar photovoltaic panels on the roof of the public library. To date, the system has generated 989,000 kWh of electricity, enough to power roughly 83 homes for a year. More recently, the county has entered into an agreement with Solar Liberty of Buffalo to install solar photovoltaic systems on top of 7 county buildings. Community leaders hope that these systems will help reduce the overall greenhouse gas emissions within Tompkins County.

Overview of Solar Energy

Solar energy is one of the most quickly evolving and exciting technologies available in the transition to a sustainable future. Although the cost of solar systems is rapidly decreasing and the efficiencies are improving, solar energy still faces some significant challenges. One inherent challenge of solar energy generation is its variability. Throughout the course of the year, the amount of sunlight in a given location is subject to both diurnal and seasonal changes that make it difficult to get a consistent and reliable supply of energy. Fortunately, since the sun's daily and seasonal paths are both predictable and mathematically calculable, changes in energy generation can be estimated to a certain degree. Weather can also affect the output of solar energy, but local historical averages can provide a reasonable estimate of future weather patterns.

The amount of energy that reaches the Earth's surface, also known as the *incident solar energy* or *solar insolation*, is very large. Much of the energy emitted by the sun is scattered or reflected by the atmosphere but about 21% of the sun's energy reaches the Earth as direct radiation and about 29% reaches as scattered or diffuse radiation. Over the course of a year, over 40,000 EJ (exajoules, a unit of energy defined as $1*10^{18}$ joules) are incident on the United States alone (Tester et al. 2005). For comparison, this dwarfs the total US energy consumption of around 100 EJ per year. If a 10% efficient solar farm were installed over just 1.6% of the U.S. land area (about 10 times the total area of all single-family residential rooftops), it would meet all of the country's domestic energy needs (DOE 2005). While solar insolation provides a huge energy potential, the aforementioned variability, low energy density compared to other sources of energy, land use requirements, and high relative costs have traditionally deterred large investments in solar energy.

There are two main ways that the sun's energy can be harvested. One method is called *photovoltaic solar energy,* commonly referred to as "photovoltaics" or simply "PV." This method uses light from the sun to generate electricity directly, which can be used just the same as electricity from a power plant. The majority of photovoltaic systems are *grid tied*, meaning they are interconnected with the electricity grid. This helps alleviate the variability issue, as the grid can supply electricity to a building if the PV system does not meet the demand. In addition, the grid can act as a de facto battery, accepting any extra electricity the PV system produces that is higher than the demand of the building. In more rare cases, usually in remote, rural areas, *standalone* PV systems are utilized, meaning they are not connected to the grid. Because they are not grid tied, standalone PV systems require large batteries to store the PV electricity for use during the night or on cloudy days. Due to the relatively high cost of batteries, these systems are more expensive than grid tied systems.

The second method for generating solar energy is called *solar thermal*, which uses thermal energy from the sun to generate heat instead of electricity. Oftentimes this energy is used to heat hot water, which can reduce the heating load of a home or business. Unfortunately they generate the least amount of energy during the winter when heating is needed the most. They work very well during the summer, though, and a large portion of a home's hot water needs during those months can be provided with a solar thermal system.

Focus of This Report

The main focus of this report will be an attempt to estimate the residential and commercial photovoltaic solar energy potential of Tompkins County. Additional information about solar thermal systems is also included. A basic overview of solar energy and the current state of photovoltaics is provided as an introduction to solar energy for anybody who is unfamiliar with the technology, followed by a more in-depth analysis of the PV potential of Tompkins County in particular. The PV potential of the county is broken down by sector: commercial, industrial, schools, and residential buildings. The commercial, industrial, and school building potential is relatively easy to determine, as most of these buildings have flat roofs with little to no shading obstructions such as tall trees or neighboring tall buildings.

The residential potential is a little more difficult, however, since houses generally don't have flat roofs and the amount of roof obstruction or potential for shading is unique to every house. Some houses may not have adequate roof space for a solar system or may have trees or neighboring houses that could cast a shadow on the solar system. Nonetheless an approximate estimate of the potential can be determined. It should be noted that this is merely a *potential* and there is a somewhat large amount of uncertainty in the estimate. Also, it should not be mistaken for a prediction of the amount of solar energy that will be installed in the county. There is a wide range of variables that will affect the actual amount of solar energy produced in the county, and only the future will tell what the level of solar energy investment in the county will be.

Solar Energy Trends

United States

Over the past few decades, the United States has shown an ever increasing interest and demand for solar energy. In 2011, the US more than doubled its solar PV capacity compared to 2010, adding enough capacity to power more than 370,000 homes (Shahan 2012). According to analysts at Ernst & Young, the U.S. is the second most attractive country in the world for renewable energy, behind China and ahead of Germany. According to the same index, the state of New York is tied with Maine, Pennsylvania, and Nevada for 8th most attractive state in the country for renewable energy (Ernst & Young 2012).

Leading the way last year in terms of number of PV systems installed were California and New Jersey, with New York in 7th place behind Pennsylvania (Shahan 2012). One main reason for the solar success of New Jersey and Pennsylvania has to do with the states' implementation of Solar Renewable Energy Certificates (SRECs). These are credits that owners of solar systems receive based on the amount of energy generated by their solar systems. Energy suppliers are required by the state to produce a given amount of energy from solar energy and can buy SRECs from home or business owners who produce solar energy (SREC Trade). These programs have been very successful in promoting the growth of solar energy, but may have become "victims of their own success" as the large number of solar installations is pushing down the price of SRECs (Ernst & Young 2012). The current low price of SRECs should slow down the rate at which New Jersey and Pennsylvania solar installations advance, at least for the short term.

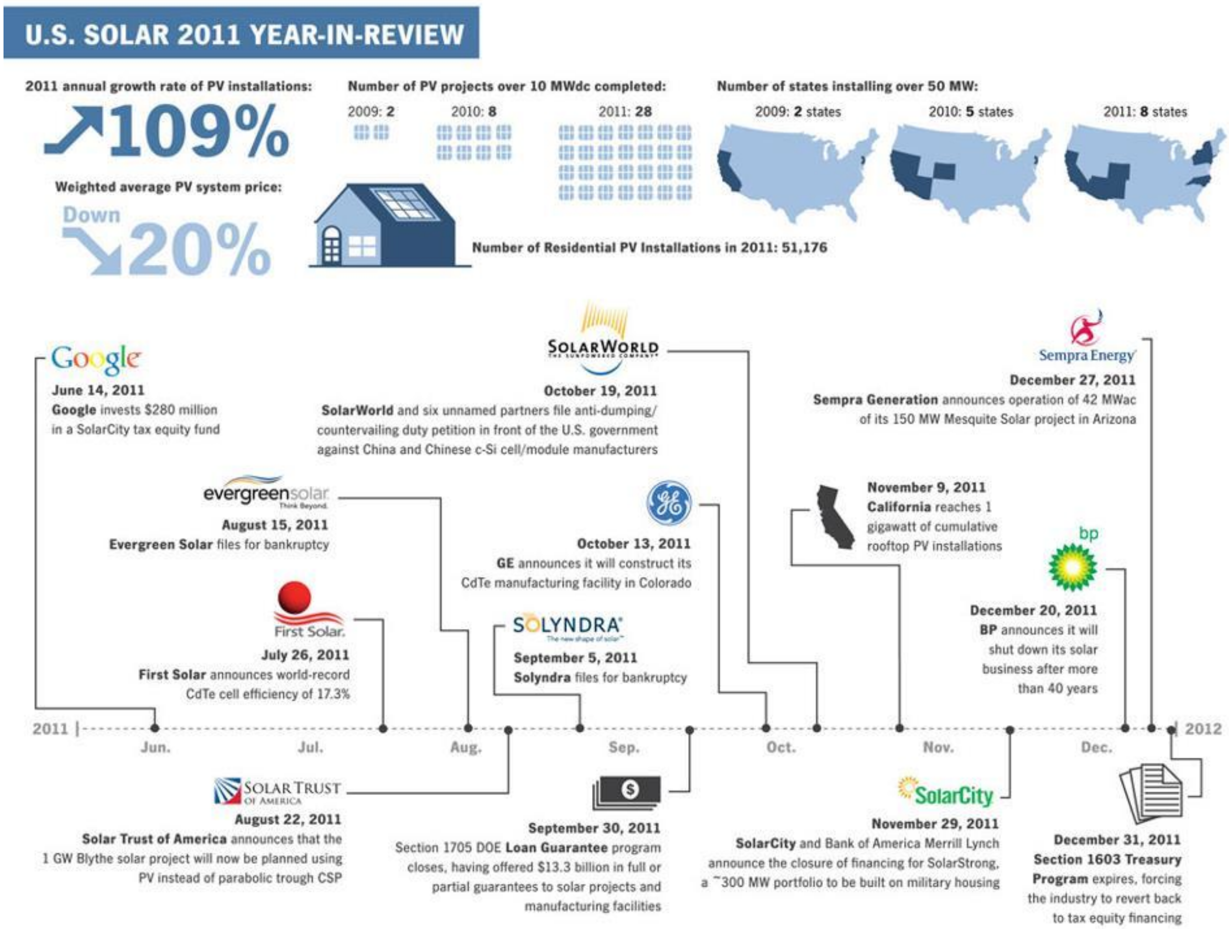


Figure 1: *The US Solar Year-In-Review. This essentially sums up the big news and developments in the US solar market during 2011.*

Tompkins County

Currently, according to NYSERDA, Tompkins County is a photovoltaic leader in central New York. The county has 211 solar PV systems overall, while the surrounding counties are lagging significantly behind, as can be seen in **Table 2**. (PowerClerk)

Tompkins and Surrounding Counties

County	No. of Systems
Tompkins	**211**
Tioga	33
Cayuga	32
Cortland	20
Chemung	19
Seneca	11
Schuyler	10

Table 2: *Number of installed photovoltaic systems in Tompkins and surrounding counties. It is clear that Tompkins County is the PV leader in central New York. (Data gathered from PowerClerk 2012).*

Looking at the state as a whole, Tompkins County currently ranks 7th in number of PV systems, recently passing Queens County (201). When accounting for population, however, the county ranks 2nd, with nearly 21 systems per 10,000 residents, as shown in **Table 3**.

Leading PV Counties of New York

County	No. of Systems	Population	Systems per 10,000 Residents
Columbia	232	63,096	**36.8**
Tompkins	**211**	**101,564**	**20.8**
Ulster	376	182,493	**20.6**
Dutchess	379	297,488	**12.7**
Albany	232	304,204	**7.6**
Westchester	352	949,113	**3.7**
Erie	315	919,040	**3.4**

Table 3: *Table showing the top 7 counties in New York in terms of number of PV installations. Tompkins County ranks 7th in number of installations but 2nd in installations per 10,000 residents. (PV data gathered from PowerClerk 2012. Population data gathered from the US Census Bureau).*

Of the 211 PV systems in Tompkins County, 176 are residential, 22 are commercial/industrial, and 13 are government/non-profit. According to the 2010 census and GIS data obtained from the Tompkins County Planning Department, there are 38,967 households, 2,118 commercial buildings, 232 industrial buildings, and 937 school buildings. As such, there exists a huge potential for rooftop solar installations in the county, which will be discussed further in the Tompkins County PV Potential section.

Resource Assessment

The most important aspect of generating solar energy is what is called *solar insolation*. This is the amount of solar energy that reaches the Earth's surface for a given location. This is usually expressed as energy per unit area for a given time period. For example, an area that has an insolation of 1500 kWh/m^2/year receives 1500 kWh of solar energy for every square meter of land area over the course of a year. This does not mean, however, that this area could annually generate 1500 kWh of solar electricity for every square meter of land area. This is limited by the efficiency of the PV cell converting the sun's light to electricity, and this efficiency is relatively low (~11-15% for low to average cells and ~15-20% for top of the line cells).

At first glance, Tompkins County may not seem like an ideal place for solar energy. When compared to Germany, the worldwide leader in solar energy, however, Tompkins County actually proves to have a better solar resource. Much like Tompkins County, Germany has a large number of cloudy days throughout the year. Overall, Germany gets an average of 1,500 hours of sunshine per year, or a little less than 63 full days' worth of sunlight ("Germany").

Figure 2 shows the average annual solar insolation of the United States and Germany. The map shows that nearly the entire contiguous United States receives more sunlight than Germany. According to the map, Tompkins County receives around 1500 kWh/m^2/year, while Germany only receives around 1000-1100 kWh/m^2/year. Nevertheless, Germany has an installed photovoltaic capacity of 17,320 MW, compared to an installed capacity of 3,954 MW in the US (German BMU & GTM Research 2012). While much of Germany's solar success is due to its more generous governmental funding programs, it is encouraging that solar energy can utilized in a country that has a lower-grade solar resource than Tompkins County.

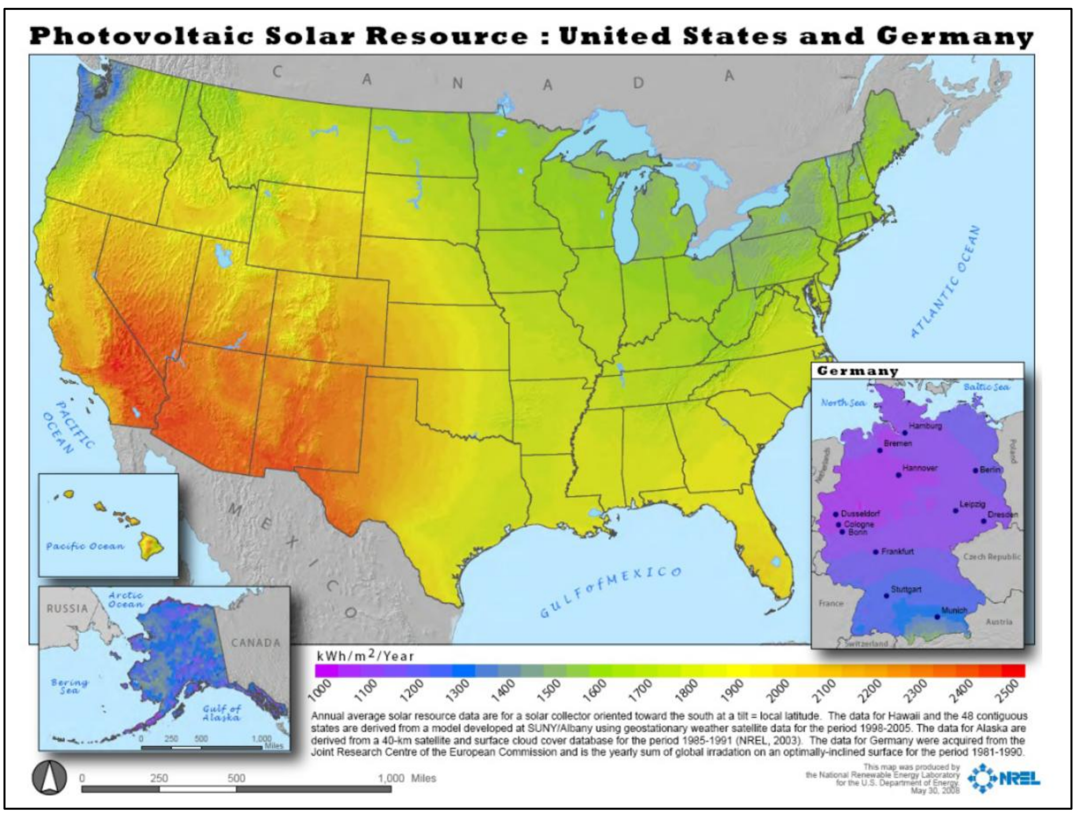


Figure 2: *Annual average solar insolation of the United States and Germany. This figure shows that almost the entire contiguous United States receives more sunlight than anywhere in Germany.*

Photovoltaic Basics

PV Overview

Solar photovoltaic systems utilize the photoelectric effect present in semiconductor materials to turn solar energy directly into electricity. When speaking of photovoltaics, there are a number of terminologies that are used to describe certain aspects of a system. First, the electricity is actually generated in what is called a *solar cell*. Each cell is only a few square inches (**Figure 3**) and only generates a small amount of voltage. However, a number of cells wired together in series increases the voltage in what are known as *panels* or *modules*. Both terms are commonly used and will be used interchangeably throughout this report. A typical photovoltaic panel rectangular measuring a few square feet and typically consists of 36 cells connected in series (Kissell 2012). **Figure 4** shows how individual cells are typically strung together to form a panel.

Figure 3: *Typical size of a solar cell. These are what actually generate the electricity in a PV system, and a number of them are strung together to form a PV panel.*

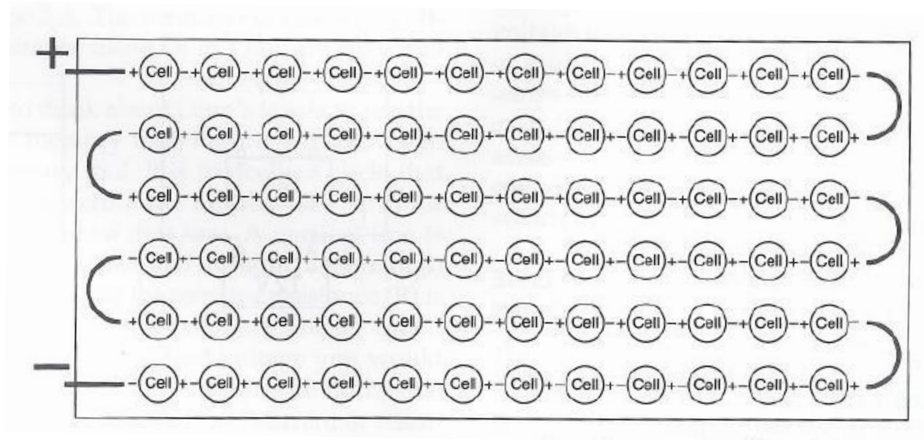


Figure 4: *A schematic of a typical photovoltaic panel. 36 individual PV cells are connected in series to create the panel, also known as a module.*

Most of the time, solar PV systems consist of more than one panel. When a number of panels are arranged in series, this is referred to as a *string.* Multiple strings can then be arranged at a single site to form an *array*. **Figure 5** shows an example of a 6 panel array, consisting of two 3 panel strings.

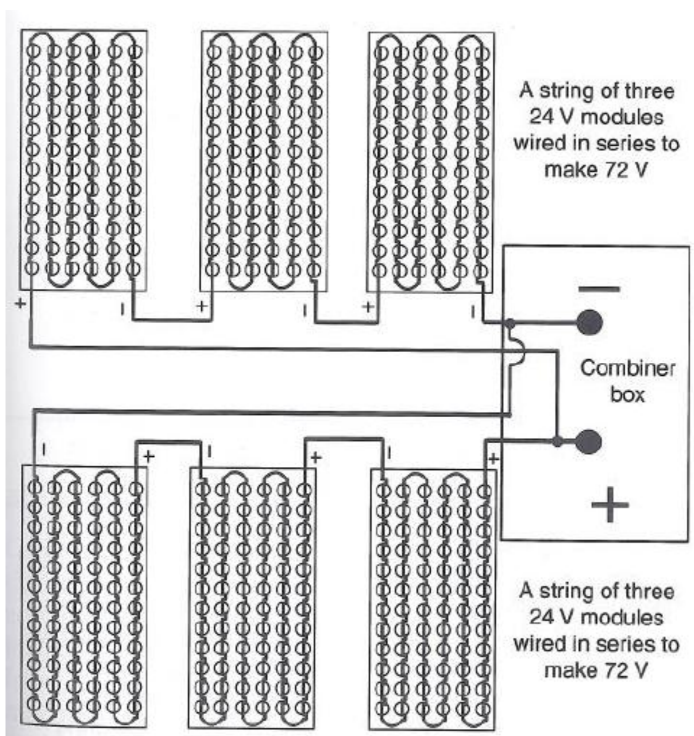


Figure 5: *An example of a PV array consisting of two strings of 3 panels each.*

In order for PV panels from different manufacturers to be compared on an equivalent basis, they need to be tested according to universal standards. Each PV manufacturer must subject their panels to a laboratory rating system, where they are tested under 1,000 W/m^2 irradiation and 25 ^{o}C temperature. The amount of power that the panel produces under these conditions is then referred to the panel's *nameplate rating*. The nameplate rating is in units of Watts, and referred to as the panel's *watt-peak* rating and given the symbol W_p. Oftentimes the "peak" portion is understood and panels are referred to in Watts. For example, a 250 W panel will produce 250 watts of power under laboratory conditions. However, it will not necessarily produce 250 W of power when installed, because conditions in the real world are not always as ideal as in the laboratory. Most of the time in Tompkins County, the panel will likely receive less sunlight than in the laboratory, and will produce less than 250 W. The system will produce less than 2 kW most of the time, but at times when the sun is very intense, it could actually produce more than 2 kW. If this panel is combined with 7 other 250 W panels into an 8-panel array, it will have a nameplate rating of 2,000 W (2kW).

Inverters

Panels are not the only piece of equipment associated with a photovoltaic system. Because solar panels produce *direct current* or DC power, and the electricity grid uses *alternating current* or AC power, the DC current from the array needs to be converted to AC before it can be used by electrical appliances or sent to the grid. To convert the electricity, a complex piece of electrical equipment, called an *inverter*, uses various algorithms to operate the PV system at maximum power. Inverters tend wear out much sooner than PV panels, and many are only warrantied for 5-10 years as compared to 20-25 years for most panels. As such, many firms are looking into producing more reliable inverters that will have a longer life (Cleantech 2009).

Current PV Cell Materials

Throughout the course of photovoltaic development, there have been three generations of solar cells, broken down by the materials they use and their cost. By far the most frequently used solar panels today are first generation panels made from crystalline silicon (c-Si). This is because of the high efficiency of silicon panels and the long history of silicon solar cell development and use.

There are two types of crystalline silicon cells: monocrystalline (mono-cSi) and polycrystalline (poly-cSi). Mono-cSi cells are produced in a very highly specialized process, identical to the process of developing silicon computer chips. These cells have the highest efficiency of silicon based cells, but they are also the most expensive. Poly-cSi cells are made in a less exacting fashion and therefore have a lower efficiency but also lower cost. Mono-cSi panels require approximately 60 ft^2 of panel area per kW of installed capacity, while poly-cSi cells need up to 120 ft^2 of panel area for each kW of installed capacity (Kissell 2012). Traditionally, crystalline silicon panels have had a relatively high price, but their price has recently plummeted, making these types of panels more cost effective in the short term.

In addition to c-Si cells, there are a number of different technologies being studied and developed that show promise moving forward. Second generation cells, commonly referred to as "thin films," have a lower efficiency than c-Si cells, but have also traditionally had a lower cost. They are also much thinner and lighter than c-Si cells and can contour to odd shapes and building angles. **Figure 6** provides typical characteristics of c-Si cells and thin films.

Type	Fabrication	Advantages	Disadvantages	Efficiency (commercial)
Monocrystalline	Single-crystal wafer cells cut from cylindrical ingots	Efficient, long lifetime	Expensive, rigid	15- 20%
Multicrystalline (Polycrystalline)	Cut from square cast ingots	Less expensive, long lifetime	Less efficient, Rigid	~ 12%
Thin film (silicon or non-silicon)	Depositing thin layers of PV material on a substrate	Less expensive, flexible (good for BIPV), relatively long lifetime	Less efficient	6 - 11%

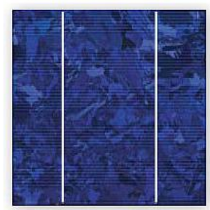


Figure 6: *Characteristics of monocrystalline, polycrystalline, and thin film PV cells. Below the table are pictures of typical monocrystalline, polycrystalline, and thin film cells, respectively. BIPV refers to "Building Integrated PV," which incorporates PV panels into the construction of new buildings.*

The three main types of thin film solar cells are amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS). Amorphous silicon has struggled to gain market share because of its low conversion efficiency and seems to have lost out to CdTe and CIGS as the main thin film technologies. CdTe was pioneered by First Solar, which is now the worldwide leader in PV production (**Figure 8**). This is currently the most cost effective technology but its lower efficiency has decreased its popularity compared to crystalline silicon (PVInsights). CIGS has shown to have higher efficiencies in the laboratory but it is much more complicated to produce than CdTe, so it has lagged behind. Many people are optimistic about the future of CIGS because of its high efficiency, but firms need to figure out how to economically commercialize the process before it can gain significant market share (Grana 2010).

Future PV Materials

Third generation cells are cells that are mostly experimental at this point, but show promise if they can be commercialized. There are a number of different types of third generation cells, but they all have higher efficiencies than silicon based cells and should be less expensive to produce. If these cells do happen to be developed and commercialized, many of the limitations of solar energy would be lessened, namely cost and efficiency.

A graph of the efficiency vs. cost of the three generations of PV modules is shown below in **Figure 7**. The diagonal dashed lines represent the module cost per watt, while the horizontal dashed lines represent different physical limitations on PV cells. The "Shockley-Queisser limit" indicates the highest theoretical efficiency that current generation 1 and 2 cells can reach. Some cells have approached this limit in the laboratory, but commercially available cells only reach efficiencies in the upper teens and, recently, 20 percent. The "ultimate thermodynamic limit at 1 sun" line indicates the theoretical efficiency limit of advanced technology cells without the benefit of concentrators, i.e. mirrors or lenses that concentrate the sunlight. Finally, the "thermodynamic limit at 46,200 suns" line indicates the efficiency possible with advanced cells at the highest theoretical concentration level (Cartlidge 2007).

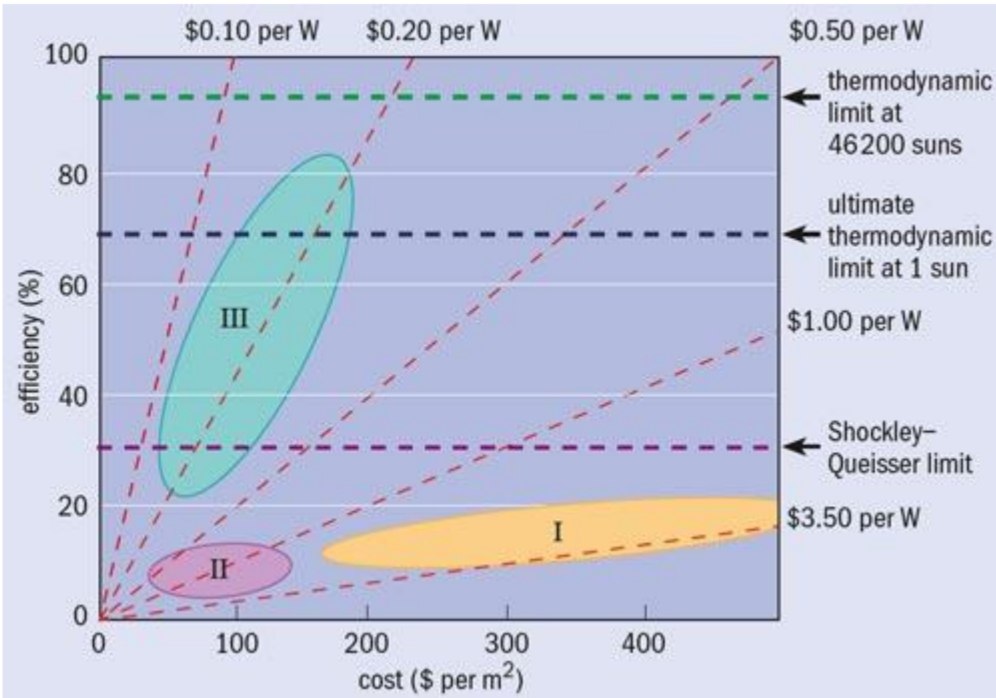


Figure 7: *Efficiency vs cost of three generations of solar cells. The dashed diagonal lines represent the module cost per watt peak and the dashed horizontal lines represent the physical limitations of solar cells. Note: this is not the total installed cost of the system, just the module cost.*

The takeaways from this chart are the fact that second generation thin film cells are less expensive but also less efficient than first generation cells, while third generation cells are both less expensive and more efficient. Current c-Si cells range $1 per watt and around $3 per watt, and ~12% efficiency to 20% efficiency (see **Table 14** for a description of average module costs). If scientists and engineers are able to develop third generation solar cells on a commercial scale, they could be economically feasible without any sort of government intervention or financial subsidy.

Module Efficiencies

As mentioned before, every commercially available PV module is tested according to standard test conditions (STC). These conditions are specified as 1000 W/m^2 (92.9 W/ft^2) irradiation at 25 ^oC (77 ^oF) module temperature and the tests are carried out in a laboratory. These conditions allow a direct comparison between different modules from different companies and even different technologies. The efficiency of the module is related to its watt peak rating and surface area by the following equation:

$$Watt\ Peak\ Rating = \eta * A * 92.9\frac{W}{ft^2}$$

Where η equals the module efficiency, A is the module surface area in ft^2 and 92.9 W/ft^2 refers to the laboratory test conditions. If the efficiency of the module is known, the surface area can be calculated from the above equation. **Table 4** shows the module surface area for each kW of installed capacity. This will not equal the total surface area of the array, however, since there are other mounting components that are required to support the modules.

For each kW of installed capacity:

Module Efficiency	Module Surface Area (ft^2)
10%	109
12%	91
14%	78
16%	68
18%	61
20%	54

Table 4: *Module surface area for different efficiencies for each kW of installed capacity. Note: module area will not equal the total installed area of the system. Instead this only refers to the module area and does not account for the frames that hold the modules or any spacing between the modules for other components.*

So for the same amount of installed power, more efficient modules will require less area, a consideration for homeowners with limited roof area. While higher efficiency panels tend to be more expensive, this higher cost is somewhat offset by the need to buy fewer panels for the same capacity, as well as the decrease in mounting hardware required and lower installation costs associated with installing fewer panels.

Temperature Effects

One of the more ironic aspects of solar PV systems is the fact that electricity output decreases with increasing temperature. In other words, as panels receive more sunlight, they could lose efficiency if the panels begin to heat up. In some cases electricity output can decrease by 10-25% depending on location and type of panel. Different panels are affected differently by temperature, which is determined by each panel's *temperature coefficient*, listed on the panel's manufacturers' data sheet as "temperature coefficient Pmax." As an example, the temperature coefficient of a Suntech 190 W monocrystalline module is -0.48%, which means that every degree above 25 ^oC (77 ^oF), the maximum power possible from the panel is reduced by 0.48% (Solar Facts).

If, for instance, a panel on a rooftop during a hot summer day heats up to 45 ^oC (113 ^oF), its energy produced would be 10% lower than at 25 ^oC (77 ^oF). Conversely, on a cool sunny day when the temperature is lower than 25 ^oC, the panel's energy output would actually increase (Solar Facts). This could even out some of the lost energy during the hot months, but because the sun is out longer during the summer, the overall temperature effect would likely be negative.

Typically, c-Si solar panels have a temperature coefficient in the range of -0.44% to -0.50%. Sunpower's E20 series monocrystalline modules have the lowest commercially available temperature coefficient at -0.38%, as well as the highest module efficiency at 20.1% (Solar Facts and Sunpower Data Sheet).

Panel Degradation

Over time, photovoltaic panels slowly begin to degrade and produce less power than when they were new. One widely held assumption about PV systems degradation is that a panel will lose about 1% of its efficiency per year (Note: this does not mean that a panel with 15% efficiency will be 0% efficient in 15 years. It means that it will produce 85% of the energy in year 15 as compared to year 1, i.e. reducing its overall efficiency to 12.75%). Branker, Pathak, and Pearce found this assumption to be unreasonably conservative and suggested a degradation rate of 0.2% to 0.5% per year. Even older panels produced in the 1980s have been shown to degrade slower than the customary 1% mark and some even still perform to their original specifications. (Trabish 2011, and Dankoff and Schwartz 2007). As technologies advance, panel degradation rates should only decrease, and perhaps even disappear altogether.

Current PV Manufacturers

Figure 8 shows the top 10 photovoltaic manufacturers in terms of market share. First Solar is the only thin film manufacturer as well as the current worldwide leader in production. This is due to the company's downstream-integrated business model that few other firms have been able to follow (Colville 2012). It will be increasingly difficult for thin film manufacturers to compete moving forward, given the price competitiveness that c-Si panels have developed.

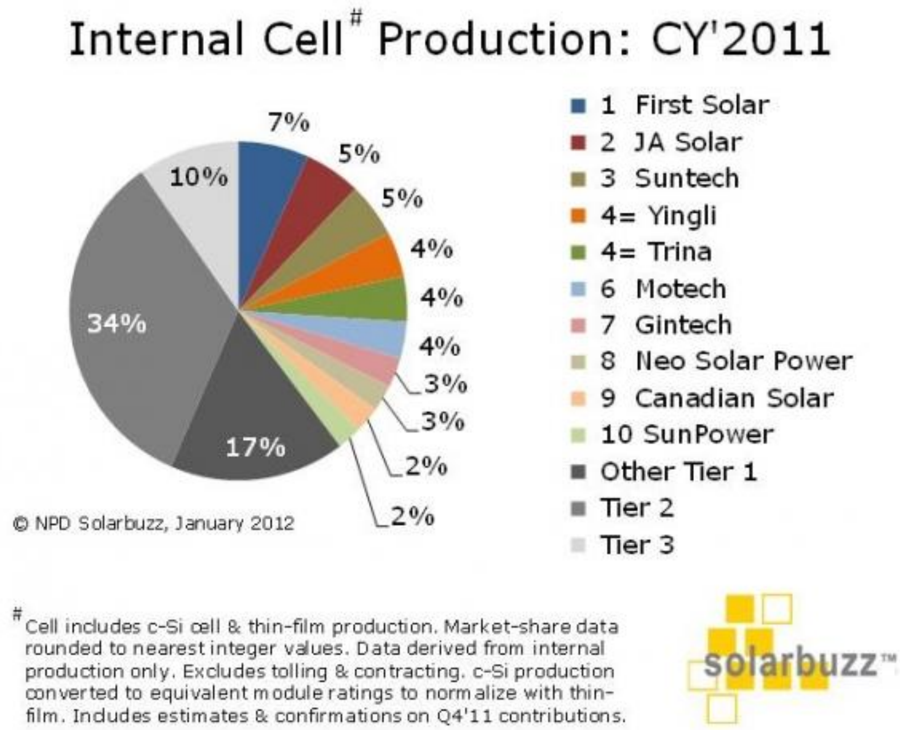


Figure 8: *Leading PV manufacturers in terms of market share. First Solar is the largest and only thin film manufacturer on the list. Chinese and Taiwanese companies occupy 8 of the top 10 spots, with Fist Solar (US) and Canadian Solar (Canada) the only two exceptions.*

Residential Photovoltaic Systems

One aspect that makes photovoltaics appealing is the simplicity and minimal operating costs and maintenance. Once the panels are installed, they are essentially left in place for about 20 to 30 years with little to no maintenance. The major stumbling block for large scale implementation of photovoltaic systems is the high up front cost. The monetary savings resulting from a solar system may be greater than the initial cost of installation, but oftentimes individuals don't have the money up front to pay for the system. Fortunately, there are a number of financial incentive and tax programs that individuals who wish to install photovoltaic systems may utilize. These programs are discussed in-depth in the PV Financial Programs and Incentives section on page 40.

Location of Panels

One of the first concerns when determining the feasibility of a photovoltaic system on a residence is the location and orientation of the panels. In general, solar panels need to be located in areas with minimal shading between the hours of 9:00 a.m. and 3:00 p.m. (Renovus). Panels typically need to face South and can be mounted either on the roof of the home or on the ground. If homeowners have adequate South-facing roof space, they will likely elect to mount the panels on the roof.

Figure 9 below shows an example of a roof mounted PV system. Roof mounted systems are less expensive than ground mounted systems (**Figure 10**) due to the large foundations and wiring requirements needed for ground systems. However, ground mounted systems allow the homeowner to change the angle of the panels seasonally to generate the most energy throughout the year (Renovus). There are a few other options for roof mounting that do not require the panels to sit flat on a south-facing roof, as shown in **Figure 11**.

Figure 9: *Roof mounted PV system. Notice the lack of trees and other obstructions that could potentially shade the panels. Also notice the slope of the panels allows snow to slide off instead of accumulating.*

Figure 10: *Ground mounted PV system. The tilt of the array can be adjusted from the ground to adapt to different seasonal sun conditions.*

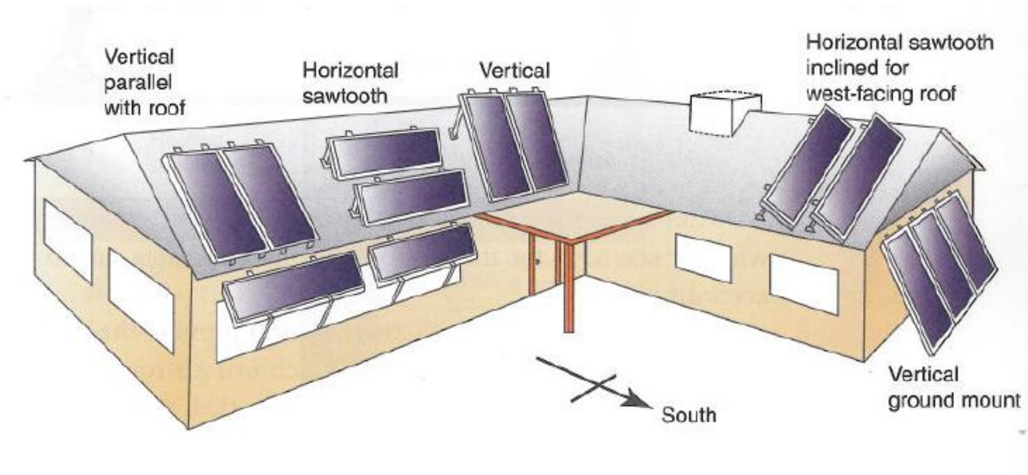


Figure 11: *Examples of various panel orientations for different roof conditions to ensure the panels are facing south and at the correct tilt angle.*

Tilt Angle

Once the location of the panels is decided, their *tilt angle* needs to be determined. This is the angle that the panels make with the ground and can have an effect on the energy output of the system. Since the sun takes different paths through the sky at different points throughout the year (**Figure 12)**, the tilt of the panels will affect the seasonal output of the PV system. During the summer, the sun takes the longest, highest path through the sky, allowing for the most PV energy during this time.

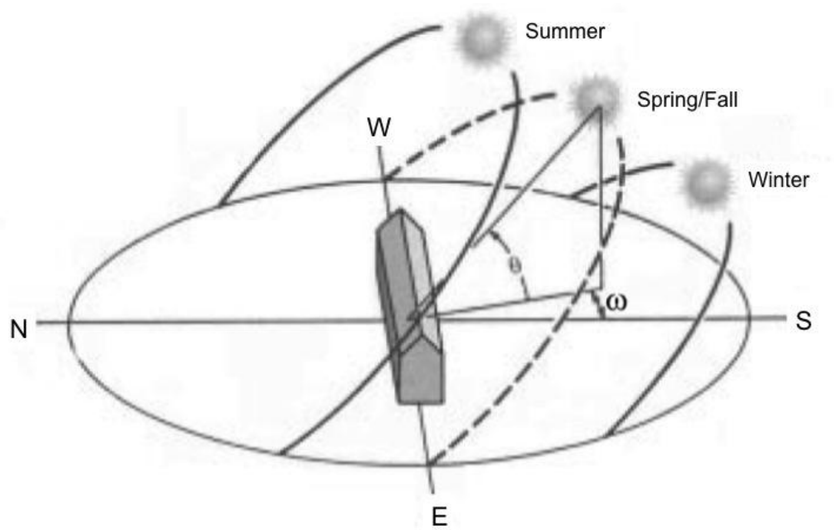


Figure 12: *Path of the sun at different points throughout the year*

If the panels are to be installed on a rooftop, the best option is likely to install them flat on the roof. This is because it is the least costly method and differences in tilt angle have a small effect on PV system output, as shown in **Table 5**.

PV Array Tilt Angle by Roof Pitch

Roof Pitch	Tilt Angle (^{o})	kWh per Installed kW
4/12	18.4	1,084
5/12	22.6	1,098
6/12	26.6	1,109
7/12	30.3	1,114
8/12	33.7	1,116
9/12	36.9	1,114
10/12	39.8	1,110
11/12	42.5	1,105
12/12	45.0	1,095

Table 5: *Array tilt angles based on roof pitch and energy generation potential as estimated by historical weather data. Tilt angle has a minimal overall effect on the amount of electricity generated over the course of a year*

One advantage of ground mounted systems is the ability to change the tilt of the panels seasonally to optimize their output. **Figure 13** shows how a ground mounted system can be adjusted throughout the year to optimize electricity generation.

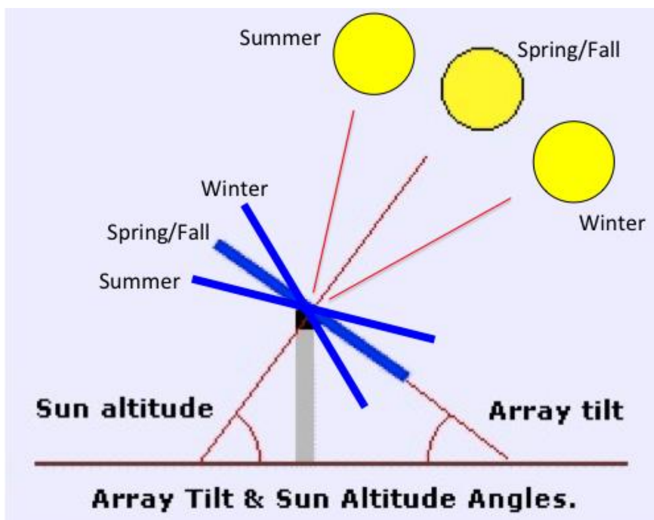


Figure 13: *Effect of seasonal sun changes on energy generation. As the figure shows, the summer sun is higher in the sky, requiring a smaller array tilt to optimize solar energy collection during this time.*

Shading

One of the most important aspects to take into consideration when siting a PV system is shading. Even small amounts of shading such as leafless tree branches or small rooftop obstructions can have dramatic impacts on the solar electricity generation of a PV system. Since the cells and panels are connected in series (**Figure 4** and **Figure 5**), a single shaded cell can limit the electricity production of the entire string (**Figure 14**). A common analogy is the frustrating situation when one bulb in a string of Christmas lights makes the whole strand go out.

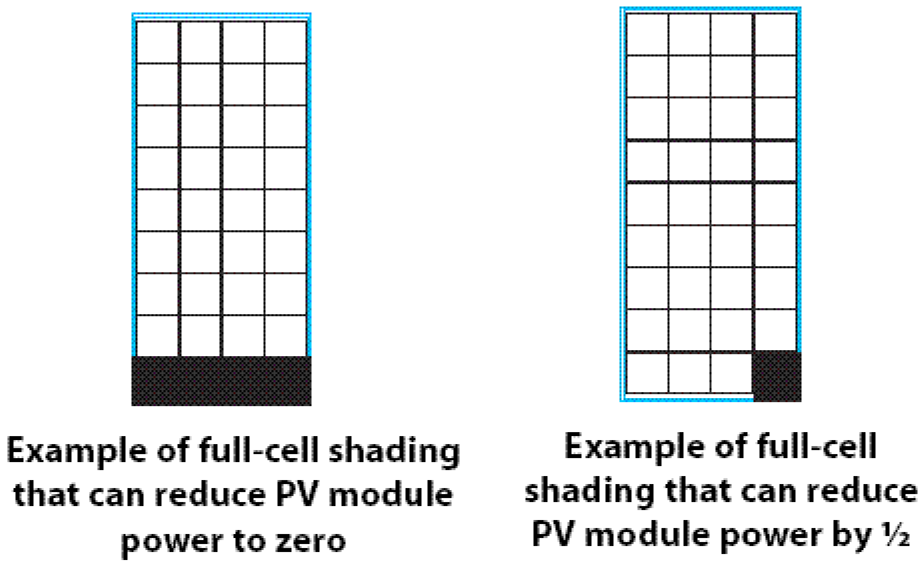


Figure 14: *Shading effects on a PV module. These situations assume the system uses a centralized inverter. If the system used microinverters, the PV power would only be reduced by the cells that are shaded instead of affecting other cells in the string.*

The reason that this occurs is due to the operation of the inverter. Since most inverters are centralized, they attempt to maximize the output for the entire system, instead of each individual panel. A solution for this would be to use panels with *microinverters*, which are small inverters that maximize the output for each panel individually. If one panel is shaded, only the output from that panel is affected, not the entire string like is the case with centralized inverters. Microinverters add to the cost of a system, however, and it is estimated that microinverters cost 52₵ per watt, compared to 40₵ per watt for a centralized inverter (Dolan 2010). In other words, microinverters will add $120 for every installed kW of PV capacity. This could be made up over the life of the system, however, through decreased shading losses. In addition, microinverters tend to last longer than centralized inverters, which could actually result in a lower lifetime cost of the system if the centralized inverter has to be replaced after the warranty has expired.

Some companies are beginning to offer *dual microinverters*, which are microinverters that service two panels instead of one. This means that a system would need half the amount of microinverters than a system with a microinverter for each panel. This would result in costs that are comparable to systems with centralized inverters, but 5-20% more energy produced (Osborn 2011).

No matter the type of inverter, every precaution should be taken to ensure the panels receive direct sunlight without shading for the majority of the day. Many PV installers will provide a site evaluation and shading assessment prior to installing a system to ensure the location is ideal for PV generation (Enviroharvest).

Solar Easements

One issue that may concern residents before installing a solar energy system is the possibility of neighbors constructing or planting something that may obstruct the amount of sunlight incident on their PV array. A solar easement prohibits neighboring property owners from this, ensuring the solar system will not be blocked by the actions of neighboring residents. A typical solar easement will contain a description of the dimensions of the easement, including horizontal and vertical angles measured from the solar installation as well as conditions for revision and termination of the easement (Garrard 2011).

New York State's solar easement provision is outlined in CLS Real Property Statute 335-b, which describes the aforementioned terms and a request for provisions for compensation in the instance that a solar installation is blocked (CLS 335-b). Like many other states, solar easements are voluntary contracts that can ensure uninterrupted solar access for solar energy systems. They are required to contain, at a minimum, information describing "the easement location and orientation to real property subject to the easement, provisions for termination, and provisions for compensation in the event that interference occurs" (DSIRE, Solar Easements).

The full text of CLS 335-b can be found here:
http://www.dsireusa.org/documents/Incentives/NY01R.htm

In addition to the general solar easement provision, New York General City, Town and Village codes allow local zoning districts to enact regulations regarding solar access within a municipality. The intent of the legislation recognizes "access to solar energy as a valid public purpose within the zoning authority of local governments." (DSIRE, Solar Easements).

This full legislation regarding municipal zoning can be found below:

General City: http://www.dsireusa.org/documents/Incentives/NY01Rb.htm

Towns: http://www.dsireusa.org/documents/Incentives/NY01Rc.htm

Villages: http://www.dsireusa.org/documents/Incentives/NY01Rd.htm

Solar Thermal Systems

Solar thermal systems differ from PV systems in the fact that they collect and store heat from the sun, instead of producing electricity. One of the most typical and practical applications of a solar thermal system is hot water heating. The heat from the sun is collected with a solar thermal collector and the heat is then transferred to water in the house, reducing the heating load of the house.

The most common type of solar thermal collector is a flat-plate collector, which is similar in size to a PV module, but operates much differently. It consists of a metal box with a tempered glass coating, called *glazing* to protect it from the elements. Inside the collector is an *absorber*, which is frequently a copper plate with copper tubing fastened to it. The top of the absorber is coated with a dark paint with a special absorber to ensure it absorbs the most amount of solar heat possible. As the plate heats up, energy is transferred from the plate to a fluid circulating through the copper piping, which is then either pumped directly to the house to be used or to a heat exchanger that gives off its thermal energy to water that is used in the house (Steeby 2012). **Figure 15** shows the typical setup of a flat-plate solar thermal collector.

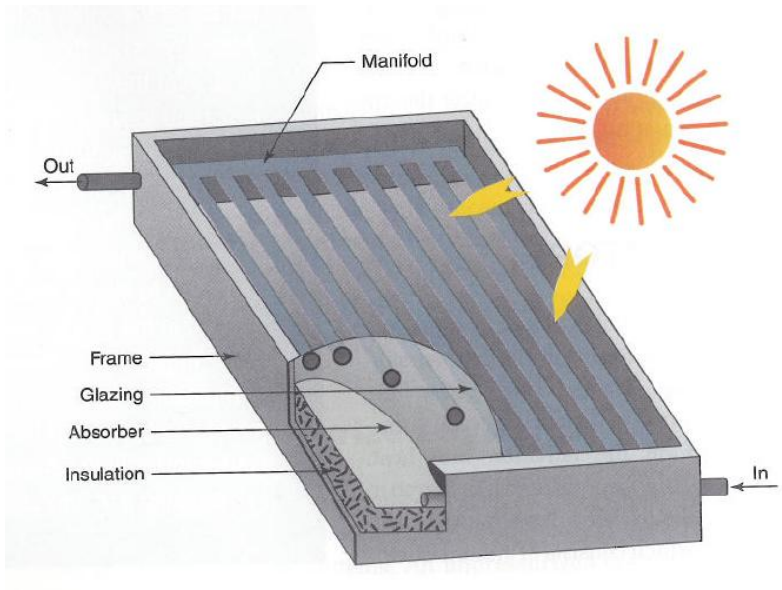


Figure 15: *Typical arrangement of a flat plate collector. The sun's energy is absorbed by the absorber, which is then transferred to a fluid that is used to heat water in the home.*

A typical residential solar hot water system will need 100 to 120 ft^2 of collector panels for hot water needs. If electricity or propane are currently used to heat water in a household, electricity rates above 7 ₵/kWh or propane prices above $1.25 per gallon could make solar water heating an attractive investment. At these rates, an average household could save between 50% and 80% of the total cost of heating their water (Steeby 2012). A typical solar thermal hot water system is shown below in **Figure 16**.

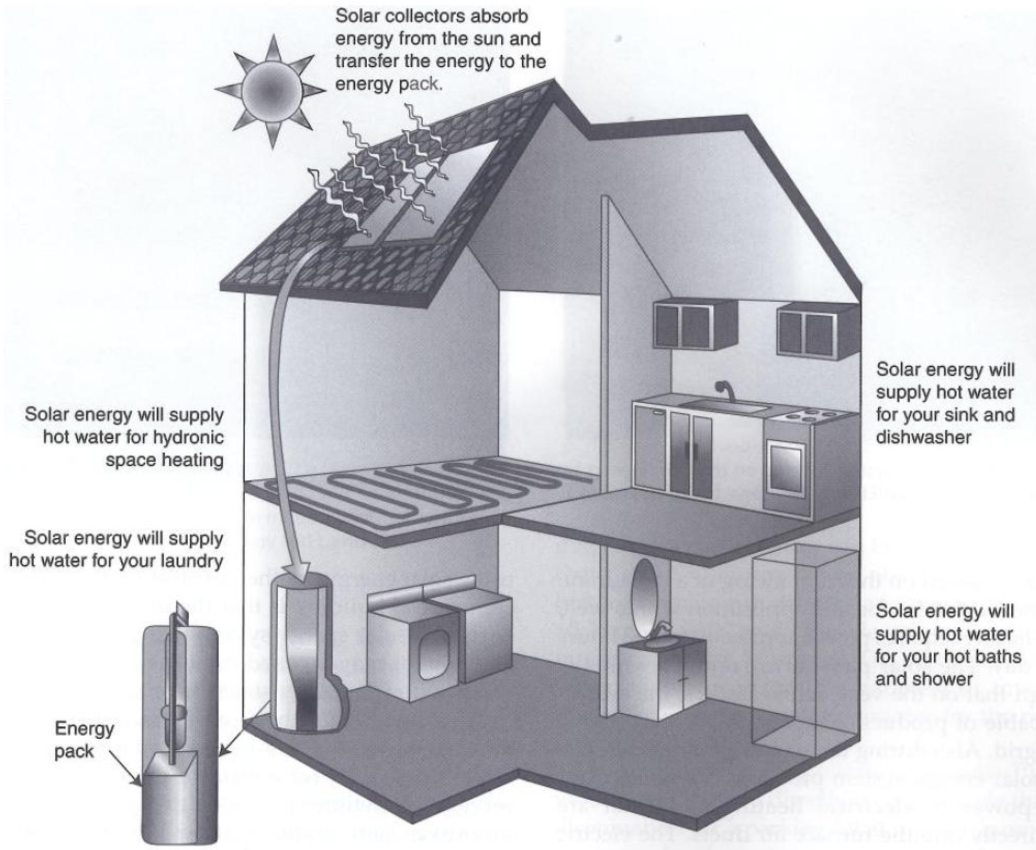


Figure 16: *An example of a typical solar thermal hot water system. The heated water is stored on the bottom floor, which is then circulated throughout the house for hot water uses such as bathing and washing clothes. In addition, the hot water can be circulated through pipes in the floor or through radiators in the winter to heat the home.*

An alternative use of solar water heating is pool and/or spa heating. The use of solar thermal heating systems for swimming pools has grown to be the number one application of solar energy in the United States today. When a solar thermal pool heating system is appropriately sized and installed, it can pay for itself in 2 to 3 years (Steeby 2012).

Tompkins County PV Performance

In My Backyard Tool

In order to specifically assess the solar energy resource potential in Tompkins County, NREL's "In My Backyard" (IMBY) tool was utilized.

IMBY can be found here: http://www.nrel.gov/eis/imby/

This tool is a variation of NREL's PVWatts tool that uses a model developed by Richard Perez from SUNY Albany in conjunction with NREL for the U.S. Department of Energy. This model uses hourly radiance images from geostationary weather satellites, daily snow cover data, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the hourly insolation falling on a horizontal surface. From there, calculations are performed to determine insolation for a specified tilt angle (NREL).

Since there are a variety of different sized PV systems in the County, three representative sized systems were used with IMBY: 2 kW, 4 kW, and 6kW. These roughly represent a "small, medium, and large" spectrum for residential PV systems. Since PV systems generally require about 100 ft^2 of roof space for each kW of installed capacity, the 2, 4, and 6 kW systems would require approximately 200, 400, and 600 ft^2 of roof space. A 2 kW system might be ideal for a more densely populated area, with many obstructions and limited roof space.

The average size of the 8 systems currently installed in downtown Ithaca is 3 kW, so the 2 and 4 kW systems should provide a reasonable estimate of the range of system sizes in a more urban environment. A 6 kW system would be suitable for a rural setting or an isolated home with a large roof or an appropriate amount of land. NYSERDA only incentivizes residential systems 7 kW and smaller, so larger systems will be ignored.

To run the IMBY tool, the pre-programmed settings (a list and description of which can be found in **Appendix B**) were used to determine the energy output for each system size in Tompkins County. Over the course of the year, IMBY calculated that for each kW of installed capacity, approximately 1,100 kWh of electricity are generated. **Table 6** shows the electricity generation potential for each system over the course of a year.

System Size:	2 kW	4 kW	6 kW
kWh Generated:	2,200	4,400	6,600

Table 6: *Yearly anticipated electricity generation for 3 different sized systems in Tompkins County*

Average Residential Electricity Demand

According to the Tompkins County Community Greenhouse Gas Emissions Report 1998-2008, the county used 293 million kWh of electricity for residential purposes in 2008 (TCPD). According to this same report, there were 37,443 households at this time, corresponding to an average residential electricity usage of 7,837 kWh per year:

$$Average\ household\ demand = \frac{293\ million\ kWh}{37{,}443\ households} = 7{,}837\ \frac{kWh}{household}$$

This is merely an approximation and every household is different, but this number can be used to get a reasonable estimate of the benefit of installing residential PV systems. **Table 7** shows the amount of electricity that each size system would provide for the average household in the county. Even the smallest system would provide over one quarter of the total electricity needs for the average residence in the County. The size of each system would have to be determined by each individual homeowner based on cost, available area, and desired amount of energy produced.

Avg. Household Demand: 7,837 kWh

System Size:	2 kW	4 kW	6 kW
kWh Generated:	2,200	4,400	6,600
% of Avg. Household Demand:	28%	56%	84%

Table 7: *Yearly anticipated electricity generation for 3 different sized system in Tompkins County and the percentage of electricity those systems would provide for the average household in the County.*

PV System Output

If the electricity output from the system were plotted over the course of a week, it would look something like **Figure 17**. This graph shows the hourly electricity production predicted by IMBY for a 4 kW system during a week in January and a week in July. This graph shows the variability of generation very well, with the energy peaking during the day then returning to zero each night. The January curve shows how much more variable solar electricity will tend to be in the winter, with cloudy days and not much consistent sunshine. The three days of July 24th-26th show what the energy profile would look like during clear, sunny days. The other days, however, show how clouds and other weather patterns can affect a PV system output.

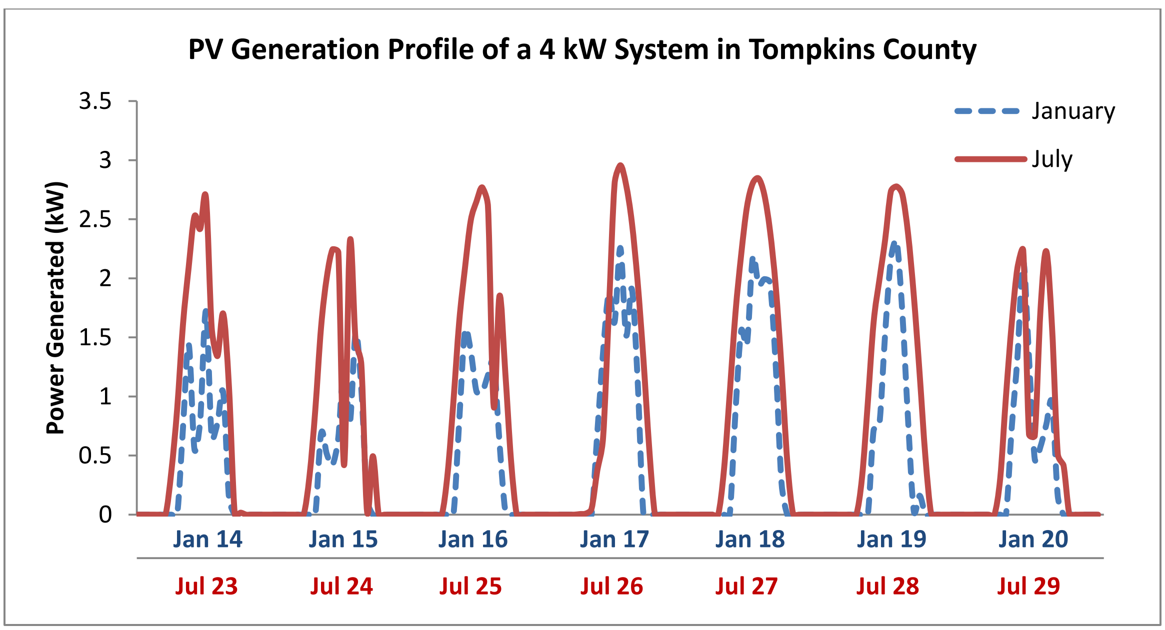


Figure 17: *Hourly electricity generation of a 4 kW system in Tompkins County during 1 week in July. July 24th-26th show the energy profile of nice, sunny days, while the other days show how variable the energy production can be when clouds or other weather patterns affect the amount of sunlight hitting the array.*

The total amount of energy generated by this system during this particular time frame would be represented by the "area under the curve" of the generation profile. Since the area under the curve during July is greater than in January, it is easy to see that the system will generate more electricity in July. For a monthly breakdown of the predicted amount of energy generated for a 4 kW system, see **Figure 18** below. As expected, the energy produced peaks during the summer months and declines during the winter. Overall, this system generates approximately 4,400 kWh of energy during the course of the year.

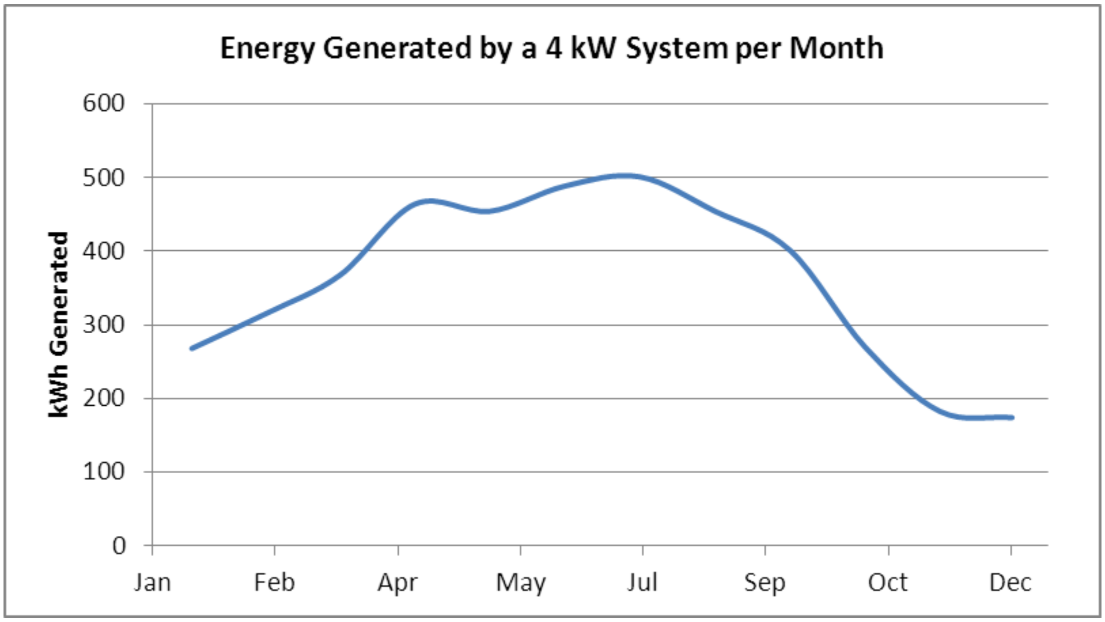


Figure 18: *Total energy produced per month. Energy production peaks during the summer and tails off during the winter.*

Tompkins County PV Potential

The overall PV potential for the county was broken down by sector, into commercial, industrial, educational, and residential buildings. Commercial and industrial potentials are discussed first, as they are relatively simple to calculate, followed by schools and residential buildings, for which PV potentials are difficult to assess. To calculate the PV potential of each sector, the "installed capacity potential" was determined, which refers to the amount of area that would be suitable for PV arrays and the resulting kW value of panels that could be installed. The installed capacity potential was then converted to an anticipated potential electricity generation by multiplying the installed capacity potential by the 1,100 kWh per installed kW value generated by IMBY. From there, the anticipated electricity generation potential was related to each sector's electricity demand in order to determine the total impact photovoltaics can make on electricity supply within the county.

Commercial Potential

The main limiting factor in determining the potential size of a commercial system is roof area (although the added weight of the panels could cause some structural issues, this analysis will assume that the buildings are structurally capable of supporting PV panels). In order to assess the commercial potential, roof area data was obtained from the Tompkins County Planning Department, by way of the County Assessment Department. According to the data, there are 2,118 commercial buildings in the county, which range in size from hundreds of thousands of square feet for large stores and malls to hundreds of square feet for smaller business buildings. Some of these buildings would not be suitable for solar panels because of their small size, oddly shaped roofs, and/or potential shading obstructions. However, a significant amount of energy can be generated from commercial PV with just a few of the largest buildings.

Table 8 below shows the roof area of the 10 largest commercial buildings within the county, as well as the cumulative county commercial building roof area. The installed capacity potential is presented in the "Installed Potential" column, assuming the entire roof is covered with 120 ft^2/kW arrays, which is the roof area required for the planned Solar Liberty PV systems on Tompkins County Municipal Buildings (see Solar Liberty Lease Program on page 49 for more information). The "Annual Energy Potential" column represents the expected energy that could be generated from the installed capacity, which was calculated by IMBY to be approximately 1,100 kWh per installed kW.

The following two examples illustrate how the "Installed Potential" and "Annual Energy Potential" columns were calculated for the Ithaca Mall:

Installed Potential:

$$\boldsymbol{Ithaca\ Mall}\text{:}\ \ \frac{575{,}559\ ft^2}{120\ ft^2/kW} = 4{,}796\ kW\ installed\ potential$$

Annual Energy Potential:

$$\boldsymbol{Ithaca\ Mall}\text{:}\ \ 4{,}796\ kW * 1{,}100\ kWh/kW = 5.28\ million\ kWh$$

**It should be noted that these annual energy potential values represent the anticipated energy production for the first year only. Due to degradation of the panels over time (see Panel Degradation on page 14), the PV system output may slowly decrease.*

	Building	Area (ft^2)	Installed Potential (kW)	Annual Energy Potential (million kWh)
1	Ithaca Mall	575,559	4,796	5.28
2	Cayuga Mall	211,315	1,761	1.94
3	Home Depot	198,220	1,652	1.82
4	Lowe's	188,861	1,574	1.73
5	Triphammer Mall	173,081	1,442	1.59
6	Walmart	156,883	1,307	1.44
7	Tops Plaza	124,966	1,041	1.15
8	Wegman's	122,195	1,018	1.12
9	East Hill Plaza	117,451	979	1.08
10	*Big K-Mart	112,934	941	1.04
	Total (Top-10):	**1,981,463**	**16,512**	**18.2**
	Total (Entire County)	**10,273,216**	**85,610**	**94.2**
		Percent of 2008 Commercial Electricity Demand:		**27%**

Table 8: *Footprint of the 10 largest commercial buildings in the County and the PV generation potential based on 120 ft^2 per kW installed and 1,100 kWh of electricity per kW installed. "Percent of 2008 Sector Electricity Demand" represents the Entire County Annual Energy Potential as a share of electricity demand in the commercial/schools sector. An *asterisk indicates that the building is currently vacant.*

It is unlikely that every square inch of a building's roof can be covered with solar panels, as obstructions such as A/C units and other rooftop devices will limit the available roof surface area. In addition, roofs need to provide adequate space for maintenance staff so they can maintain the panels and/or other components of the building. However, the assumption that the roof is completely covered should provide a reasonable estimate within an order of magnitude of the installed capacity potential of these buildings. **Appendix C** provides satellite images of the 10 largest commercial buildings in the county. Fortunately, most of the buildings have flat, relatively unobstructed roofs, which would be ideal for solar PV systems.

To illustrate the potential of the largest commercial buildings within the county, **Figure 19** shows the cumulative PV electricity potential for all 2,118 commercial buildings in the county. The size of the buildings is decreasing to the right, meaning the largest buildings in the county are at the leftmost portion of the chart. The top 10 largest buildings in the county have the ability to cover nearly 20% of the electricity potential at 18.2 million kWh. The chart also shows that half of the commercial electricity potential for the county (47.3 million kWh) can be provided with less than 10% of the buildings (180 buildings). Finally, the largest 50% of buildings in the county represent roughly 87% of the potential installed capacity (82.5 million kWh).

According to the *Tompkins County Community Greenhouse Gas Emissions Report, 1998-2008*, total electricity demand in the commercial/schools sector in 2008 was 348 million kWh. If the full potential of commercial buildings were to be reached, the buildings could produce around 27% of the sector's electricity with photovoltaics.

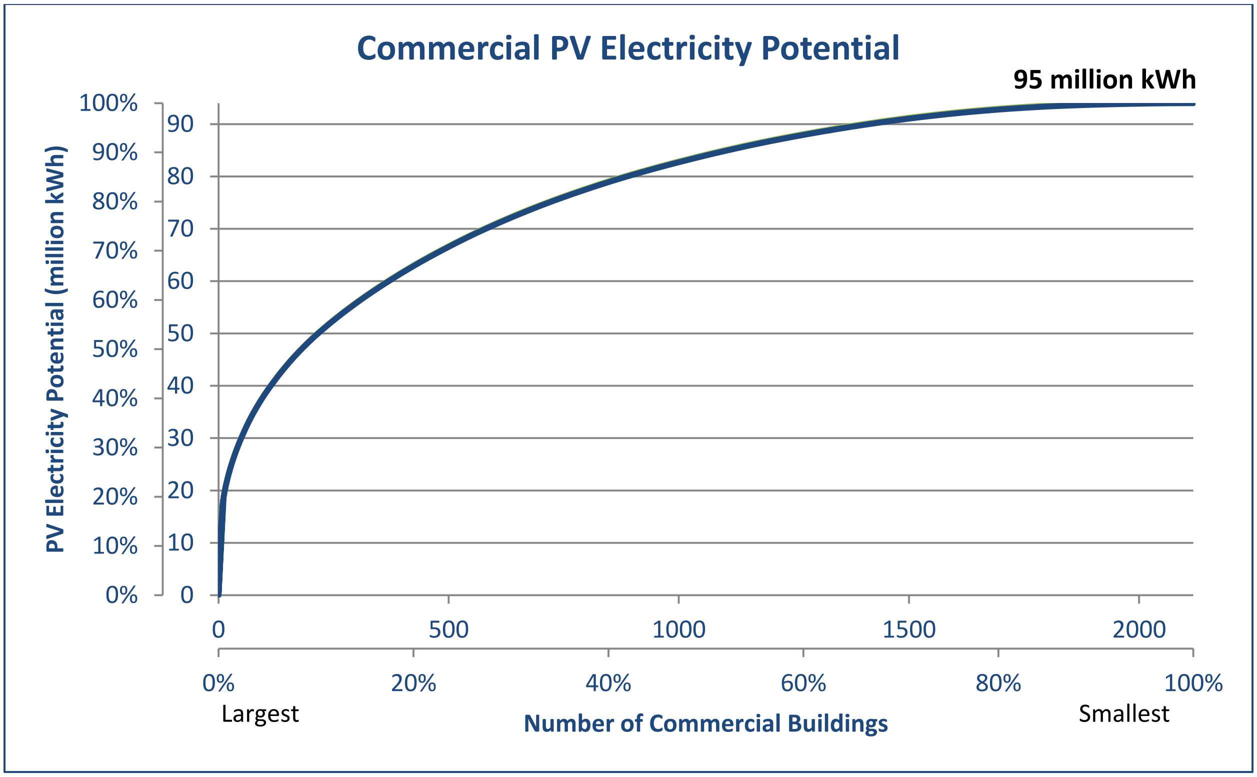


Figure 19: *Cumulative potential installed capacity of commercial PV as a function of the number of buildings. The size of the buildings is decreasing to the right, meaning the largest buildings in the county are on the far left of the graph.*

Industrial Potential

The industrial potential was determined using the same method as the commercial potential. In the county, there are 232 industrial buildings with a total PV electricity potential of around 24.5 million kWh. **Table 9** shows the 10 largest industrial buildings in the county, as well as the overall industrial PV potential.

	Building	Area (ft²)	Installed Potential (kW)	Annual Energy Potential (million kWh)
1	Borg Warner	552,395	4,603	5.28
2	*Morse Chain/Emerson Power Transmission Site	278,409	2,320	1.94
3	Borg Warner	227,005	1,892	1.82
4	Vanguard Printing	176,082	1,467	1.73
5	South Hill Business Campus	136,574	1,138	1.59
6	*Morse Chain/Emerson Power Transmission Site	106,979	891	1.44
7	Cargill De-Icing Technology	87,079	726	1.15
8	TransAct Technologies	75,239	627	1.12
9	Therm Incorporated	73,091	609	1.08
10	Cargill De-Icing Technology	63,659	530	1.04
	Total (Top-10):	**1,776,511**	**14,804**	**16.3**
	Total (Entire County):	**2,671,386**	**22,262**	**24.5**
	Percent of 2008 Industrial Electricity Demand			**17%**

Table 9: *Footprint of the 10 largest industrial buildings in the County and the PV generation potential based on 120 ft² per kW installed and 1,100 kWh of electricity per kW installed. "Percent of 2008 Sector Electricity Demand" represents the Entire County Annual Energy Potential as a share of electricity demand in the industrial sector. An *asterisk indicates that the building is currently vacant.*

Similar to the commercial potential, the majority of the industrial PV potential can be met with just the largest buildings. **Figure 20** shows the cumulative PV electricity potential of all 232 industrial buildings in the county. Once again, the size of the buildings is decreasing to the right, meaning the largest buildings in the county are at the very left of the chart. The top 10 buildings in the county account for roughly 67% of the potential PV energy, or 16.3 million kWh. The chart also shows that half of the installed capacity potential for the county (12.1 million kWh) can be reached with only the 5 largest buildings. Furthermore, the largest 50% of buildings in the county represent roughly essentially all of the potential installed capacity.

According to the *Tompkins County Community Greenhouse Gas Emissions Report, 1998-2008,* total electricity demand in the industrial sector in 2008 was 138 million kWh. If the full potential of industrial buildings were to be reached, they could produce around 17% of their own electricity with photovoltaics.

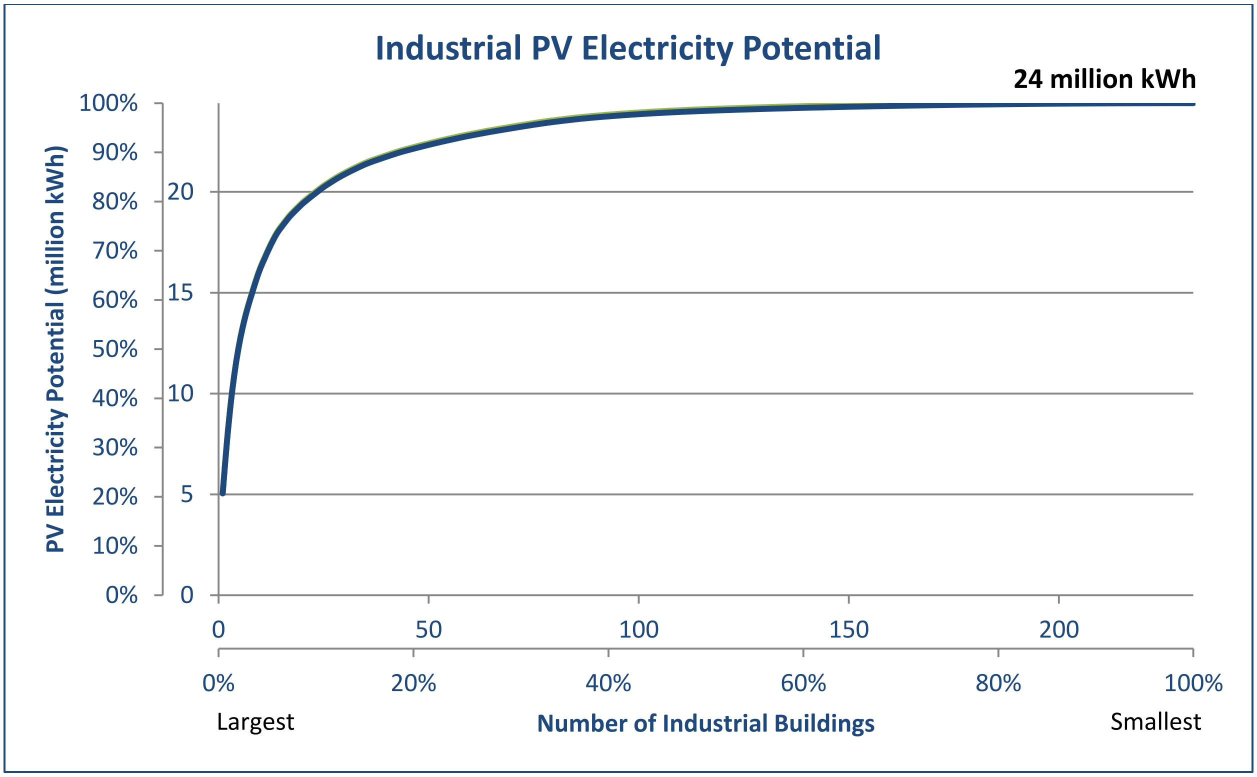


Figure 20: *Cumulative potential installed capacity of industrial PV as a function of the number of buildings. The size of the buildings is decreasing to the right, meaning the largest buildings in the county are on the far left of the graph.*

School Building Potential

Since Tompkins County is home to a number of large educational buildings, a similar approach was applied to the largest school buildings in the County. **Table 10** shows the 10 largest school buildings in Tompkins County and their roof areas. These buildings have many more obstructions and odd contours than the commercial buildings and are therefore less ideal for solar installations. Nonetheless, they still offer a large amount of space for installing solar panels. The values in the "percent available" column indicate roughly what percentage of the roofs would be usable for solar panels using aerial images. **Appendix D** shows the aerial images that were used to make these estimates.

	Building	Area (ft^2)	Percent Available	Installed Potential Available (kW)	Annual Energy Potential (million kWh)
1	Ithaca High School	222,484	70%	1,298	1.43
2	Dryden High School	179,743	50%	749	0.824
3	TC3	157,088	70%	916	1.00
4	Cornell Vet School	138,050	50%	575	0.633
5	Charles O. Dickerson High School	116,211	80%	775	0.852
6	Groton Elementary School	96,574	90%	724	0.797
7	Duffield Hall (Cornell)	94,771	20%	158	0.174
8	Barton Hall (Cornell)	91,762	50%	382	0.421
9	Bartels Field House (Cornell)	90,568	90%	679	0.747
10	Boynton Middle School	89,901	60%	450	0.494
	Total (Top-10):	**1,212,337**		**6,706**	**7.38**
	Total (Entire County):	**9,422,465**	**~50%**	**39,260**	**43.2**
		Percent of 2008 Commercial/Schools Electricity Demand			**13%**

Table 10: *Footprint of the 10 largest commercial buildings in the County and the PV generation potential based on 120 ft^2 per kW installed and 1,100 kWh of electricity per kW installed. "Percent available" was estimated from satellite images of the 10 largest buildings and assumed to be 50% for the entire county estimate. "Percent of 2008 Sector Electricity Demand" represents the Entire County Annual Energy Potential as a share of electricity demand in the commercial/schools sector.*

Since school buildings have less ideal roofs for solar systems than either commercial or industrial systems, it is difficult to estimate the overall potential for the county like in the commercial and industrial cases. Assuming that 50% of the total school roof area in the county is usable for PV systems, the total installed capacity should be almost 40 MW **(Figure 21)**, resulting in 43 million kWh of PV electricity.

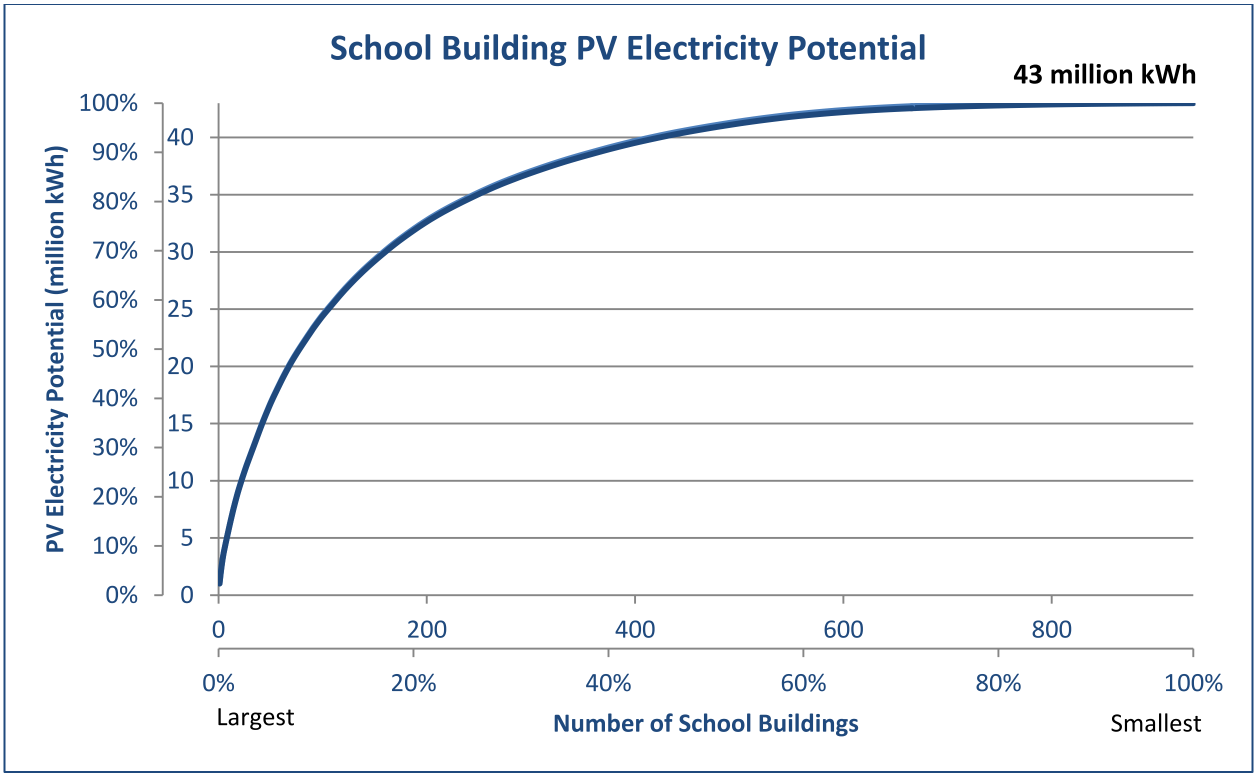


Figure 21: *Cumulative potential installed capacity of school building PV as a function of the number of buildings. The size of the buildings is decreasing to the right, meaning the largest buildings in the county are on the far left of the graph.*

Residential Potential

Since there are so many variables involved with installing solar energy systems on homes, it is difficult to estimate the overall residential potential for the county. Not every house has an ideal roof for solar panels due to a wide range of factors, including limited roof area, roof obstructions, or shading issues. Nevertheless, it is possible to estimate the energy potential of residential PV systems within the county when operating under a few calculated assumptions.

Number of Homes

Tompkins County Housing Units in Structures of 1-9 Units in Size

Urban: 8,797 housing units

Rural: 16,249 housing units

Total: 25,046 housing units

Katherine Borgella, Principal Planner with the Tompkins County Planning Department, issued the following statement regarding the number of homes in the county:

"These data were calculated by the Tompkins County Planning Department using U.S. Census, 2006-2010 American Community Survey 5-Year Estimates. Figures were determined by allocating housing units per structure to determine an estimated number of housing structures in Tompkins County, as follows:

1 unit (attached or detached) = 1 structure

2 units/structure = total units reported divided by 2

3-4 units/structure = total units reported divided by 3.5

5-9 units/structure = total units reported divided by 7

"This essentially is dividing the number of housing units located in 1-9 unit size range structures by the average of the unit range, as presented in the American Community Survey. For example, in the City of Ithaca there are 1,881 housing units in structures of 5-9 units in size. In order to estimate the number of structures that contain those housing units, 1,881 was divided by 7. Multi-unit structures that include 3-9 housing units were considered with this analysis because it was assumed that these structures were likely to be built in a similar fashion and have similar potential roof area for solar PV as 1-2 unit structures.

"This methodology omits 4,695 multi-unit (those that include 10+ units) housing that will need to be evaluated in the future, likely by identifying solar-appropriate roof area potential in a manner similar to this report's work on commercial sites. Furthermore, 3,993 mobile home units were not included in the analysis. They may be evaluated for community or joint-ownership opportunities for solar potential in the future."

Number of Homes with PV Potential

Art Weaver, CEO of Ithaca based Renovus Energy, estimates that of these 25,046 homes, about 80% (20,037) have the potential for solar energy systems (Weaver 2012). The other 20% are impractical for solar system use, due to shading issues of nearby trees or buildings or inadequate roof or land area. It will be assumed that homes in rural areas have enough open space to install either a roof mounted or ground mounted system, and that all of the unsuitable homes are located in urban areas. Given this assumption, there are 3,788 urban households and 16,249 rural households that are suitable for installing a solar PV system. **Table 11** below shows the number of households in urban and rural areas in the county overall versus the number of households that would benefit from solar energy systems based on Art Weaver's 80% estimation.

TC Housing units		**80% Scenario**	
Urban	8,797	Urban	3,788
Rural	16,249	Rural	16,249
Total	**25,046**	**Total**	**20,037**

Table 11: *Number of households in Tompkins County in urban and rural areas. "80% Scenario" refers to the estimate that 80% of the households in the county have the potential for PV systems. It is assumed that all rural*

households have enough area to install PV systems, so the only homes in the county that are excluded are in urban areas, due to closely spaced houses, limited roof area, and numerous trees that could cause shading.

PV Potential Calculations

As previously mentioned, the county used 293 million kWh of electricity for residential purposes in 2008 (TCPD). Since IMBY calculated around 1,100 kWh of electricity should be produced for every kW of installed capacity, the hypothetical installation capacity required to meet this entire demand would be:

$$\frac{293\ million\ kWh}{1{,}100\,\dfrac{kWh}{kW\ installed\ capacity}} \sim 266{,}000\ kW\ installed\ capacity$$

Since this value of 266,000 kW (266 MW) is such a large number, the county should make a point to encourage energy efficiency in conjunction with renewable energy investment, in order to lessen the overall energy burden of the county. Because energy efficiency is outside the scope of this report, the current energy usage patterns will be analyzed, which could hopefully improve in the future with more energy efficient buildings and appliances.

To hypothetically meet the entire residential electricity demand from 2008 with photovoltaics, every house in the county would need to install a 13.3 kW system:

$$\frac{266{,}000\ kW\ capacity\ needed}{20{,}037\ housing\ units} = 13.3\ kW\ per\ housing\ unit$$

This is an extremely large system that would generate about twice as much electricity as the average Tompkins County household would require. Since it is unlikely that 100% of the county's residential electricity demand will be met with photovoltaics, a few more assumptions will be applied to the analysis, as described below.

Urban Systems

The current average size of a PV system in the downtown Ithaca area, with closely spaced houses and numerous trees, is 3 kW (PowerClerk). Using the previous assumption that there are 3,788 urban households with the potential for PV systems, and the average 3 kW installed system for each home, the urban residential installed capacity would be around 11,000 kW (11 MW).

Rural Systems

In contrast to urban households, rural homes tend to have much more roof and/or land area upon which to install a PV system. Rural areas are typically unencumbered by shading obstructions and should have enough roof or land area to install a system large enough to meet the majority of their electricity demands. Given that a 7 kW system will provide nearly 100% of the average Tompkins County household's electricity, it will be assumed that every rural household in the county has the potential to install a 7 kW system. As such, this would result in a rural installed capacity of 113,000 kW (113 MW), and a total residential capacity of 136,000 kW (136 MW), as shown below in **Table 12**. This would result in an annual photovoltaic electricity generation of approximately 136 million kWh or roughly 46% of total residential demand.

	Urban	Rural
Homes	3,788	16,249
Avg system size (kW)	3	7
Total Installed Capacity (MW)	11	113
Energy potential (kWh)	12 million	124 million
Total Potential Energy (kWh)	**136 million**	
% of Total Demand	**46%**	

Table 12: *Installed capacity and total energy generation potential of Tompkins County residential solar PV, given an average size of 3 kW for urban systems and 7 kW for rural systems. Energy Potential was calculated based on 1,100 kWh of electricity for every kW of installed PV capacity. These are very rough estimates of the potential and are likely best case scenarios that can only be achieved with large scale community participation and involvement.*

Once again, this is only a *potential* estimate and is not a prediction of the amount of residential PV that will be installed within the county. The actual number and scale of residential PV systems installed within the county will likely be less than the estimates, but this can be seen as an upper-bound potential. Nevertheless, this should be seen as an encouraging sign that Tompkins County could potentially supply almost half of its residential electricity with solar energy. If homeowners within the county invest in supplemental energy efficiency measures, it does not seem outlandish to think that half of the county's residential electricity can be produced using photovoltaics.

Total Photovoltaic Potential

Compiling all of the potentials from each sector, **Table 13** shows the installed capacity potential and expected energy potential for the entire county. As can be seen from the table below, nearly 40% of the county's electricity demand could be met with photovoltaics, assuming large scale community involvement and participation. If these efforts are met with improved energy efficiency measures, the share of electricity produced from photovoltaics could potentially be even higher.

Photovoltaic Potentials by Sector			
	Capacity Potential (MW)	**Energy Potential (million kWh)**	**Percent of Electricity Demand**
Commercial	86	95	27%
Industrial	22	24	17%
Schools	39	43	13%
Residential	124	136	46%
Total	**271**	**298**	**38%**

Table 13: *Upper limit photovoltaic potentials by sector. Nearly 40% of the county's electricity needs can be met with photovoltaics. Combined with improved energy efficiency, this value could even be higher.*

Solar System Costs

Module Prices

The biggest reason for the recent precipitous drop in solar PV costs is the falling price of silicon and silicon based modules. As can be seen in **Figure 22**, the price of PV modules has fallen over 50% since 2009. This has put tremendous stress on PV manufacturers but has been a boon for PV installers as well as home and business owners who wish to install PV systems. A few module price statistics are shown below in **Table 14**, which is the result of a survey 1,000 PV companies in March 2012. Currently, there are 329 available solar modules that are less than $2 per watt, a price that is getting close to fossil fuel grid parity (which is discussed further in the Grid Parity of Solar PV section on page 46) (Solarbuzz 2011). Furthermore, Ernst & Young analysts predict that the price decline will continue through 2012, with the potential for modules to drop to the $0.70 per watt range (Ernst & Young 2012).

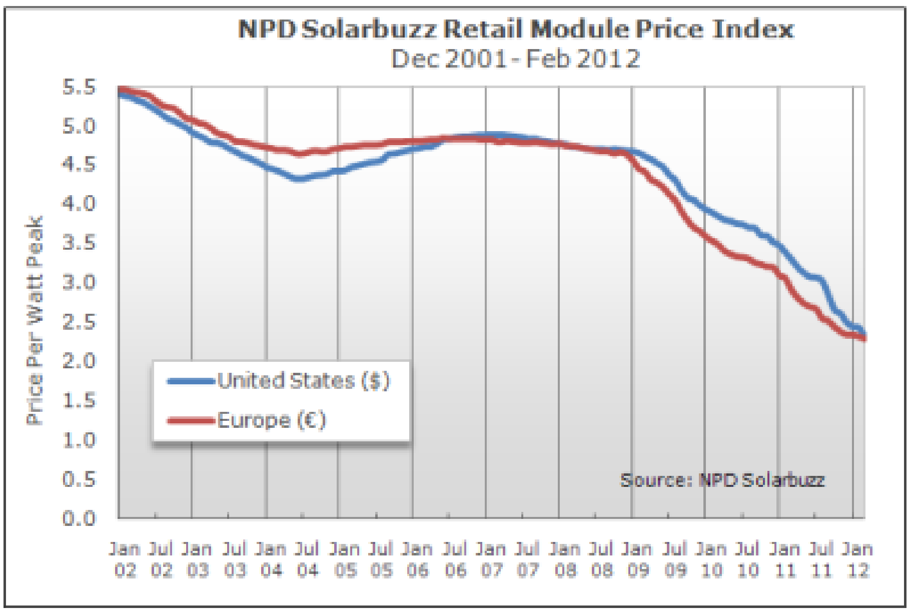


Figure 22: *Historical price of solar modules. Module price has dropped by more than 50% in the last 10 years.*

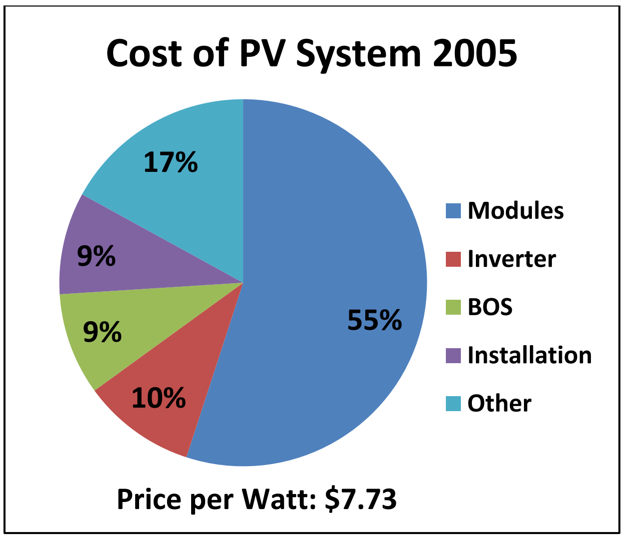
Current Module Prices (per W_p)	
Average Price	$2.29
# of prices below $2/$W_p$	329
Lowest mono-cSi price	$1.10
Lowest poly-cSi price	$1.06
Lowest Thin Film price	$0.84

Table 14: *PV module price data from a survey of 975 companies in March 2012. It should be noted that these are prices for just the modules, and is only a portion of the total installed system cost. Source: Solarbuzz.com*

Installed System Prices

While the solar panels themselves actually turn the sunlight into electricity, there are a number of other costs that go into installing a photovoltaic system. In addition to the cost of the modules are the cost of the inverter, balance of system (BOS) costs, i.e. all of the mounting and other equipment that goes along with installing the modules, installation costs, and "other" costs, such as site evaluations, tax or regulatory work, and any other expenses that go along with installing a PV system.

Figure 23 shows the cost breakdown of a solar PV system by component in 2005 and 2012. The 2005 chart shows that the cost of the modules accounts for over 50% of the cost of a PV system. In comparison, the relative cost of modules in 2012 dropped to 41% of the total cost of the system. This is due to the previously mentioned rapidly falling price of modules. All other system costs are relatively stable, and have only decreased a small percentage as compared to module price. In terms of overall cost, the 2011 system is 25% less expensive than the 2005 system.



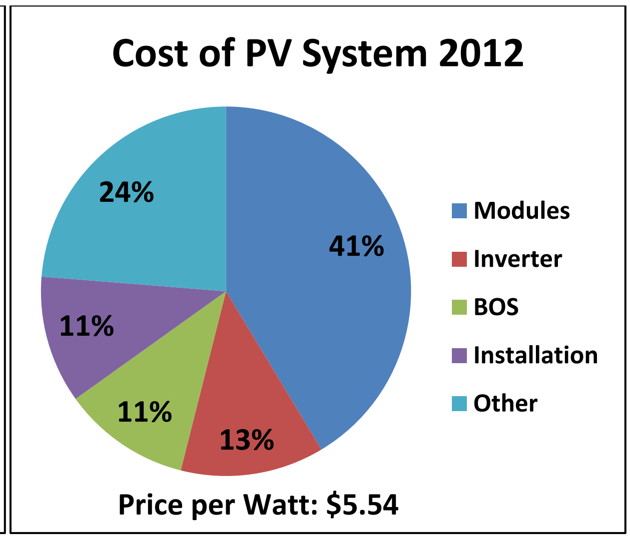


Figure 23: *Cost breakdown of a PV system by components. 2005 chart comes from lecture slides of Tobias Hanrath, Ph.D, Cornell University. 2012 chart was developed using the change in module pricing shown in* **Figure 22** *to determine the approximate cost of modules today. All other variables were held constant.*

Ernst and Young tabulated the average PV system price by sector from 2010-2011, which is shown below in **Figure 24**. Each bar represents a quarter of the year and each grouping of bars represents a different end use segment. The first two groupings, residential and commercial, are of interest to this report, as utility scale PV solar farms are more suited to high-grade solar climates, such as Arizona and Nevada. Looking at the residential segment, the average installed price per watt has decreased by nearly $1 in just the past two years. At the end of 2011, the average residential system installed price was $6.18/W, with a range of about $4.50/W to $8.00/W. The commercial segment shows economies of scale, as the average price of this segments is $4.92/W, ranging from about $3.25/W to nearly $8.00/W.

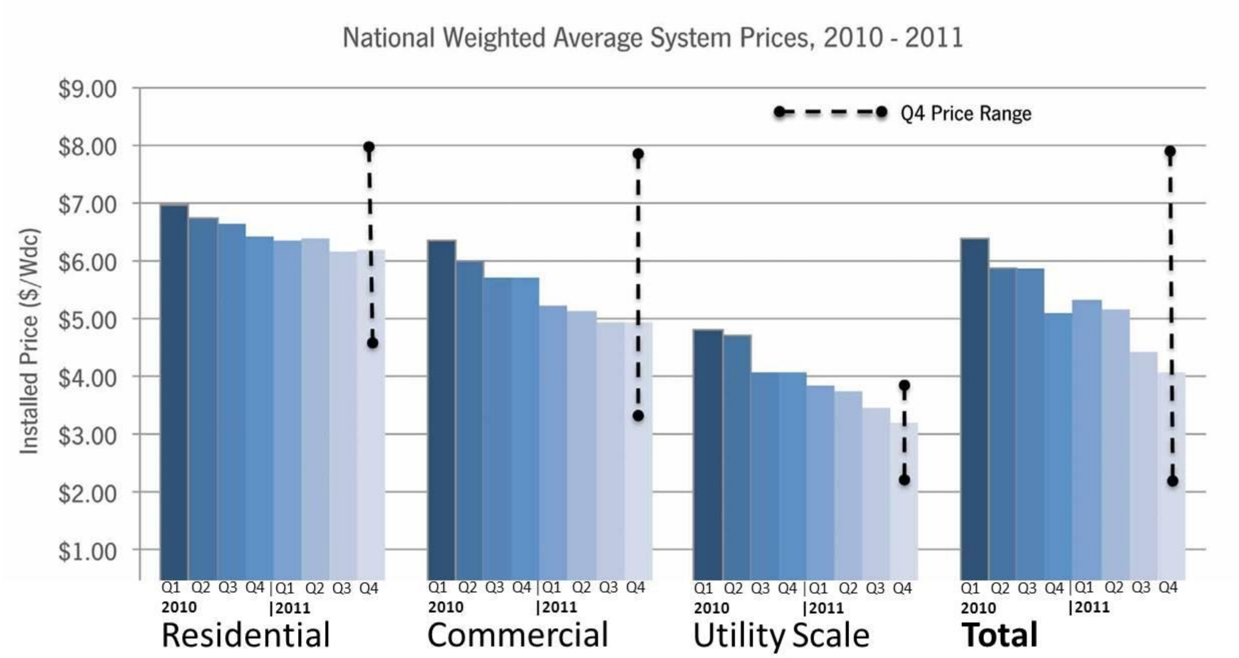


Figure 24: *Average of installed system PV prices for 2010-2011. Average prices are broken down by end use sector and by quarter. The residential and commercial segments are of particular interest, as utility scale PV investment is unlikely due to the lower-grade solar resource. The dashed line represents the range of prices during the fourth quarter of 2011.*

Tompkins County System Prices

Of the 192 PV systems in Tompkins County, 170 are residential, with an average size of 4.9 kW, and an average price of $8.11/W (PowerClerk). This is a relatively high price compared to current installations, but systems installed in 2011 had an average price of $6.63/W, slightly higher than the average shown above. The 3 systems approved for installation already during 2012 have an average price of $5.99/W, which is slightly below the average Q4 2011 price (PowerClerk).

In addition to the 170 residential systems, there are 22 commercial/industrial systems, with an average size of 18 kW, and an average price of $6.06/W. Once again, economies of scale allow for a lower price of larger commercial installations as compared to residential systems. During 2011, there were 10 commercial/industrial systems installed, with an average price of $5.55/W (PowerClerk). This is slightly above the average value of $4.92, but well within the reported price range.

PV System Net Cost Breakdown

Ithaca based Renovus Energy provides a chart on their website displaying rough estimates of the costs and incentives for a few different sized systems and mounting styles (roof or ground). This table has been updated to take into account the recent drop in PV prices, and can be seen in **Table 15**. These values are only rough approximations, as every case is different. These numbers can be used as a rule of thumb, however, and should provide a reasonable “ballpark” estimate of the initial up front cost facing a homeowner wishing to install a PV system. The estimated installed cost per watt of each size for a roof mounted system is $7, $6, and $5 per watt for the 2 kW, 4 kW, and 6 kW systems, respectively. The ground mounted systems are slightly higher, at $7.50, $6.50, and $5.50 per watt. Since PV systems are not a "uniform commodity," is difficult to determine with certainty an installed price per kW, as individual circumstances always have some sort of influence on the price (Vanek 2012).

System Size	Mount Style	Gross Cost	NYSERDA Incentive	NYS Tax Credit	Fed Tax Credit	Total Incentives	Net Cost
2 kW	Roof	$14,000	-$3,000	-$2,750	-$3,300	-$9,050	**$4,950**
	Ground	$15,000	-$3,000	-$3,000	-$3,600	-$9,600	**$5,400**
4 kW	Roof	$24,000	-$6,000	-$4,500	-$5,400	-$15,900	**$8,100**
	Ground	$26,000	-$6,000	-$5,000	-$6,000	-$17,000	**$9,000**
6 kW	Roof	$30,000	-$9,000	-$5,000	-$6,300	-$20,300	**$9,700**
	Ground	$33,000	-$9,000	-$5,000	-$7,200	-$21,200	**$11,800**

Table 15: *Costs and incentives of various sized systems and mounting styles from the Renovus Energy website, updated for decreased cost of photovoltaics. These numbers are only rough estimates and should only be used as a rule of thumb, as every situation will be different. Detailed descriptions of the incentives are given in the* PV Financial Programs and Incentives *section.*

As can be seen from the above table, there are a number of financial incentives that can alleviate the cost burden to homeowners who wish to install PV systems. The details of the incentives are discussed in depth below in the PV Financial Programs and Incentives on page 40.

Table 16 below shows the expected energy savings of each system, given a PV electricity production of 1,100 kWh per installed kW and a residential electricity price of 14₵/kWh. "Simple Payback Time" refers to how long it will take for the energy savings to pay for the system, at which point the system will actually begin making money for a homeowner. This calculation uses the costs for roof mounted systems in **Table 15** and no interest rate. An example calculation of a 2 kW system is shown below:

$$Simple\ Payback\ Time;\ 2kW\ system\text{:}\ \frac{\$4{,}950\ total\ system\ cost}{\$308\ savings/year} = 16\ years$$

System Size	% of Average Household Electricity Demand	Annual Electricity Savings	Simple Payback Time (years)
2 kW	28%	$308	16
4 kW	55%	$616	13
6 kW	83%	$924	11

Table 16: *Annual energy savings for each system size based on an average of 1,100 kWh per installed kW of capacity and an electricity rate of 14₵/kWh. Simple payback time is an approximation of the time for the electricity savings to pay for the system, assuming roof mounted systems from* **Table 15** *and no interest rate*

Net Metering

Since 1997, New York State has offered net metering for residential photovoltaic systems (DSIRE, New York – Net Metering). This means that homeowners will only be charged for the net amount of electricity consumed, i.e. total electricity consumed minus solar electricity produced. In the above example for a 4 kW system, the net amount of energy that the homeowner pays for during the year would be 3,496 kWh (7,837 kWh consumed – 4,341 kWh solar electricity produced). Any situation where PV electricity exceeds demand will be carried over month to month.

If there is still excess at the end of the year, however, the excess will be bought back at the wholesale rate, which is typically much lower than the retail rate that the customer pays. As such, it makes the most economic sense to have a system that provides less electricity than the home or business uses over the course of a year, as any excess will be sold back at a much lower price.

PV Financial Programs and Incentives

Traditional Financing Arrangements

Historically, homeowners who wished to install PV systems on new homes have used home equity loans, mortgage loans, or cash, to pay for the leftover sum after federal, state, and utility incentives were applied. One benefit of using a home equity loan or a refinanced mortgage loan is that interest paid on these loans may be tax deductible. Much like other home improvements, home owners can draw on standard home equity lines of credit, take out a home equity loan, or take cash out of a home mortgage refinance to help pay for the cost of their PV system. The primary determinants of the amount of money that can be borrowed are the equity value of the home combined with the credit score of the homeowner (Coughlin and Cory 2009).

Alternative Financing Arrangements

In addition to the traditional financing arrangements mentioned, there exist a few newer financial models that can help lower the financial burden of a residential PV system. Not all of these options are available in New York State (I don't think, I will inquire with the contact I made at NYSERDA), but they are options that the state and county could look into in the future.

Third Party Ownership Models

These are financing arrangements such as solar leases and residential power purchase agreements (PPA) can take advantage of commercial tax benefits and reduce the up-front costs to the homeowner, while also relieving the homeowner of maintenance responsibilities. In a solar lease program, the homeowner does not purchase the system, instead they enter into a contract with the PV installer to make monthly lease payments over a specified period of time. At the end of the lease, there may be a purchase option, whereby the homeowner can purchase the system. Alternatively, the homeowner may be able to extend the lease or have the system removed at the end of the lease. Leases may involve the PV installer guaranteeing maintenance over the course of the lease, relieving the homeowner of any maintenance responsibilities (Coughlin and Cory 2009). This model could help homeowners who desire a PV system but are intimidated by the large up-front costs.

A PPA is an attractive model for large PV systems in the commercial and public sector and has begun to work its way to residential customers as well. Similar to a solar lease program, a PPA takes advantage of the federal PV tax incentives available to non-residential owners, since the PV installer will own the system. The PV installer agrees to purchase, install, own, operate, and maintain the PV system, while the homeowner simply agrees to host the system. The homeowner and PV installer will then agree on a price the homeowner will pay the installer for the electricity that is produced from the system. Once again, this relieves the homeowner of the large up-front cost of a PV system as well as the operation and maintenance responsibilities. At the end of the PPA, the homeowner may elect to renew the contract, purchase the system, or have the system removed. As the PPA model is new, however, there may be other end-of-term options that develop moving forward as the market matures (Coughlin and Cory 2009).

Property Tax Assessment Model

This model is being piloted in Berkeley, California, Palm Desert, California, and Boulder, Colorado and addresses two of the major barriers associated with residential PV systems: high up-front cost and the difficulty of recouping a 20-year investment when the homeowner may have moved in that time frame. The model involves loans made by a city to homeowners to purchase and install PV systems.

The city raises the money for the program by issuing long-term bonds (Berkeley and Boulder) or tapping into the city's general fund (Palm Desert). The city then makes loans to homeowners to finance the installation of PV systems, which are paid back over a long period of time (20 years in the case of Berkeley) via a special property tax assessment that is collected annually or semi-annually. The only up-front cost is a small administrative cost of entering into the agreement. In addition, if the homeowner decides to sell the home before the term of the agreement is up, the PV system and associated special property tax remains with the house. In this instance, the homeowner only pays the associated tax while living in the house and when the home is sold, the new homeowner assumes the cost of the system until the tax assessment is paid off or they move (Coughlin and Cory 2009).

Solar Renewable Energy Certificates

Solar Renewable Energy Certificates (SRECs) represent the environmental benefits of electricity being produced from a PV system. New Jersey is one state that has been utilizing this model through its Renewable Portfolio Standard (RPS). One of its utilities, PSE&G, has declared that it will comply with the state's RPS through obtaining SRECs through a new solar loan program. The loan size for a PV system is based on the expected total generation of SRECs over the course of the system's life so that the revenue from SREC sales closely matches the loan payments. The homeowner agrees to sell all SRECs generated by their system, which would be supplemented by cash payments if the PV system does not generate the expected SRECs.

NYSERDA Renewable Portfolio Standard

In 2004, the New York State Public Service Commission issued an order adopting a Renewable Portfolio Standard (RPS), with the goal of increasing the percentage of renewable energy used in the state to 25% by 2013. As part of the plan, the Commission appointed NYSERDA the administrator for the RPS program. In 2009, the Commission undertook mid-course review of the RPS program and expanded the RPS goal to 30% renewables by 2015 (NYSERDA).

The RPS energy targets fall into three different groups: Main Tier Generators: large scale generators that sell power to the wholesale grid, Customer Sited Tier: small scale, distributed generators, and Other Market Activites: individuals and businesses that choose to pay a premium on their electricity bills to support renewable energy development. This report will focus on the Customer Sited Tier (CST), which was updated in April 2010 to include more ambitious goals for energy generation. The CST portion of the RPS actively supports enrollment in programs for photovoltaic systems, supported by the NYSERDA Solar PV Incentive Program (NYSERDA).

NYSERDA Incentive

The main incentive, Program Opportunity Notice 2112 (PON 2112), provides cash incentives of $1.50 per watt to help reduce the costs of installation of grid-connected PV systems 7 kW and smaller. As a reference, NYSERDA determined that a 2 kW system provides about 20-30% of an average home's energy needs, which is consistent with previously calculated average Tompkins County household percentage of 28%. As of April 2012, PON 2112 has $132 million available and will be accepting applications on a first-come, first-served basis until December 31, 2015 or until the funds are fully committed, whichever comes sooner. Customers must purchase their PV systems from an "Eligible Installer" that has demonstrated technical competence in the field of photovoltaic systems. Incentives are paid directly to the Eligible Installer, but must be passed on to the consumer. Incentives are capped based on a PV system size that does not exceed 110% of the previous 12 month's energy usage. In general, incentives cover 25-35% of the overall costs of installation but not more than 40% after all tax credits are applied (NYSERDA).

The full description of the program can be found here: http://www.nyserda.ny.gov/Funding-Opportunities/Current-Funding-Opportunities/PON-2112-Solar-PV-Program-Financial-Incentives.aspx?sc_database=web

New York State Tax Credits

In addition to direct incentives, there are also tax credits and incentives that can be applied to residential solar systems. Since tax issues can become very complicated, only a basic overview of the tax opportunities available will be presented. New York State offers a tax credit of 25% of the system expenditures (after incentives have been applied) capped at $5000. The system must be grid-tied and net metered, and any excess credits can be carried forward five years (DSIRE, Residental Solar Tax Credit).

The full statute can be found here: http://www.dsireusa.org/documents/Incentives/NY03F.htm

New York State also recognizes that a PV system may increase the value of a property. If the municipal assessor's office determines that it does, this would increase the homeowner's property tax burden. As such, the state provides 15 year property tax exemptions for systems purchased and installed before

January 1, 2015. The total amount of the exemption is equal to the increase in assessed value attributable to the solar system (DSIRE, Local Option).

The full statute can be found here: http://www.dsireusa.org/documents/Incentives/NY07F.htm

A property tax exemption handbook can be found here: http://www.dsireusa.org/documents/Incentives/NY07Fb.pdf

Federal Tax Credits

Finally, the federal government also offers a tax credit of 30% for residential PV systems. Due to recently passed legislation, there is now no cap on the amount that may be claimed. The tax credit is calculated from the net cost of the system after any direct incentives, such as the NYSERDA incentive, which are not federally taxable (Boler 2012).

The full statute can be found here: http://www.dsireusa.org/documents/Incentives/US37F1.pdf

The application for the tax credit (Federal tax form 5695) can be found here: http://www.irs.gov/pub/irs-pdf/f5695.pdf

There is a degree to subtlety to the federal tax credit, though, because it is only a credit against *federal taxes owed*. It is not a line item deduction to lower a homeowner's tax liability nor an automatic refund from the government. The homeowner must owe federal taxes, and the tax credit is simply carved out of that. If the tax credit is larger than the homeowner's federal tax burden for the year, the remaining balance may be rolled over one more year, but no more (Gordon 2010). So if, for example, a homeowner owes $5,000 in federal taxes in the two years following the installation of a PV system, and the federal tax credit comes to $6,000, then the homeowner will have lost that extra $1,000 credit. This is why it is imperative for homeowners to speak with tax professionals before committing to a PV system to ensure they are receiving the full benefit.

As mentioned before, there is also a "Federal Tax Increase" that goes along with installing a PV system. This essentially negates part of the state tax credit, because the state credit will likely increase the homeowner's federal tax liability due to a higher reported income. This could cause the homeowner to fall into a different tax bracket and pay more because of it (Boler 2012). Since this is such a complicated issue and unique to each individual, it is omitted from the previous calculations of net cost in **Table 15**. Furthermore, every home or business owner should talk to his or her accountant before installing a photovoltaic system, to ensure the incentives are calculated properly.

NYSERDA Clean Power Estimator

Since every situation is different, and there are an endless amount of different variables that can influence the cost, performance, and selection of a PV system, NYSERDA has developed an online calculator, called the Clean Power Estimator, to help home and business owners decide if a PV system is right for them.

The estimator can be found here: http://nyserda.cleanpowerestimator.com/nyserda.htm

With the Clean Power Estimator, a home or business owner can input a variety of different variables, ranging from PV system specs to financial assumptions and tax considerations. **Figure 25** shows the calculator with the default inputs for Ithaca and a system summary. It shows a 4 kW system, with an overall cost before incentives of $24,000, which is the same as a roof mounted system in the above table. Also, the calculated annual electricity generation of 4,304 kWh is close to the average estimate used in this report of 4,400 kWh. The net cost is slightly different because of the "Total Federal Tax Increase" portion in the bottom right. This is discussed above in the Federal Tax Credits section, but essentially this is dependent on the individual homeowner's tax liability, which will be different for each situation.

The Estimator allows individuals to tailor the PV system to their needs, based on each home or business's electricity usage and desired energy savings. The tool allows for the adjustment of system size, tilt angle, cost per watt, and operation and maintenance costs, among other things. It also allows the user to input a number of financial assumptions, including the price of a typical electric bill, how much the user anticipates this price to increase and seven different methods of payment. These methods are: pay cash, new home loan, refinance, tax-deductible loan, non-tax deductible loan, lease, and power purchase agreement. Each method has further settings that can be adjusted to better suit each individual system.

Once the Estimator has the required inputs, it will calculate a system summary, which includes a net cost after benefits, PV electricity production, percentage of household electricity supplied by the PV system, and CO_2 emission reduction. In addition, it shows internal rate of return, net present value, and years to payback estimates. This is a quick snapshot of the benefits of the system and can provide a quick glimpse of what kind of investment a PV system would be given the selected parameters.

The Estimator also includes more in depth tables in graphs, which the user can click on and view. It allows users to see: net cost for year 1, a monthly breakdown of the user's electric bill and PV generation, a daily breakdown by month of both PV electricity production and net electricity usage, four different in-depth cash flow charts, and a description of the PV system's environmental benefits and pollution prevention. Overall, the Clean Power Estimator is a thorough, easy to use tool that can offer a great deal of insight to any home or business owner who is thinking about installing a PV system. This tool could be used as an educational instrument to show individuals the benefits of a PV system installed at their home or place of business.

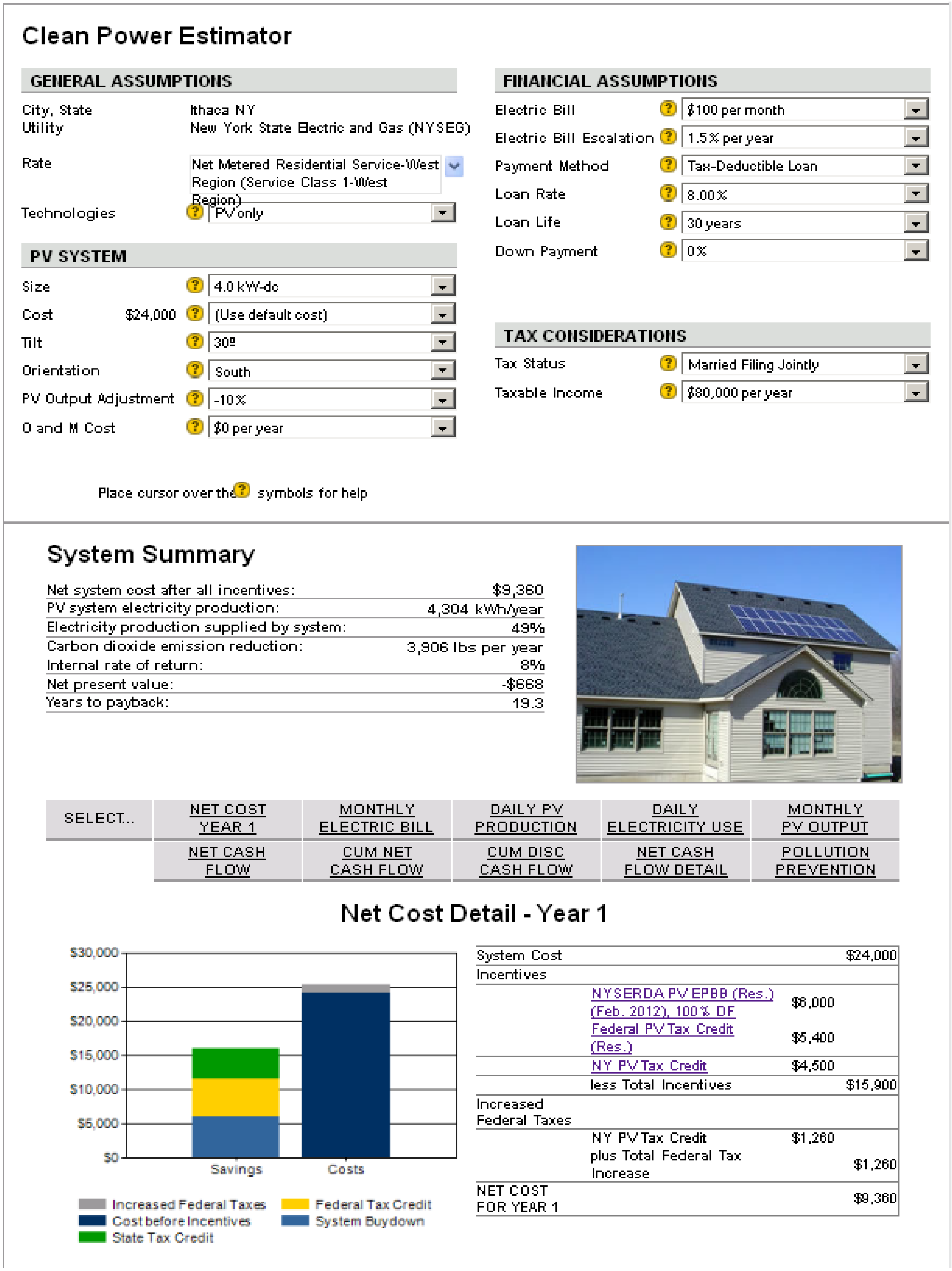


Figure 25: *NYSERDA's Clean Power Estimator with default inputs for Ithaca and system summary.*

Grid Parity of Solar PV

Grid parity is a commonly used term within renewable energy circles, and it refers to the time when the lifetime cost of generating PV electricity is comparable to the cost of electricity from conventional sources on the grid. A term called "levelized cost of electricity" (LCOE) is used to relate costs on an apples-to-apples basis between different energy sources. The lower the LCOE, the better, so a main goal of the solar industry is to lower the LCOE of solar energy equal to or below the LCOE of generating electricity for the grid.

If the total lifetime cost of generating electricity from a PV system is equal to the cost of receiving that energy from the grid, the system is said to have reached grid parity. Solar systems in states with high residential electricity prices (Hawaii 36.21 ₵/kWh, Connecticut: 18.17 ₵/kWh, Alaska 17.76 ₵/kWh) will reach grid parity much sooner than in states with low residential electricity prices (Idaho: 7.45 ₵/kWh, Louisiana: 8.30 ₵/kWh, North Dakota: ₵/kWh) (EIA Electric Power Monthly). In this case, the homeowner is not only decreasing his or her carbon footprint, but also saving money at the same time. It is easy to see why reaching grid parity has become a focus of many firms in the solar industry.

A recent study has reviewed the LCOE of solar photovoltaics, and has found that many of the assumptions in previous LCOE calculations are outdated or incorrect. They have found that PV has reached a "tipping point" and that solar has gone past grid parity in some cases. The study reviewed over 40 PV LCOE calculations that have been done and analyzed the assumptions that were made, as well as their validity. The LCOE estimates ranged from a low of 6.2 ₵/kWh to a high of 86 ₵/kWh, which shows the large impact that different assumptions can have on these estimates (Branker, Pathak and Pearce 2011). The researchers were able to identify a few key parameters that affected every study, most notable being financing options, module performance, and module lifetime (Trabish 2011).

The study found that the largest and most important costs facing a homeowner are the upfront costs and costs of financing. They argue that policy and initiatives must be focused on these two areas in order to make residential PV installations more affordable (Branker, Pathak, and Pearce 2011). Because they found financing so crucial, they posited that zero interest financing could be a more effective incentive than a feed in tariff or tax credit. Furthermore, previous LCOE calculations are irrelevant to today's systems because of the precipitous drop in module prices, as well as decreasing BOS costs and improvements along the supply chain and installation practices (Trabish 2011).

One widely held assumption about PV systems is related to the panel's degradation over time. It is commonly assumed that a panel will lose about 1% of its efficiency per year (Note: this does not mean that a panel with 15% efficiency will be 0% efficient in 15 years. It means that it will produce 85% of the energy in year 15 as compared to year 1, i.e. reducing its overall efficiency to 12.75%). Branker, Pathak, and Pearce found this assumption to be unreasonably conservative and suggested a degradation rate of 0.2% to 0.5% per year. Even older panels produced in the 1980s have been shown to degrade slower than the customary 1% mark, and as technologies advance, this rate should only decrease (Trabish 2011).

Finally, the authors found that the common assumption of a 20 year panel lifetime was also too conservative. They assert that at least a 30 year lifetime should be used in predicting the economic performance of a system. If lending institutions correcting the aforementioned misguided assumptions in PV financing arrangements, they should be more willing to finance PV systems at more beneficial terms (Trabish 2011).

County Municipal Solar Installations

Tompkins County Public Library

In January 2002 the Tompkins County Public Library (TCPL) began receiving electricity from a 147 kW photovoltaic system on the roof of the library. The system consists of 1430 modules and covers a surface area of 17,222 ft^2. The system provides roughly 13% of the overall energy use of the library and to date, has produced 989,000 kWh of energy, enough to power 83 homes for a year (Sunpower). In addition the system has reduced carbon dioxide emissions by 750 tons, which is roughly equivalent to driving 1.5 million miles in an average car (Sunpower).

The system was a result of a request by Tompkins County Legislator, Dooley Kiefer, who approached the Tompkins County Engineering Division (which has now been incorporated into the Facilities Division) to explore the possibilities of installing a PV system on the roof of library during renovation. The Engineering Division went out in search of firms to install a PV system, who then selected a proposal from Powerlight (now Sunpower) out of California to install the system. The county wanted to maximize the amount of energy available on top of the roof and Powerlight did all of the design and installation (LeMaro 2012).

One of the challenges in designing the system was the structural limitations of the roof, which couldn't support the added weight a tilted panel system. Structural reinforcement would be needed to accommodate a tilted array system, but the PV design was performed late in the process of renovating the library, so reinforcing the library's structure would have been time consuming and costly (LeMaro). As such, the panels lay flat on top of the roof, which results in an overall reduction in output when compared to a tilted system

A concern with the design of the system is the presence of the Holiday Inn hotel across the street. **Figure 26** shows a picture taken from the roof of the hotel, with the hotel shading a large portion of the PV array. Arel LeMaro, the Tompkins County Facilities Director, emphasized that the hotel has little to no effect on the overall energy generation of the system. A cursory analysis of the hourly electricity generation data throughout the course of a year reveals that there is no significant drop in electricity production in the afternoon, when the system would be shaded by the hotel. Although a rigorous, statistical analysis would be necessary to completely support this argument, this brief analysis seems to reinforce Mr. LeMaro's claim that the hotel does not significantly harm the PV system's energy generation.

Figure 26: *Photo of the Tompkins County Public Library taken from the roof of the Holiday Inn across the street. Notice the shadow of the hotel blocking a significant portion of the solar panels from sunlight. This is a problem that should have been foreseen and avoided.*

Another concern regarding the PV array was the construction of the Cayuga Street Parking Structure. **Figure 27** shows an aerial view of the location of the PV array, the Holiday Inn and the parking structure. When the PV system was installed, the lot where the parking structure stands was only used as surface parking. A few years after the panels had been installed, the city decided to turn the surface parking into a garage. There was concern that the parking facility would shade the panels, but it has since been determined that the structure had minimal impact on the amount of energy generated by the PV array. For the small impact that it does have on the array, the County has worked out an arrangement with the city, whereby the city will pay the county some amount to compensate for shading, which the county then uses for additional energy improvement measures on the library (LeMaro 2012).

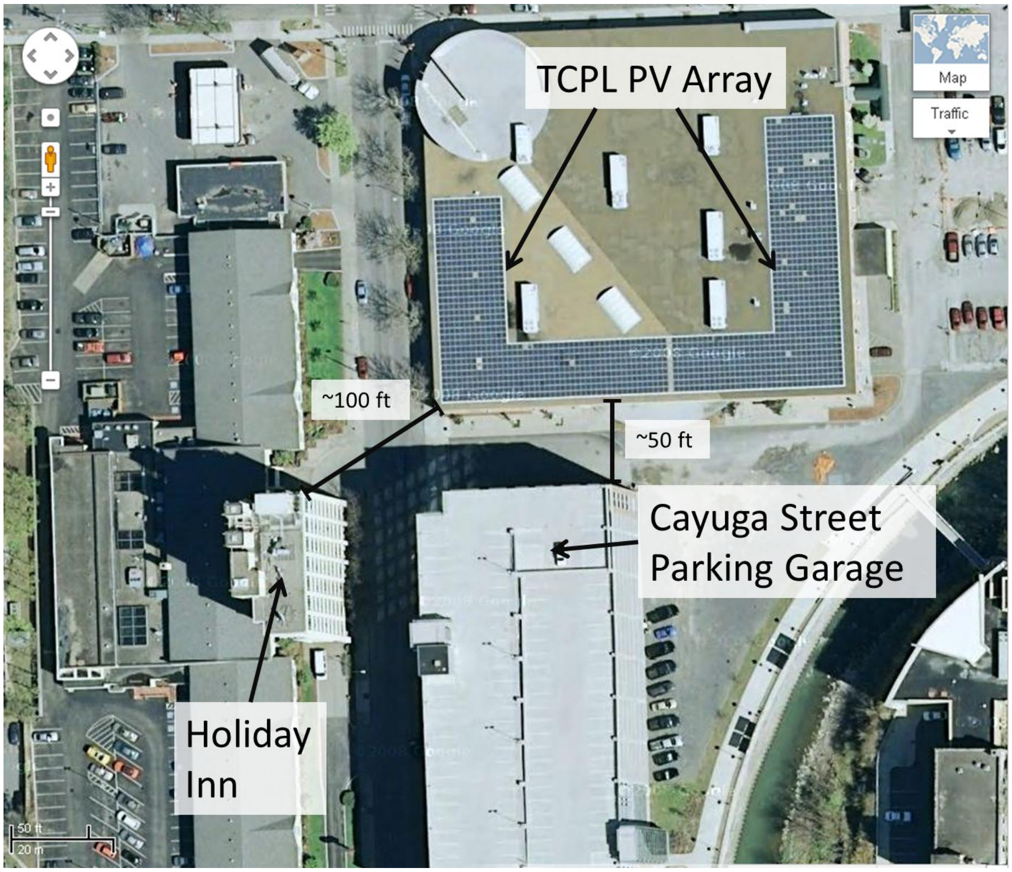


Figure 27: *Aerial view of the TCPL PV array with the Holiday Inn and Cayuga Street Parking Garage and their approximate distances from the array. Both structures only contribute a minimum amount of shading to the array and do not affect its output significantly.*

In terms of operation and maintenance, the system has been quite reliable. There were some issues with the inverter soon after completion of the installation, but these repairs were covered by Powerlight's warranty, and were done free of charge. The inverters were guaranteed for 10 years and the panels themselves were guaranteed for 25 years. The most significant, although still minor, maintenance issue has been vandalism that has arisen since the construction of the Cayuga Street Parking Garage. People have thrown bottles and rocks off the garage and onto the library roof, which has necessitated the replacement about a dozen of the panels. Another unexpected issue has been vegetation growing up between the panels, causing minor shading. This has been especially challenging because the vegetation needs to be removed by hand due to the library's policy on herbicide use. Since the panels are too fragile to walk on, maintenance workers need to crawl out on pads to remove the weeds while protecting the integrity of the panels. So far, only 2 of the 1,430 panels have been replaced due to failure of the panels from normal operation.

Solar Liberty Lease Program

Late in 2011, Tompkins County entered into a 15 year lease with Buffalo based Solar Liberty for the installation and maintenance of seven solar PV systems on top of county owned buildings. The county took advantage of a lease program offered through Solar Liberty, where federal tax credits and NYSERDA grants cover most of the $1 million price tag. In this program, the county doesn't actually buy the panels from Solar Liberty, instead they lease them for 15 years, at the end of which the county has the option of removing the panels or buying them at current market value (DiPietro 2011).

The seven systems consist of 6-25 kW arrays and one 20 kW array. The 25 kW arrays are limited by NYSERDA's cap on government systems of 25 kW to be eligible for financial incentives, while the 20 kW system is limited by the roof area of the intended building. In contrast to the TCPL system, these systems will be installed with a 10^{o} tilt, which will help capture more solar energy throughout the year. In addition, the tilted panels would help reduce any snow accumulation as well as mitigate the problem of vegetation experienced with the TCPL system.

The leasing program is a novel solution to the problem of up-front costs of solar installations. While the Tompkins County Facilities Division was researching PV installers, Solar Liberty was the only one they found that offered this leasing program in New York State. Solar Liberty performs all of the engineering design, from determining if the roofs are structurally capable to hold the arrays to siting the arrays to ultimately installing and maintaining the arrays. If the county opts to remove the arrays at the end of the 15 year term, Solar Liberty will also remove the panels and any other associated equipment (LeMaro 2012). If Solar Liberty determines that there needs to be structural reinforcement, however, the county will have to pay for that itself (DiPietro 2011).

The most attractive aspect of the leasing program was the cost. A single 25 kW system would most likely cost the county $150-200 thousand to install, while the county will be paying Solar Liberty a little over $10 thousand per year for all seven systems. Over the 15 year life of the lease, the county will pay roughly the same amount to lease 7 systems as it would pay to purchase one system. Even Mr. LeMaro admits this sounded too good to be true, but Solar Liberty is banking on the aforementioned tax credits, NYSERDA grants, and the hope that the State of New York will implement a Renewable Energy Credit system, whereby they will be able to trade credits with other companies (LeMaro 2012).

Table 17 shows the specifications of each of the installations (a more detailed description of the Solar Liberty specifications can be found in **Appendix E**). The annual payment column represents the lease payment that the county will pay to Solar Liberty each year and the Annual Savings column represents the monetary energy savings minus the annual lease payment, i.e., the county will save $19,474 in total energy bills, while lease payments will be $10,260, for a total savings of $9,214. Finally, the % offset represents the amount of energy that will be saved for each building given its historical energy consumption. It should be noted that the % offset is high for the Human Service Annex because it has been vacant and has had low energy usage. Once it is occupied, it will likely similar to Annex Building C (LeMaro 2012).

BUILDING	KW	ANNUAL PAYMENT	ANNUAL SAVINGS (AFTER LEASE PAYMENT)	% Offset
Annex Building C	20.16	$1,260	$1,261	11.57%
Emergency Response	24.36	$1,500	$1,133	5.68%
Health Department	24.36	$1,500	$843	8.68%
Human Service Annex	24.36	$1,500	$2,145	98.57%
Human Services Building	24.36	$1,500	$1,364	2.95%
Public Safety	24.36	$1,500	$1,104	3.86%
Public Works	24.36	$1,500	$1,364	10.83%
TOTAL	166.32	$10,260	$9,214	20.28%

Table 17: *System specifications and estimated costs of the seven PV arrays of the Solar Liberty lease program. Note: human service annex has been vacant, and therefore has had a low historical electricity load, which is the reason for the large % offset value. Table provided by Arel LeMaro from interview on 2/3/2012.*

If a worst case scenario were to happen and Solar Liberty were to become bankrupt, county attorney Jonathan Wood said that "it would be a breach of the lease, and Tompkins County has various options to protect the county" (DiPietro 2011).

Conclusions

The research presented in this report shows that the solar energy potential in the county is significant. With large scale community involvement and investment, the county could generate a sizable portion of its electricity with photovoltaics, especially if combined with improvements in energy efficiency. **Table 18** below shows the calculated PV potential by sector for the county and each sector's share of total electricity demand.

Photovoltaic Potentials by Sector			
	Capacity Potential (MW)	Energy Potential (million kWh)	Percent of Electricity Demand
Commercial	86	95	27%
Industrial	22	24	17%
Schools	39	43	13%
Residential	124	136	46%
Total	**271**	**298**	**38%**

Table 18: *PV potential by sector. "Percent of Electricity Demand" refers to the energy potential in relation to each sector's 2008 electricity usage as stated in the* Tompkins County Community Greenhouse Gas Emissions Report, 1998-2008**.** *It should be noted that the demand for commercial and school buildings are grouped together in the Greenhouse Gas report. In other words, the 95 million kWh energy potential of commercial buildings alone could account for 27% of both commercial and school building electricity usage.*

In order to reach the large scale levels of photovoltaic investment listed in the table above, PV technologies need to reach grid parity without financial subsidies or incentives. For the time being, however, a number of financial incentives exist to encourage solar energy investment. NYSERDA offers a direct financial incentive, along with tax incentives from the state of New York and the Federal government. Alternative financing arrangements such as solar leases and power purchase agreements are becoming more popular, and some cities in the US have actually loaned money to residents to purchase and install solar systems, using a special property tax assessment to repay the loan.

Every home and business owner should seriously consider installing a PV system, and the In My Backyard tool (page 22) and Clean Power Estimator (page 43) should provide sound technical and financial information on what individuals can expect out of a PV system. Individuals should consult a qualified solar installer for a site evaluation and cost estimate before deciding to purchase a PV system, and contact an accountant to clarify any tax issues.

Tompkins County itself has already taken steps toward meeting its aggressive climate goals with two major solar energy projects. The first was the installation of 147 kW of solar photovoltaic panels on the roof of the public library, and more recently, the county has entered into an agreement with Solar Liberty of Buffalo to install solar photovoltaic systems on top of 7 county buildings. Community leaders hope that these systems will help to reduce overall greenhouse gas emissions within the county and provide an example of how solar energy can help individuals reduce their utility bills and minimize their impact on the climate.

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Appendix A: Image sources

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Figure 3: http://www.itechnews.net/wp-content/uploads/2009/05/sanyo-hit-solar-cell-has-highest-energy-conversion-efficiency.jpg

Figure 4: Kissell 2012.

Figure 5: Kissell 2012.

Figure 6: Figure used with permission from lecture slides of KE “Max” Zhang, Ph.D., Cornell University.

Figure 7: http://environmentalresearchweb.org/cws/article/news/30489/1/Generationgap

Figure 8: http://www.pv-tech.org/guest_blog/npd_solarbuzz_top_10_pv_cell_producers_in_2011

Figure 15: Steeby 2012.

Figure 16: Kissell 2012.

Figure 2: Figure used with permission from lecture slides of KE “Max” Zhang, Ph.D., Cornell University.

Figure 9: http://netzerorenewableresources.com/wp-content/uploads/2010/10/Roof-Mount-1.jpg

Figure 10: http://www.powertripenergy.com/images/2009/Pole-mount-for-web.jpg

Figure 11: Steeby 2012.

Figure 12: Image used with permission from lecture slides of Tobias Hanrath, Ph.D, Cornell University.

Figure 13: http://www.wattsun.com/misc/photovoltaic_tilt.html

Figure 14: http://www.enviroharvest.ca/pv_shading.htm

Figure 23: 2005 chart developed with permission from data from lecture slides of Tobias Hanrath, Ph.D, Cornell University.

Figure 22: http://solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

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Figure 26: http://midhudson.org/admin/facilities_resources/green/QPK_Design.pdf

Figure 27: http://maps.google.co

Appendix B: Description of Variables Used by PVWatts

DC Rating

The size of a photovoltaic (PV) system is its nameplate DC power rating. This is determined by adding the PV module power listed on the nameplates of the PV modules in watts and then dividing the sum by 1,000 to convert it to kilowatts (kW). PV module power ratings are for standard test conditions (STC) of 1,000 W/m^2 solar irradiance and 25°C PV module temperature. The default PV system size is 4 kW. This corresponds to a PV array area of approximately 35 m^2 (377 ft^2).

Caution: For correct results, the DC rating input must be the nameplate DC power rating described above. It cannot be based on other rating conditions, such as PVUSA test conditions (PTC). PTC are defined as 1,000 W/m^2 plane-of-array irradiance, 20°C ambient temperature, and 1 m/s wind speed. If a user incorrectly uses a DC rating based on PTC power ratings, the energy production calculated by the PVWatts calculator will be reduced by about 12%.

DC-to-AC Derate Factor

The PVWatts calculator multiplies the nameplate DC power rating by an overall DC-to-AC derate factor to determine the AC power rating at STC. The overall DC-to-AC derate factor accounts for losses from the DC nameplate power rating and is the mathematical product of the derate factors for the components of the PV system. The default component derate factors used by the PVWatts calculator and their ranges are listed in the table below.

Derate Factors for AC Power Rating at STC

Component Derate Factors	PVWatts Default	Range
PV module nameplate DC rating	0.95	0.80–1.05
Inverter and transformer	0.92	0.88–0.98
Mismatch	0.98	0.97–0.995
Diodes and connections	0.995	0.99–0.997
DC wiring	0.98	0.97–0.99
AC wiring	0.99	0.98–0.993
Soiling	0.95	0.30–0.995
System availability	0.98	0.00–0.995
Shading	1.00	0.00–1.00
Sun-tracking	1.00	0.95–1.00
Age	1.00	0.70–1.00

Overall DC-to-AC derate factor	0.77	0.09999–0.96001

The overall DC-to-AC derate factor is calculated by multiplying the component derate factors.

For the PVWATTS default values:

Overall DC to AC derate factor

= 0.95 x 0.92 x 0.98 x 0.995 x 0.98 x 0.99 x 0.95 x 0.98 x 1.00 x 1.00 x 1.00

= 0.77

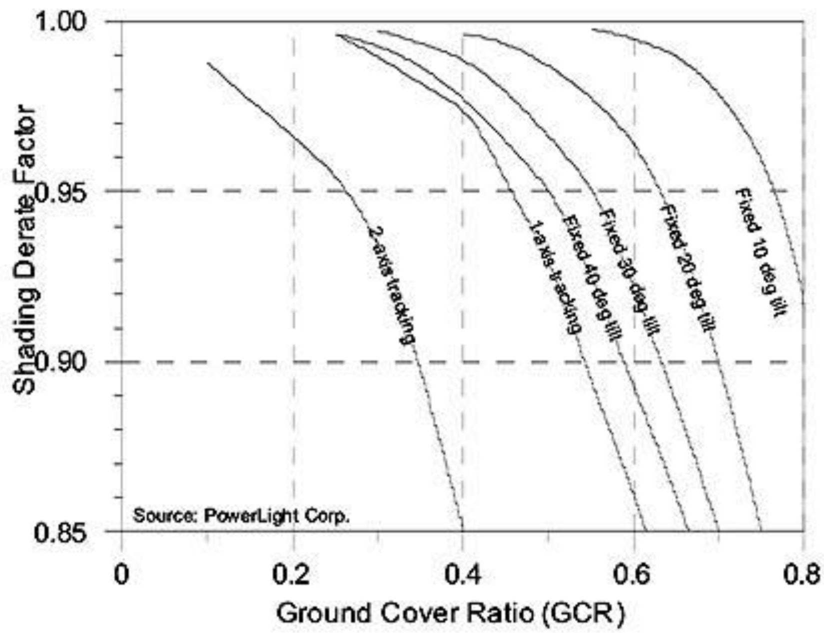
The value of 0.77 means that the AC power rating at STC is 77% of the nameplate DC power rating. In most cases, 0.77 will provide a reasonable estimate. However, users can change the DC-to-AC derate factor. The first option is to enter a new overall DC-to-AC derate factor in the provided text box. The second option is to click the **Derate Factor Help** button. This provides the opportunity to change any of the component derate factors. The derate factor calculator then calculates a new overall DC-to-AC derate factor.

The component derate factors are described below.

- **PV module nameplate DC rating**
  This accounts for the accuracy of the manufacturer's nameplate rating. Field measurements of PV modules may show that they are different from their nameplate rating or that they experience light-induced degradation upon exposure. A derate factor of 0.95 indicates that testing yielded power measurements at STC that were 5% less than the manufacturer's nameplate rating.
- **Inverter and transformer**
  This reflects the inverter's and transformer's combined efficiency in converting DC power to AC power. A list of inverter efficiencies by manufacturer is available from the Consumer Energy Center. The inverter efficiencies include transformer-related losses when a transformer is used or required by the manufacturer.
- **Mismatch**
  The derate factor for PV module mismatch accounts for manufacturing tolerances that yield PV modules with slightly different current-voltage characteristics. Consequently, when connected together electrically, they do not operate at their peak efficiencies. The default value of 0.98 represents a loss of 2% because of mismatch.
- **Diodes and connections**
  This derate factor accounts for losses from voltage drops across diodes used to block the reverse flow of current and from resistive losses in electrical connections.
- **DC wiring**
  The derate factor for DC wiring accounts for resistive losses in the wiring between modules and the wiring connecting the PV array to the inverter.
- **AC wiring**
  The derate factor for AC wiring accounts for resistive losses in the wiring between the inverter and the connection to the local utility service.

- **Soiling**
The derate factor for soiling accounts for dirt, snow, and other foreign matter on the surface of the PV module that prevent solar radiation from reaching the solar cells. Dirt accumulation is location- and weather-dependent. There are greater soiling losses (up to 25% for some California locations) in high-trafffic, high-pollution areas with infrequent rain. For northern locations, snow reduces the energy produced, and the severity is a function of the amount of snow and how long it remains on the PV modules. Snow remains longest when sub-freezing temperatures prevail, small PV array tilt angles prevent snow from sliding off, the PV array is closely integrated into the roof, and the roof or another structure in the vicinity facilitates snow drift onto the modules. For a roof-mounted PV system in Minnesota with a tilt angle of 23°, snow reduced the energy production during winter by 70%; a nearby roof-mounted PV system with a tilt angle of 40° experienced a 40% reduction.
- **System availability**
The derate factor for system availability accounts for times when the system is off because of maintenance or inverter or utility outages. The default value of 0.98 represents the system being off 2% of the year.
- **Shading**
The derate factor for shading accounts for situations in which PV modules are shaded by nearby buildings, objects, or other PV modules and arrays. For the default value of 1.00, the PVWatts calculator assumes the PV modules are not shaded. Tools such as Solar Pathfinder can determine a derate factor for shading by buildings and objects. For PV arrays that consist of multiple rows of PV modules and array structures, the shading derate factor should account for losses that occur when one row shades an adjacent row.

  The figure below shows the shading derate factor as a function of the type of PV array (fixed or tracking); the ground cover ratio (GCR), defined as the ratio of the PV array area to the total ground area; and the tilt angle for fixed PV arrays. As shown in the figure, spacing the rows further apart (smaller GCR) corresponds to a larger derate factor (smaller shading loss). For fixed PV arrays, if the tilt angle is decreased, the rows may be spaced closer together (larger GCR) to achieve the same shading derate factor. For the same value of shading derate factor, land area requirements are greatest for two-axis tracking, as indicated by its relatively low GCR values compared with those for fixed or one-axis tracking. If you know the GCR value for your PV array, the figure may be used to estimate the appropriate shading derate factor. Industry practice is to optimize the use of space by configuring the PV system for a GCR that corresponds to a shading derate factor of 0.975 (or 2.5% loss).



Shading derate factor for multiple-row PV arrays as a function of PV array type and ground cover ratio

- **Sun-tracking**
  The derate factor for sun-tracking accounts for losses for one- and two-axis tracking systems when the tracking mechanisms do not keep the PV arrays at the optimum orientation. For the default value of 1.00, the PVWatts calculator assumes that the PV arrays of tracking systems are always positioned at their optimum orientation and performance is not adversely affected.
- **Age**
  The derate factor for age accounts for performance losses over time because of weathering of the PV modules. The loss in performance is typically 1% per year. For the default value of 1.00, the PVWatts calculator assumes that the PV system is in its first year of operation. For the eleventh year of operation, a derate factor of 0.90 is appropriate.

Note: Because the PVWatts overall DC-to-AC derate factor is determined for STC, a component derate factor for temperature is not part of its determination. Power corrections for PV module operating temperature are performed for each hour of the year as the PVWatts calculator reads the meteorological data for the location and computes performance. A power correction of -0.5% per degree Celsius for crystalline silicon PV modules is used.

Appendix C: Aerial Views of the 10 Largest Commercial Buildings in the County

*(contained in separate file)

Appendix D: Aerial Views of the 10 Largest Industrial Buildings in the County

*(contained in separate file)

Appendix E: Aerial Views of the 10 Largest School Buildings in the County

*(contained in separate file)

Appendix F: Solar Liberty System Specifications

*(contained in separate file)