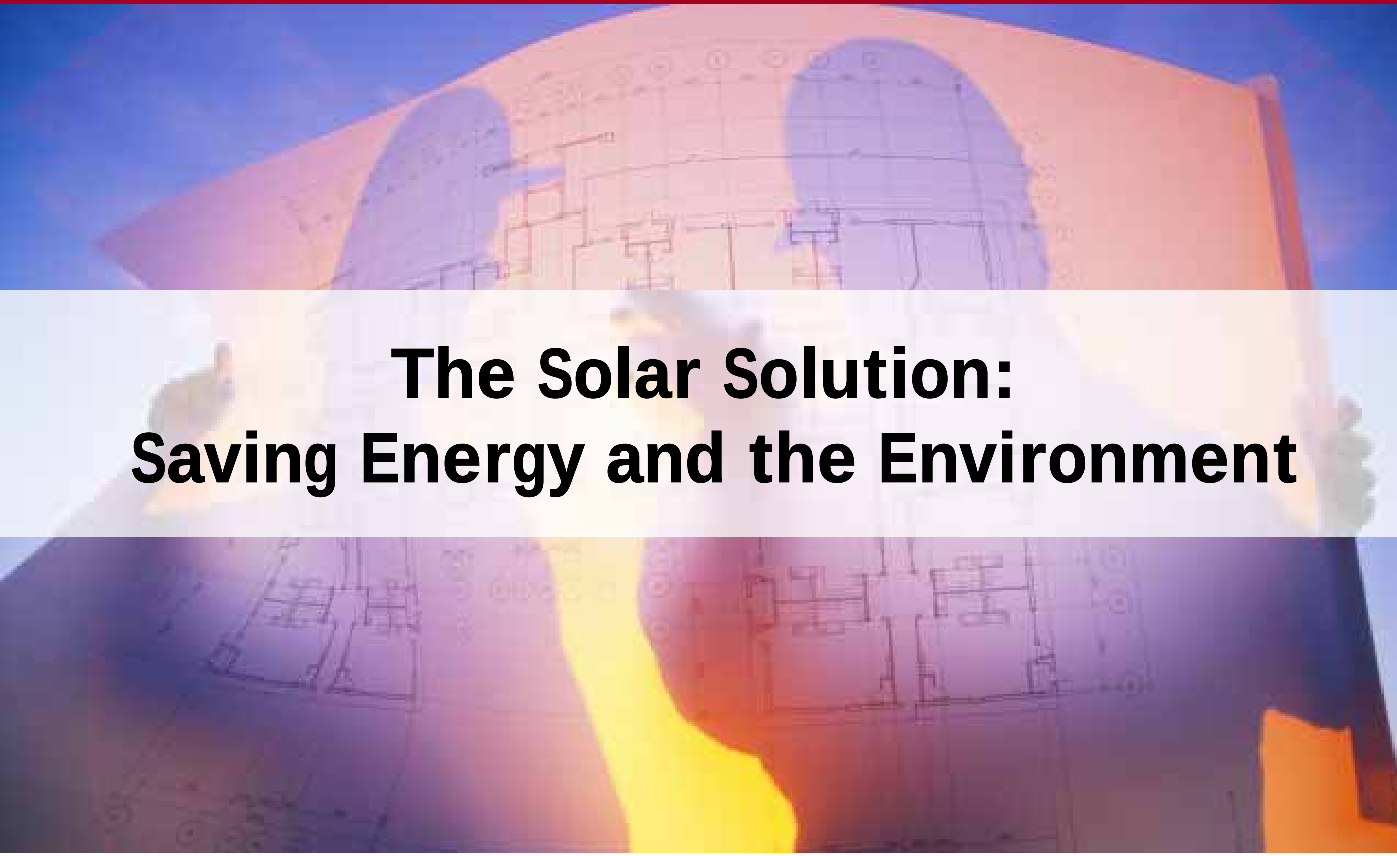
The Solar Solution: Saving Energy and the Environment



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The Solar Solution: Saving Energy and the Environment

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Description: Provides an overview of the features and benefits of solar energy for steep slope roofing, including discussions on how it is generated, performance variables, and key considerations when sizing a system.

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Learning Objectives

Upon completing this course, you will be able to:

- discuss the financial and environmental benefits of installing a solar electric system
- list the components of a solar electric system and explain how solar electricity is generated
- state the performance variables relating to solar electric systems, and
- explain the steps required to determine the size of the system best suited for each application.

Table of Contents

Click on title to view

Energy: Costs and Consumption

Introduction

The need for innovative energy solutions is evidenced by the following statistics.

- World energy consumption is expected to increase 40%-50% by the year 2010.
- Per person, Canada consumes the most energy in the world, the United States ranks second, and Italy consumes the least energy among industrialized countries.
- Developing countries use 30% of global energy.
- America uses about 15 times more energy per person than does the typical developing country.
- Americans consume 26% of the world's energy.
- Total U.S. residential energy consumption is projected to increase 17% from 1995-2015, and
- Worldwide, 2 billion people are currently without electricity.

Global Warming

Furthermore, on average, 16 million tons of carbon dioxide are emitted into the atmosphere every 24 hours by human use worldwide, contributing to global warming.[1]

In fact, 1995 was the warmest year since global temperatures were first recorded in 1856.[2]

Carbon emissions in North America reached 1,760 million metric tons in 1998, a 38% increase since 1970 and they are expected to grow another 31%, to 2,314 million metric tons, by the year 2020.[1]

With world energy consumption expected to increase by at least 40% by 2010 and global fuel mix (renewable 18%, nuclear 4%, fossil 78%) projected to remain basically unchanged from today, the resulting increase in carbon dioxide emission is projected to be 50-60%.

[1] *Source: U.S. Department of Energy*

[2] *Source: Chivilan and Epstein, Boston Globe*

U.S. Carbon Dioxide Emissions

The United States is the worlds largest single emitter of carbon dioxide, accounting for 23% of energy-related carbon emissions worldwide.[1]

An average, 23,000 pounds of carbon dioxide is emitted annually from each American home.[3]

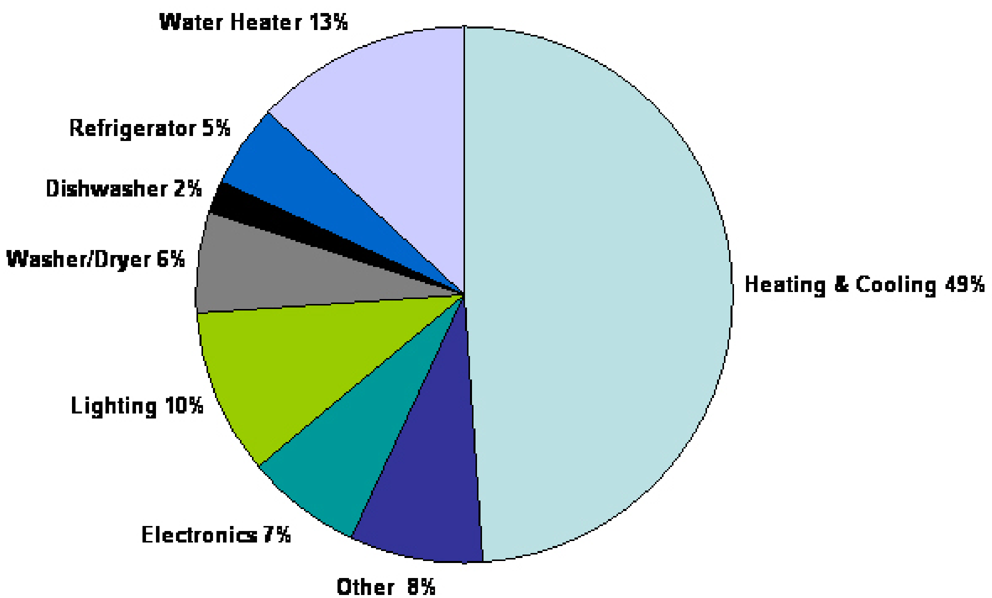
The transportation sector consumed 35% of the nation's energy in 1990; this sector is 97% dependent on petroleum. As well, fossil fuels are depleted at a rate that is 100,000 times faster than they are formed.

[1] *Source: U.S. Department of Energy*

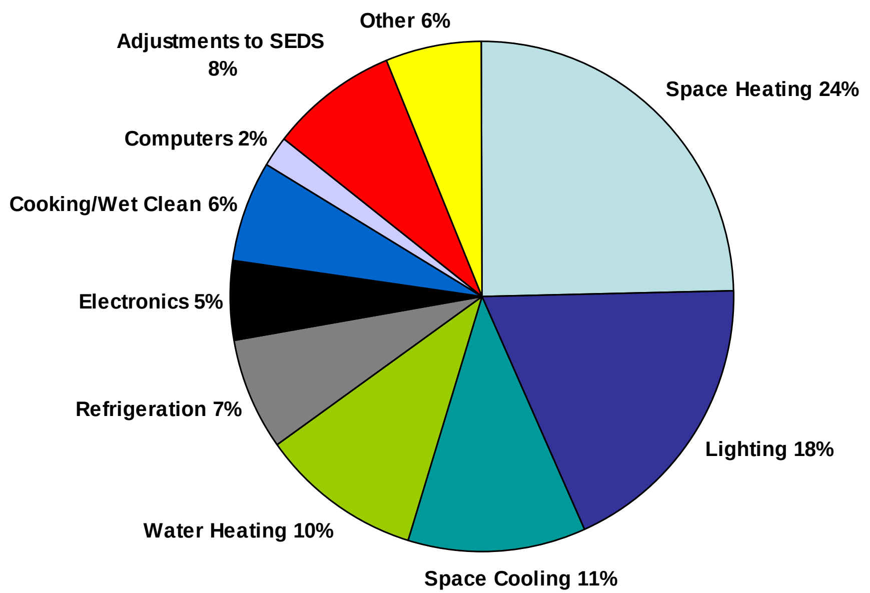
[3] *Source: U.S. Environmental Protection Agency*

Rising Energy Costs

Annually, energy costs average $200 billion for U.S. consumers and $100 billion for U.S. manufacturers. The diagrams below indicate the percentages of energy consumption for both residential and commercial sectors. Appliances, including water heaters and heating/cooling equipment, expend roughly 90% of all energy used in the U.S. residential sector. Additionally, $1 trillion will be needed in this decade, and upwards of $4 trillion during the next 30 years to meet developing countries' electricity needs.



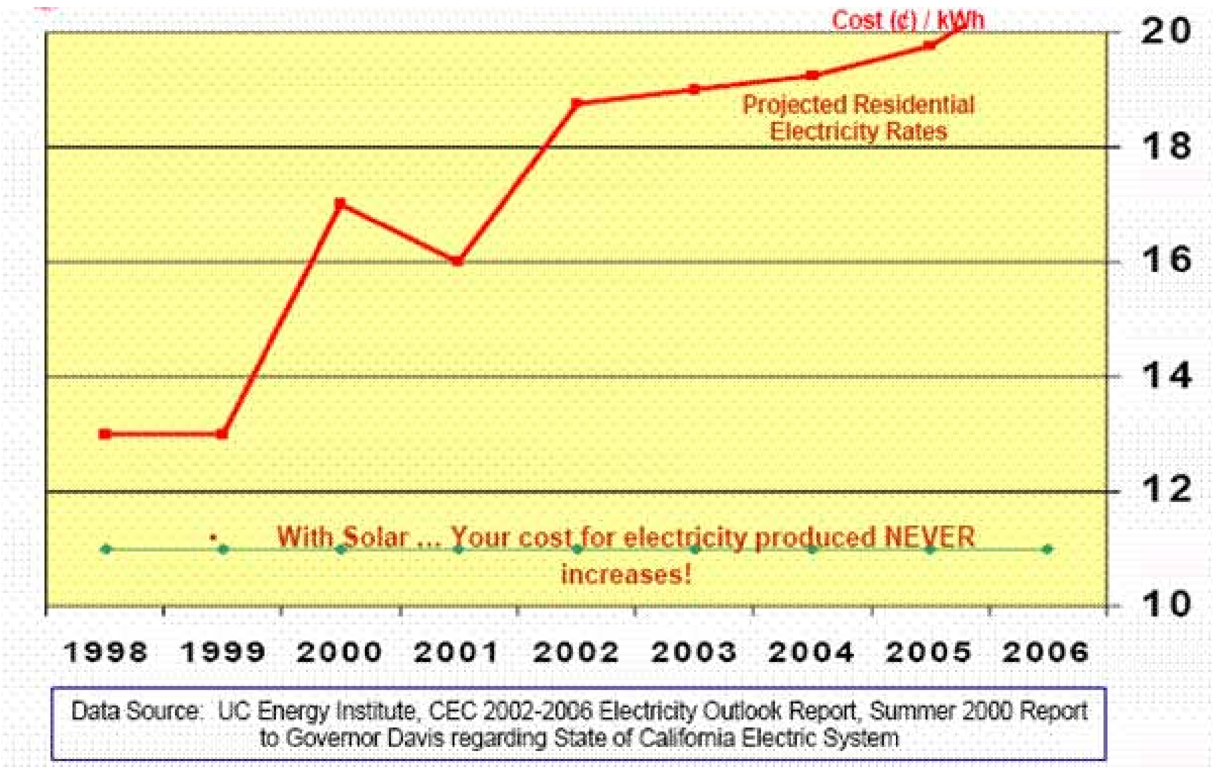
Residential Energy Consumption



Commercial Energy Consumption

Rising Energy Costs cont'd...

The average price of electricity in the United States has quadrupled in the past 30 years and electricity prices continue to increase nationwide. The graph below illustrates the cost savings of solar power (indicated by the green line) versus utility electricity (red line).



California’s Title 24

California’s Title 24 (also known as The Energy Efficiency Standards for Residential and Nonresidential Building) was established in 1978 in response to a mandate to reduce California's energy consumption.

Note that it is approximately 30% more stringent than the National Energy Code.

Currently, Title 24 focuses on space heating and cooling, water heating and lighting, but will be revised to include, among other products, kitchen, bathroom and laundry fans and cool roofs. The 2008 Title 24 will take effect in early 2009.

Since California tends to lead the nation in energy considerations, it is expected that the National Energy Code will adopt parts of Title 24 in the future.

California's Title 24 cont'd...

The requirements of California's Title 24 is based on 16 climate zones across the state of California. Every single-family and multi-family dwelling needs to meet Title 24 in order to obtain a building permit.

Title 24 requirements can be met in one of two ways:

1. **Prescriptive**: List of products to use and quantities required (e.g., R-11 or R-13 walls)

2. **Performance**: An energy consultant uses computer simulation software to determine what features are required to achieve code

California's Title 24 cont'd...

Cool Roofs that meet specific requirements for reflectivity and emissivity will be required in many of the 16 climate zones.

In those zones where the performance is greater than minimum standards, an energy credit is gained in the computer simulation method described previously.

This energy credit allows the builder to trade the credit against installing other energy efficient products. Using the credit in this manner effectively lowers the roof costs to the builder because it reduces the need to add other energy efficient products, such as insulation, windows, and HVAC equipment.

Building Integrated Photovoltaic

California's Title 24 cont'd...

Title 24 also affects the potential for solar rebates in residential new construction projects.

- The California Public Utilities Commission offers up-front rebates for solar installations. In order to qualify, a builder must build to at least 15% over Tier 1 Title 24 requirements, and
- The California Energy Commission offers builders rebates through local public utilities under the New Solar Homes Rebate Program. There are two rebate thresholds based on where the homes meet Tier 1 or Tier 2 Title 24 requirements.

The Solar Solution

Introduction

The sun's heat and light can be harnessed with PV cells (photovoltaic: photo = light; voltaic = voltage) that convert light into electricity.

Photovoltaic effect was discovered in 1838, and the first commercial cells were used on satellites in the 1950s.

Electrons on the surface of the PV cells are stimulated by sunlight. A percentage of the electrons flow through metallic circuitry in the cell. This flow of electrons creates Direct Current or DC electricity.

The sun produces more power in one second than our largest power plants can produce in one year.

Introduction cont'd…

At noon, on a cloudless day, the energy in sunlight as it hits the Earth's surface is equivalent to about 1,000 watts per square meter.

Each square meter of the Earth's surface can collect the approximate equivalent of one barrel of oil per year, or 4.2 kilowatt hours of energy every day (when averaged over the entire planet surface at 24 hours per day for one year.)

Advantages of Solar Power

- **Renewable Resource**
  - As a renewable resource, solar power avoids depletion of resources that are needed by future generations.
- **Clean Energy / No pollution**
  - Fossil fuels generate ecological consequences such as acid rain, smog, carbon dioxide emissions and climate destabilization.
- **Lower Energy Bills**
  - Users do not pay for the electricity that is generated.
- **Net Metering**
  - The utility will credit the homeowner for the excess energy that the solar system produces (refer to Slides 38, 39 for details).

Advantages of Solar Power cont'd...

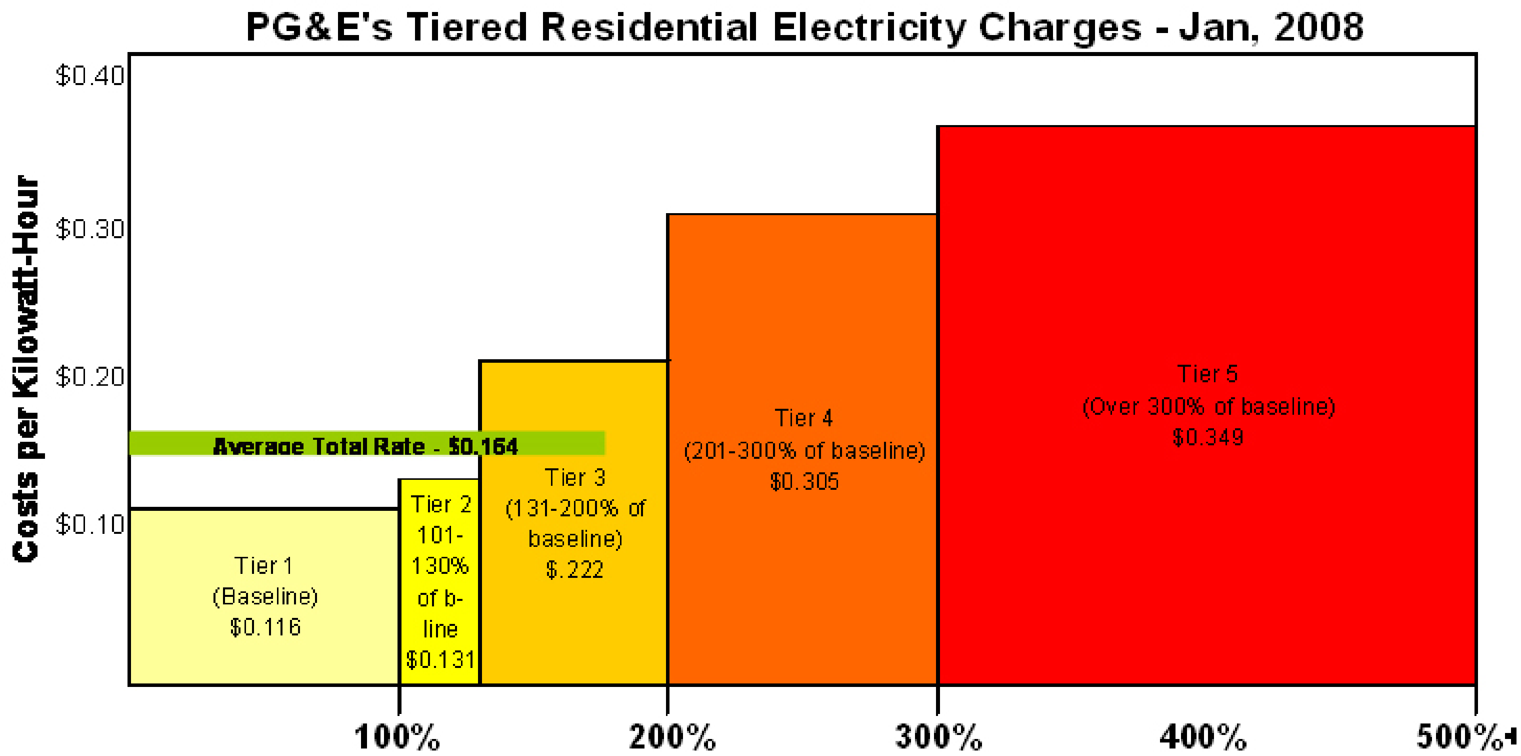
- **Little or No Maintenance**
  - Solar systems have no moving parts requiring repair or replacement.

- **Federal Tax Credits**
  - Residential systems may receive a 30% federal tax credit with no cap if the system was placed in service after December 31, 2008. Commercial systems are eligible for a 30% federal grant (the business must be a tax paying entity). Visit www.irs.gov for more information.

- **Rebates**
  - In many areas, state and utility rebates and incentives are available.
  - $500 to builder from utility for 15% + Title 24; $2,000 to builder for 35%+
  - State rebates and incentives vary greatly and can change frequently. For the most up to date information about solar rebates and incentives, check the Database of State Incentives for Renewable Energy at www.dsireusa.org.

Advantages of Solar Power – Protection Against Rising Energy Prices

Solar electricity provides protection against rising energy prices because the cost for the electricity generated by solar is fixed (refer to the green bar in the diagram below). Conversely, utility electricity operates on a tiered rate structure.



Advantages of Solar Power - Increases Home Value

"A solar electric system increases home value by $20,000 for each $1,000 annual reduced operating costs, according to the Appraisal Institute. That is to say, if a solar system can reduce the electric bill by $1,000 per year, the home is worth about $20,000 more in increased appraisable value."

"A solar electric system compares very favorably with other home improvements in percentage of cost recovered. Often, a solar system can recover much more than 100% of its cost and this percentage actually increases over time as electric rates rise."

Source:

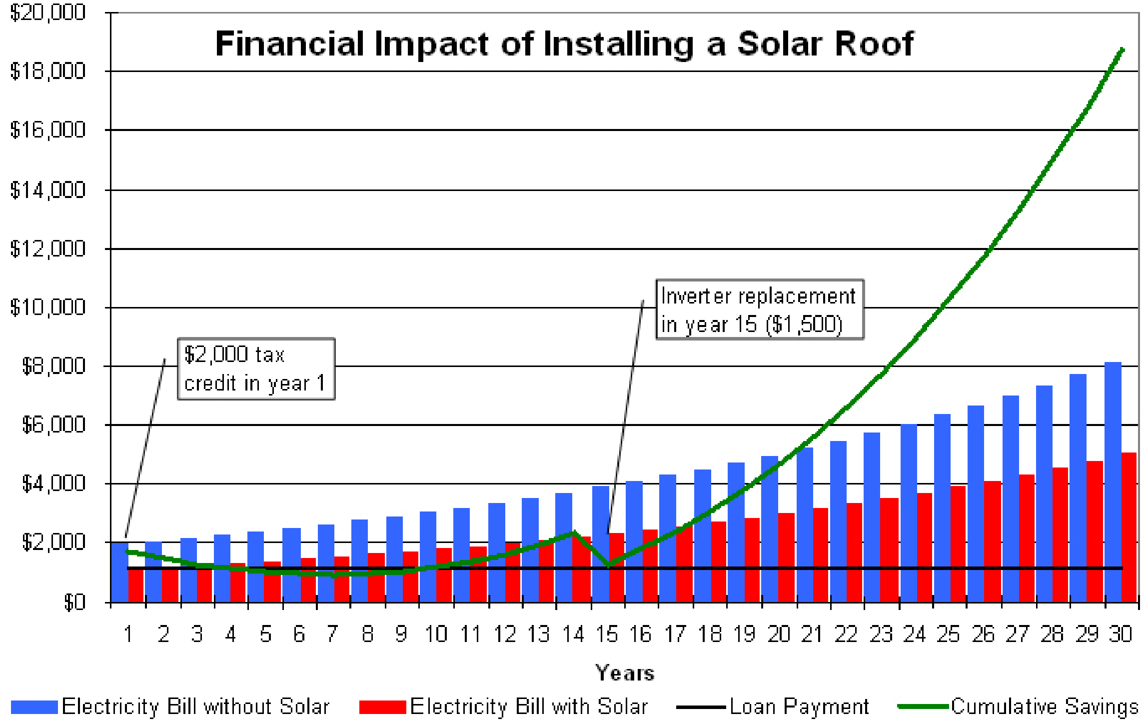
Why Is a Solar Electric Home Worth More?

Andrew J. Black

Copyright 2004 Andy Black & The American Solar Energy Society, www.ongrid.net

Why Solar is a Good Investment

Over time, solar electricity is a cost effective solution. It is cheaper than utility electricity, when considering the cost of the system divided by its electric production. Even if a homeowner adds to their mortgage, or takes a loan to pay for the system, the electricity savings are often greater than the cost of borrowing, i.e., mortgage increases by $90, electric bill may decrease by $100.



Why Solar is a Good Investment - Financial Analysis Example

Profile: 2,800 sq.ft. California home

Solution: 3kW DC system; 86 BIPV Tiles; generating about 60% of electricity demand of the household.

Financial Analysis:

Total Installed Cost:	$25,500
California Cash Rebate:	($7,500)
Federal Tax Credit:	($2,000)
Net Cost to Homeowner:	$16,000
Annual Energy Savings:	$960

Payback: 16 years, plus higher resale value of the home. Note: Analysis does not take into account rising electricity prices, therefore, the payback period will likely be less than 16 years.

Consumer Reaction to Solar

Results of surveys completed in California indicate the following:

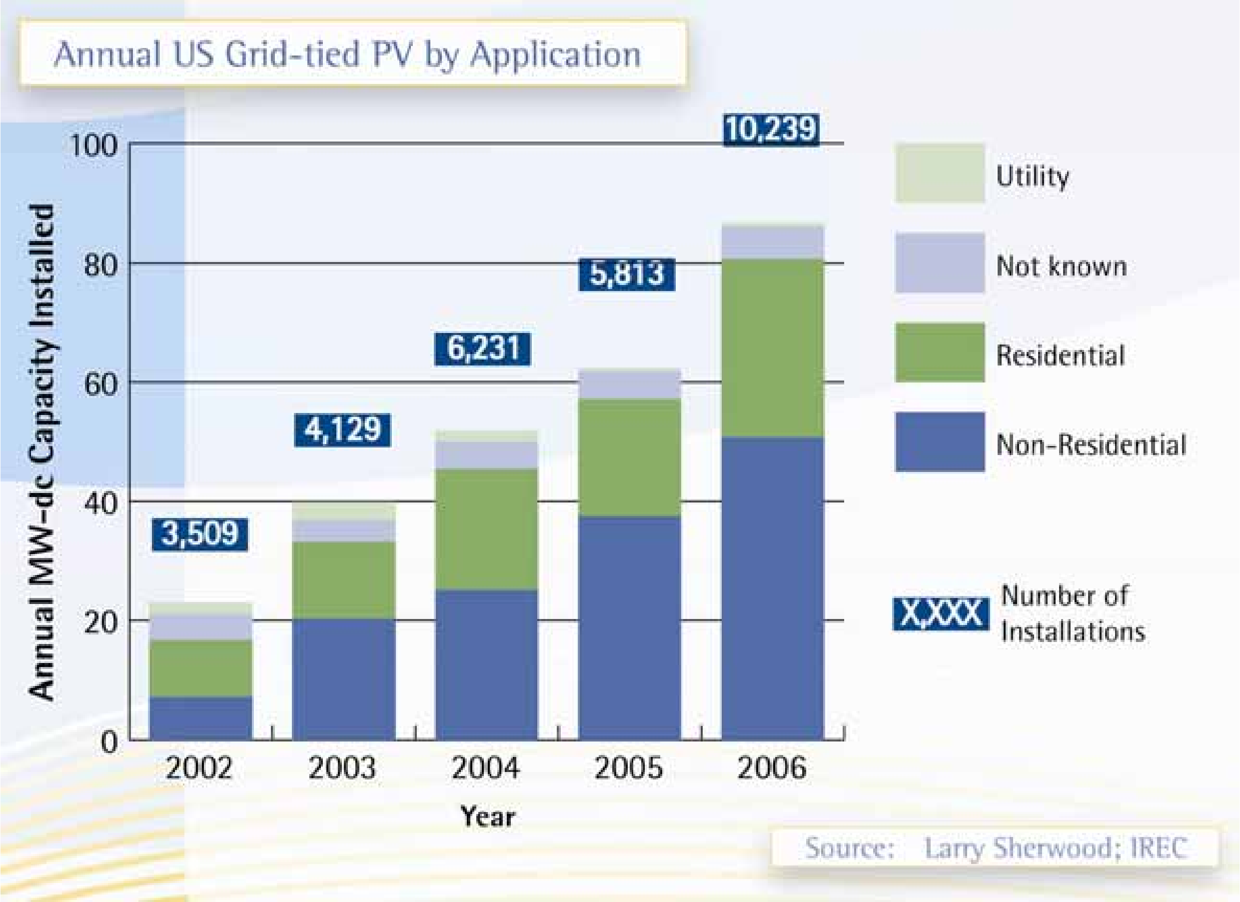
- 87% have a favorable opinion of PV solar
- 57% have a very favorable opinion of PV solar
- 68% willing to buy a home with PV solar
- 63% willing to pay more for a home with PV solar
- 93% of people who currently own a home with PV solar will buy their next home with PV solar
- 92% will recommend solar to their friends

The State of California passed initiatives that include mandates for builders to offer solar to their customers.

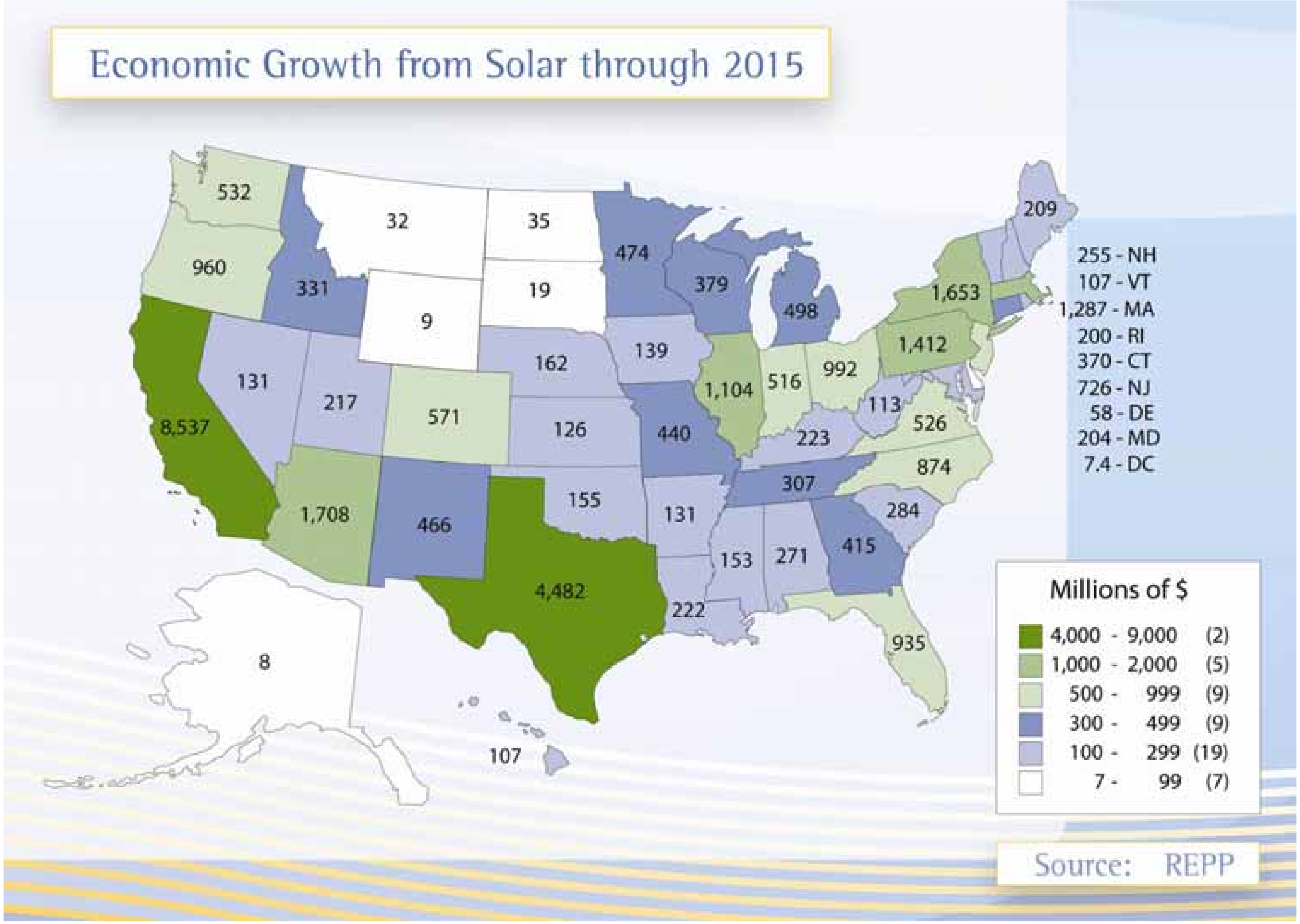
Signed in August 2006, SB 1, the "Million Solar Roofs Bill" complements the California Solar Initiative established by the Public Utilities Commission and puts California on track toward building one million solar roofs in the next ten years.

Growth of U.S. PV Installations

In 2006, growth of PV installations in the U.S. exceeded 20% to 120 MW-DC, one of the fastest growth rates among world markets. Federal and state incentives position the U.S. for continued PV growth. By 2011, builders in CA will be required to offer solar as an option.



Projected Growth of Solar



How Solar Electricity is Generated

Common Terminology

Before we discuss how solar electricity is generated, it's helpful to have a basic understanding of electricity. Defined below are some of the commonly used terms.

- Current

  Electric current, measured in amperes (amps), is the flow of negatively charged electrons in a circuit.

- Voltage

  Electrical voltage is the "force" or "pressure" of the electric current in a circuit. It is measured in volts.

- DC Electricity

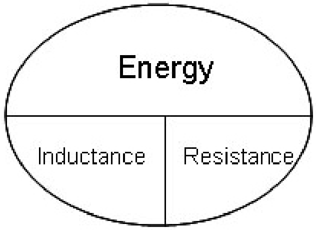
  DC stands for direct current. It refers to electrical systems where the voltage and current are steady over time, typically associated with batteries. Solar cells and solar modules also produce DC electricity.

- AC Electricity

  AC refers to alternating current. Homes use AC electricity that is supplied by the grid. Common household electricity is 120 volts AC.

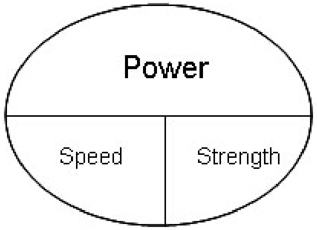
The Basics of Electricity - Ohm's Law

An ohm is a unit used to express resistance. By definition, an ohm is equal to one volt creating one ampere in a device, abbreviated as V/A.



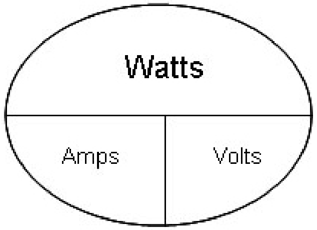
E = I x R

Energy equals Inductance times Resistance



OR

Power equals speed times strength



SO

W = A x V

Watts equals Amps times Volts

Watts

The base unit of measure of energy by the utility is 1 watt.

One kilowatt (1 kW) is a unit of energy on a utility meter and is the measure of 1,000 watts.

One kilowatt hour (1 kWh) is a measure of thousands of watts that are consumed during any 60-minute period, or, put another way, a kWh is a measurement of kW's over time.

A 60-watt light bulb utilizes 60 watts of energy per hour of operation, similarly, a 100-watt light bulb utilizes 100 watts of energy per hour.

Therefore, a 100-watt light bulb running for 10 hours (8 pm - 6am) has operated for 1,000 watts or one kilowatt hour (kWh). It follows then, if that 100-watt light bulb ran for 30 days (8 pm – 6 am) that light bulb would have consumed 30 kWh's (30 kilowatt hours).

Power and Energy

- Power is an energy rating measured in watts or kilowatts.
  - Power = watts or kilowatts - instantaneous
- Energy is a time specific measurement expressed in kilowatt-hours (kWh) and this is what is shown on an electric bill.
  - Energy = kilowatt hours – over time
- Example: A solar array producing 1 kW (AC) and operating for 5 hours would generate 5 kWh.
  - Power (kW) x Time (hours) = Energy (kilowatt-hours, kWh)

Solar System Components

Now that the fundamentals of electricity have been discussed, next for review are the components that comprise solar electricity systems.

Silicon Ingot Wafer

- **Silicon**: High purity silicon ("Polysilicon") is the key feedstock for almost all solar cells and modules produced today.

- **Ingot**: Comprised of silicon-based solar modules.

- **Wafer**: Wafer sawing is the process of cutting the monocrystalline ingot into thin slices to enable the processing of silicon into solar cells.

Solar System Components cont'd...

- **Cell**: A solar cell converts sunlight into usable electricity through a process known as the PV effect.

- **Module**: A PV module is a finished product consisting of the assembly of PV solar cells that have been electrically connected and laminated in a highly durable, weatherproof frame.

- **System**: Systems installation covers a broad range of possible PV applications, such as off-grid, utility-scale PV, commercial and residential rooftops, and Built Integrated Photovoltaic (BIPV), and

Cell

Module

System

Solar System Components cont'd…

- **Inverter**: An inverter changes the DC power from the solar array into AC power. Available in residential and commercial models, from 1 kW to 500 kW. Inverters are grid-dependent and shut down automatically during power outages. Max Power Point Tracking (MPPT) constantly monitors solar array and sets the voltage for optimum efficiency. The inverter is often included in Balance of System (BOS) costs.

Residential Inverter

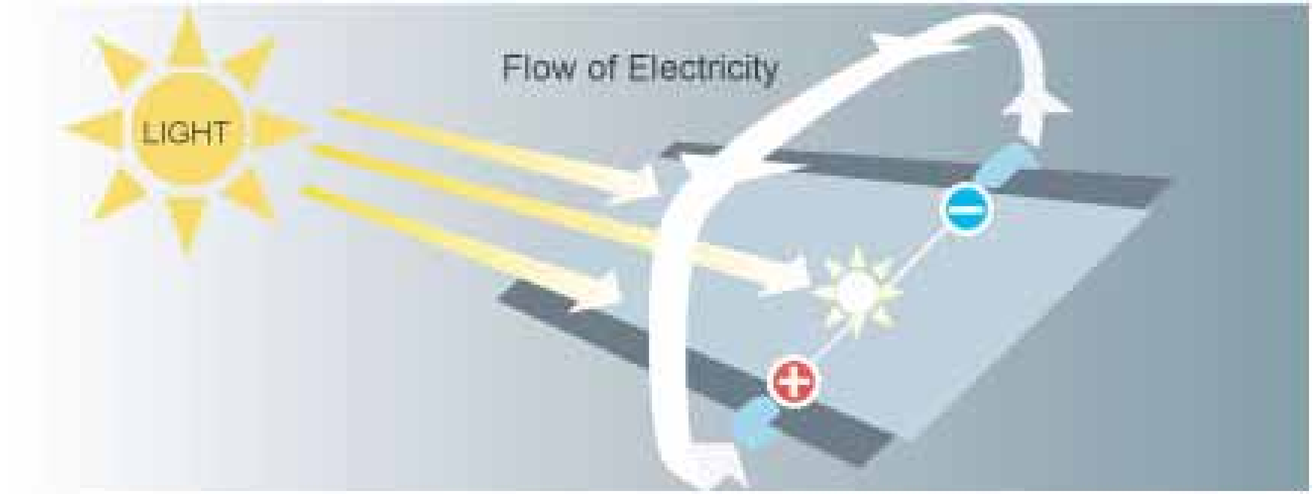
Commercial Inverter

Solar System Components cont'd...

Additional equipment required to complete the system include junction boxes, wire and conduit, disconnect switches, and meters.

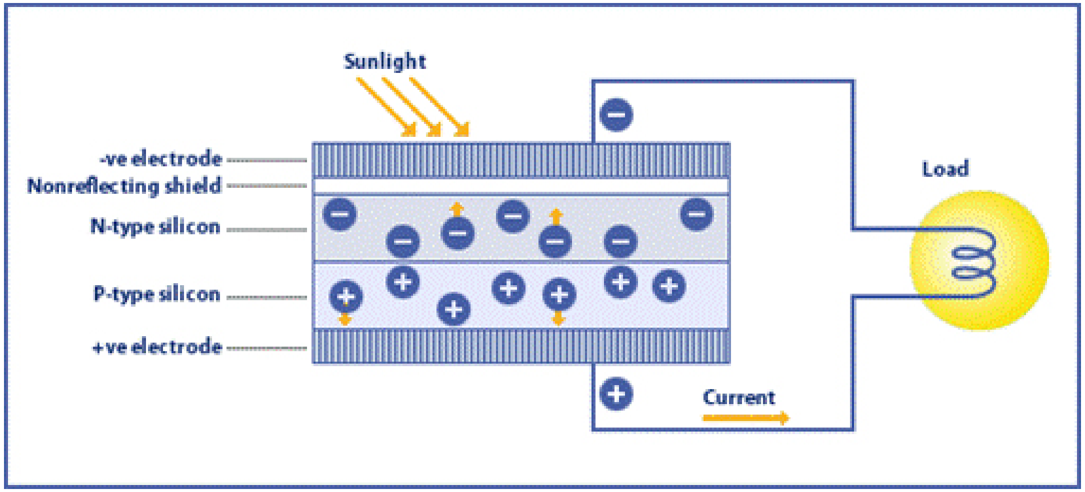
The PV Effect

The following slides illustrate the PV effect that occurs as a result of the components that comprise a solar electric system. When sunlight strikes the solar cell, electrons are knocked loose. As they move toward the treated front surface, an electron imbalance is created between the front and back surface.



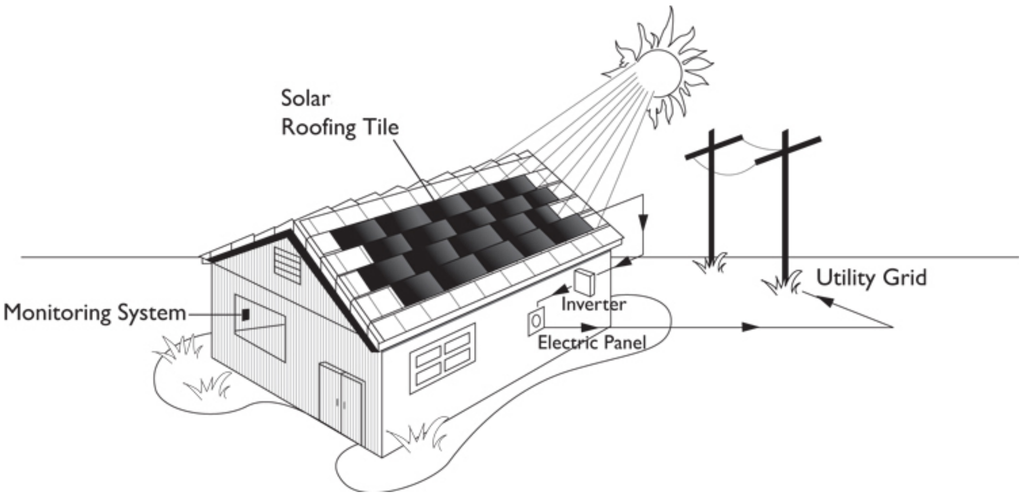
The PV Effect cont'd…

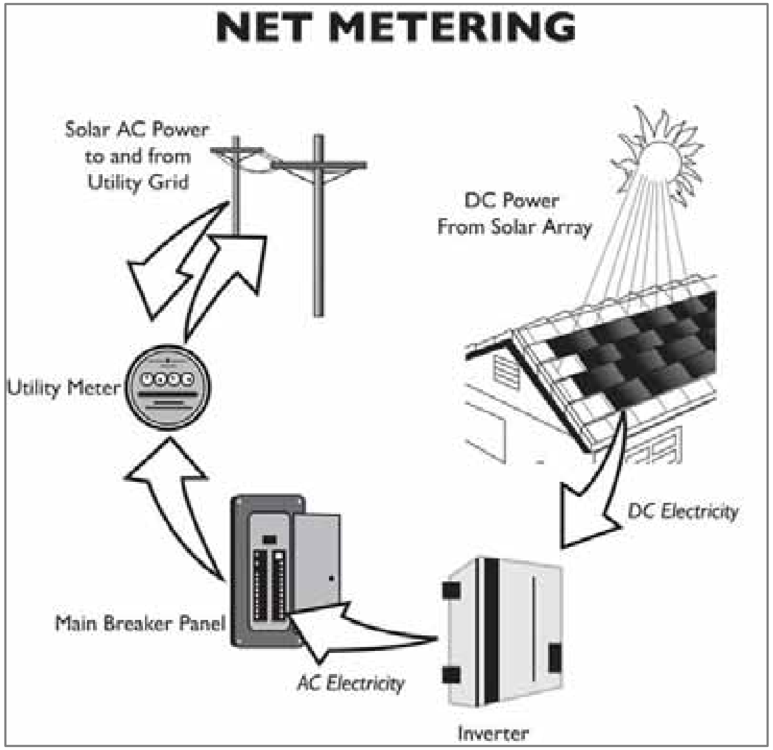
When the two surfaces are joined by a connector (e.g., a wire), a current of electricity is produced between the negative and positive sides.



Net Metering

The energy collected by the solar panels is channeled to an inverter that changes the DC electricity to AC electricity for household use. AC electricity that is not used by the house is fed into the grid.



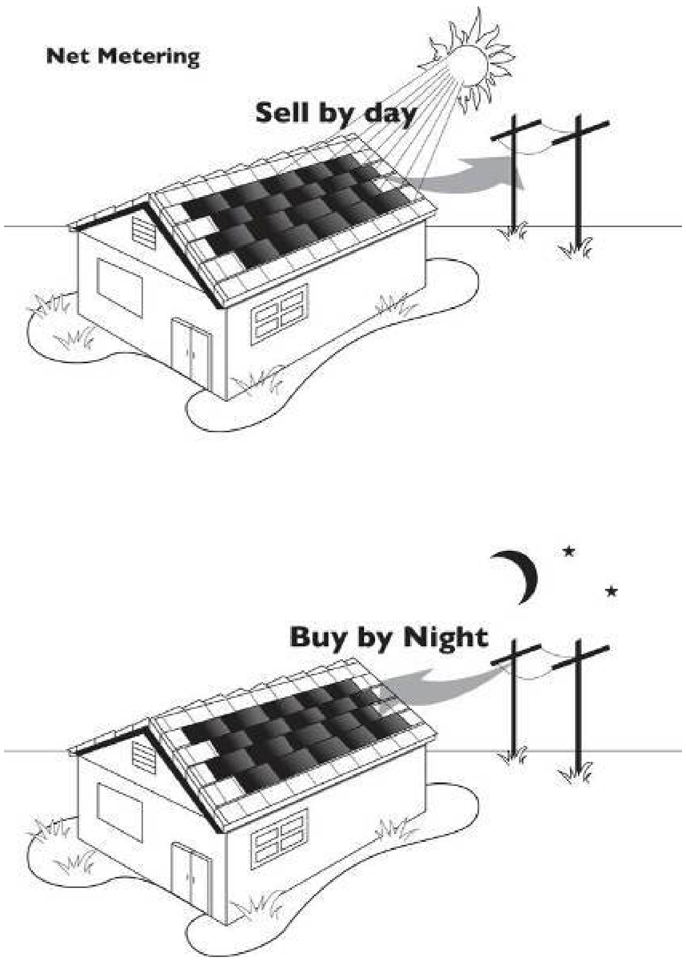


Net Metering cont'd…

The utility will credit the homeowner for the excess energy that the solar system produces.

Homeowners may actually be able to watch their meter turn backwards during the day. During the night, when the solar system is not producing electricity, the meter will run forwards because the home is drawing energy from the utility grid. The meter's forward and backward movement tracks the production and consumption of energy.

Homeowners can choose to install a system that prevents usage of electricity at the highest rates, thereby greatly reducing their bill, or they can choose to eliminate the bill entirely.



Solar Cell Options

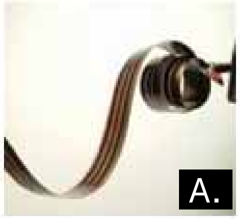
It is the solar cells covering the surface of a solar panel that create the electricity; the level of power output is dependant on the type of solar module used in the solar panel.

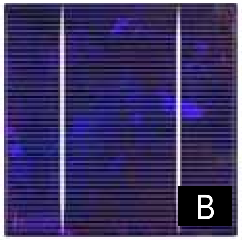
A. Thin film (Amorphous Silicon)
   Lowest power output ~ 5-7% efficiency

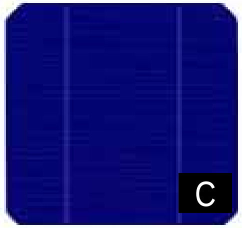
B. Multicrystalline
   Mid level power output ~ 12-15% efficiency

C. Monocrystalline
   High level power output ~ 16-18% efficiency

D. Nano-Technology







Performance Variables

Introduction

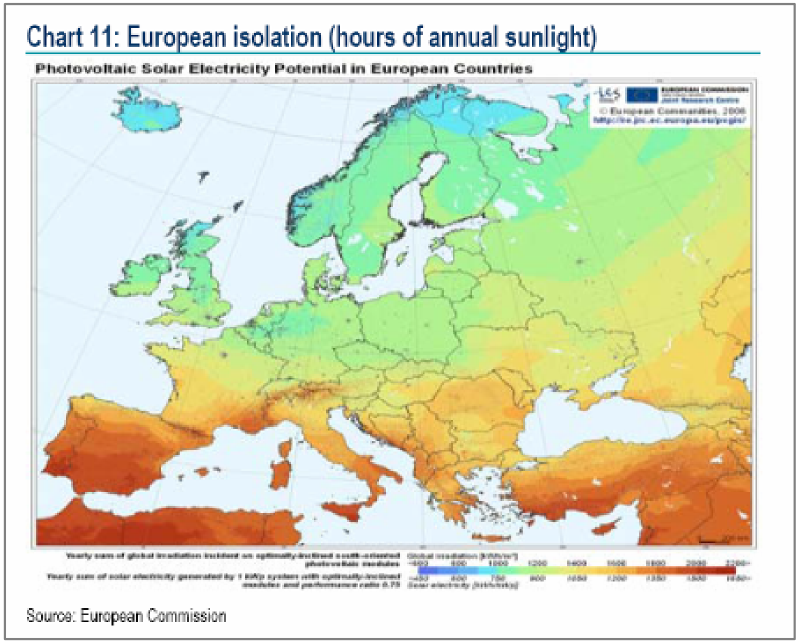
There are several factors that need to be taken into account when designing a solar system, including:

- geography
- weather
- orientation of panels
- shade
- time of day
- time of year

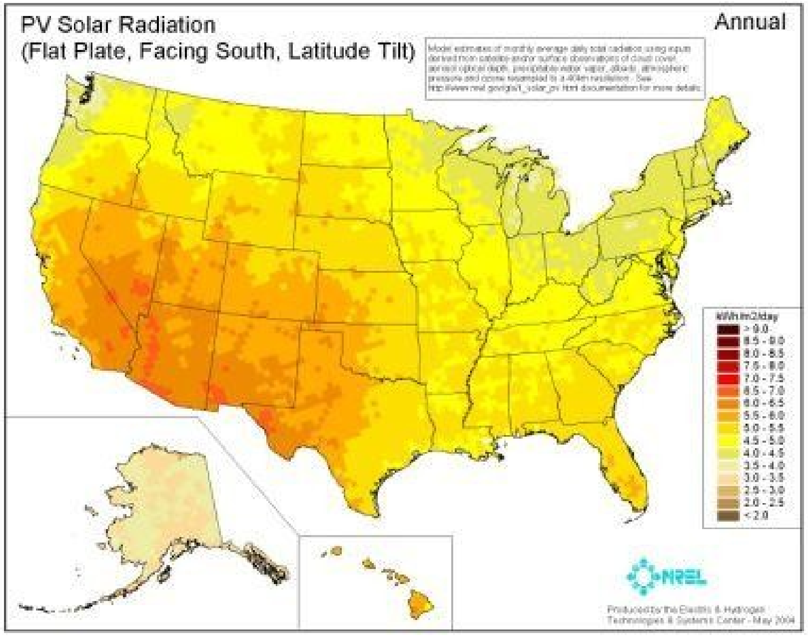
Each of these factors will be reviewed in the following slides.

Geography

The geographical location of the solar system installation is an important factor in terms of the number of daily sun-hours and kWh production. Lower latitudes increase solar energy output. The latitude will determine the best roof pitch for the installation in order to achieve the highest energy output from a solar system.



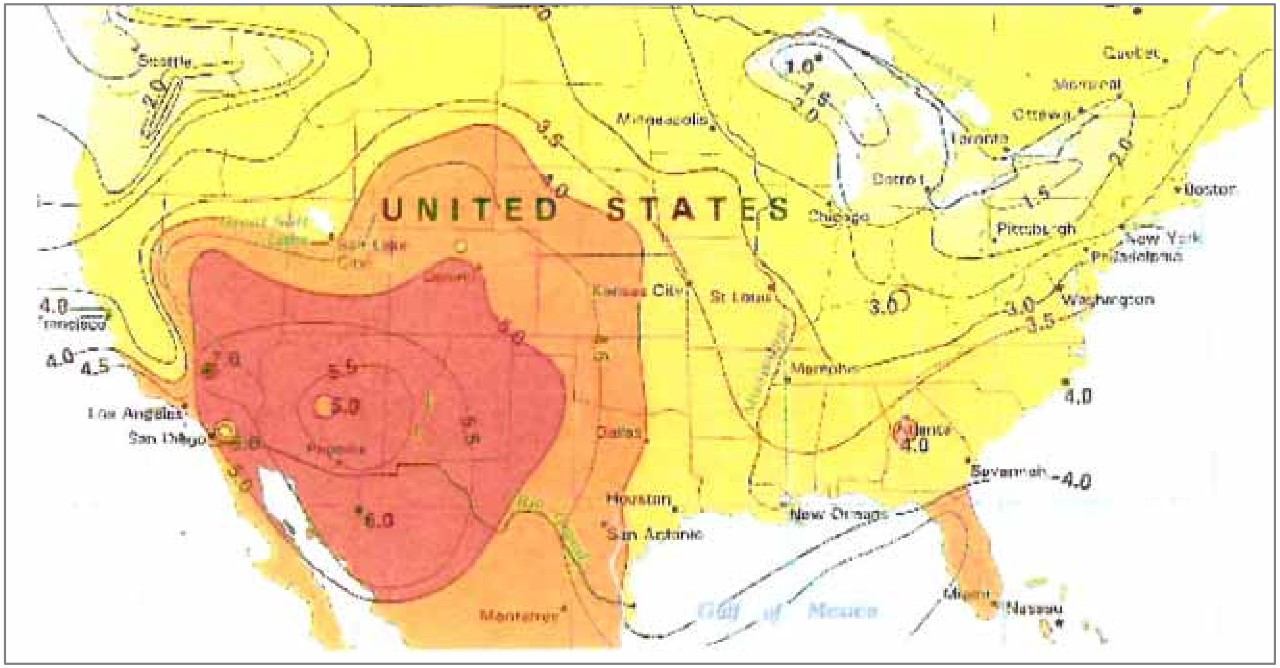
Germany 3 to 4.5 sun hours per day



California Average 5.5 sun-hours per day

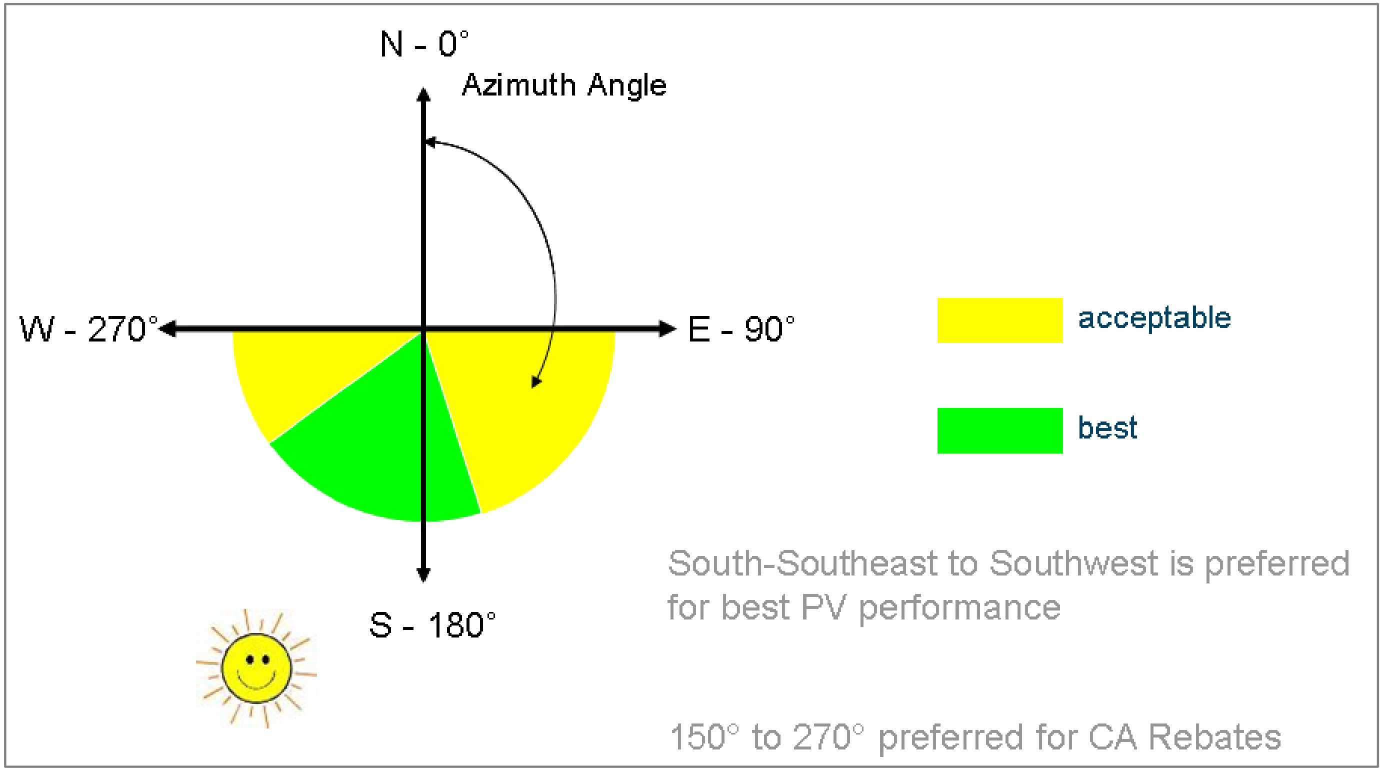
Weather

Climate, weather and geography directly affect the performance of a solar system. Clear, sunny skies increase solar energy output. Certain areas in the U.S. provide more sun hours per day for the production of solar power, but all areas of the U.S. have enough sun hours per day to produce enough power to make a solar system viable.



Orientation of Panels

Solar panels should face south for highest energy output, although east and west facing arrays are also acceptable.



Shade

Shading of the solar cells causes energy harvest loss. For optimal performance of a solar system, shading issues need to either be removed or accounted for when calculating the size of the solar system.

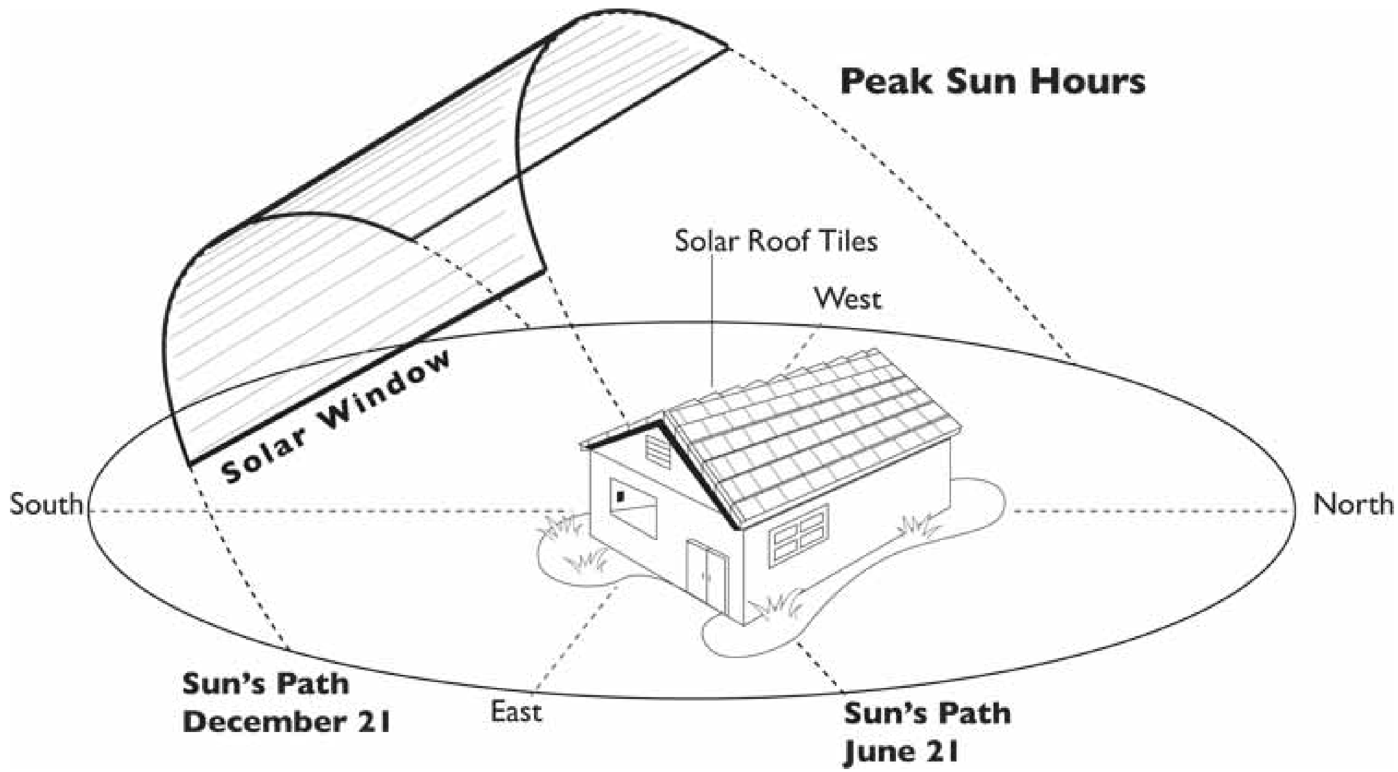
Power loss is a 3 X factor compared with shaded area, i.e., if 10% of the solar array is shaded, then 30% of the power production may be lost.

Listed below are examples of several common shading objects:

- trees
- neighboring buildings
- air conditioning units
- chimneys / vent pipes /combustion stacks
- TV antennas / satellite dishes
- dormers and other roof features

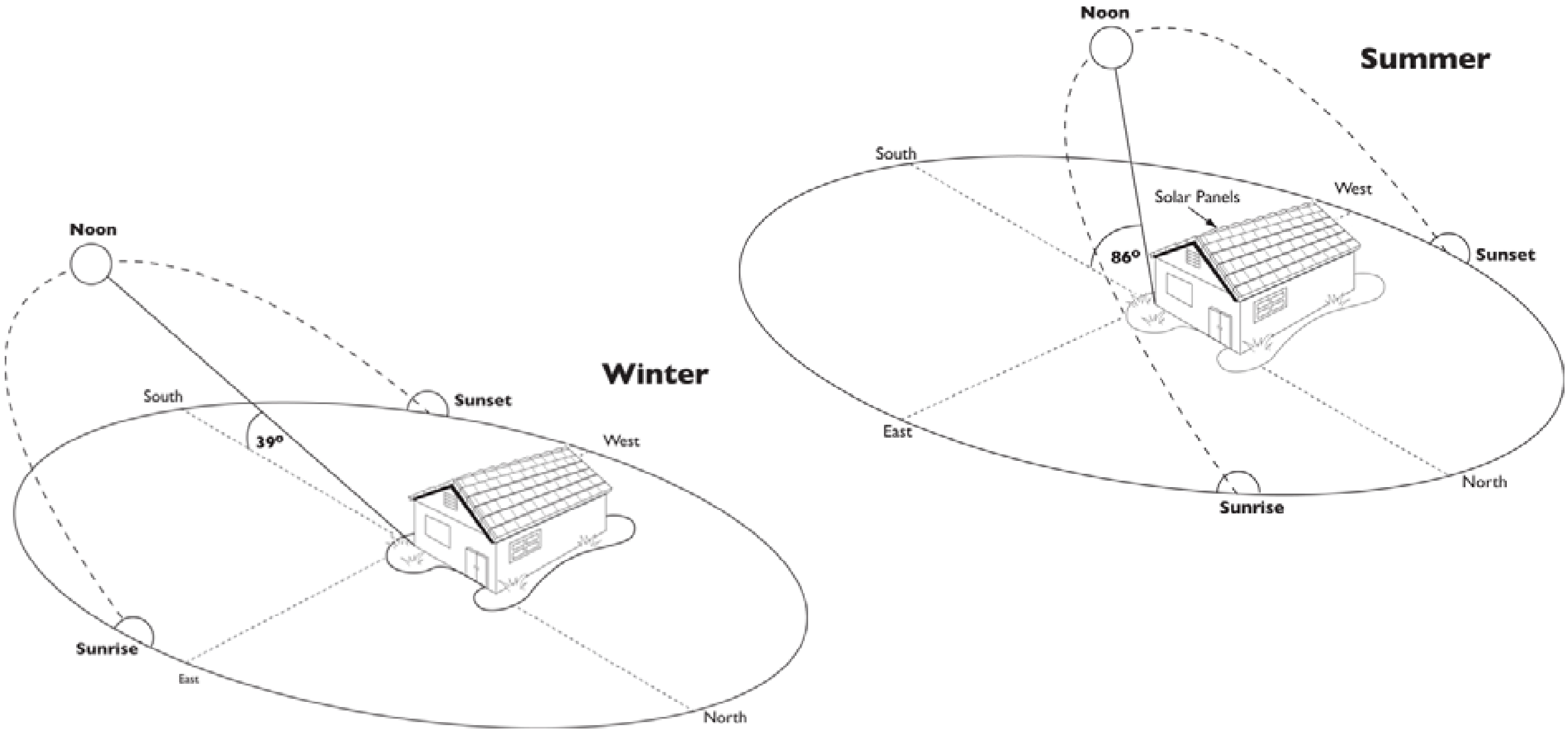
Time of Day

Each day there is a solar window (optimal time range of daylight) in which a solar system produces the most energy.



Time of Year

A solar system produces more energy during the summer months because the sun is higher in the sky in the summertime than it is during the winter months.



Solar Site Analysis

There are several resources available to aid designers/engineers with site-specific solar site analysis.

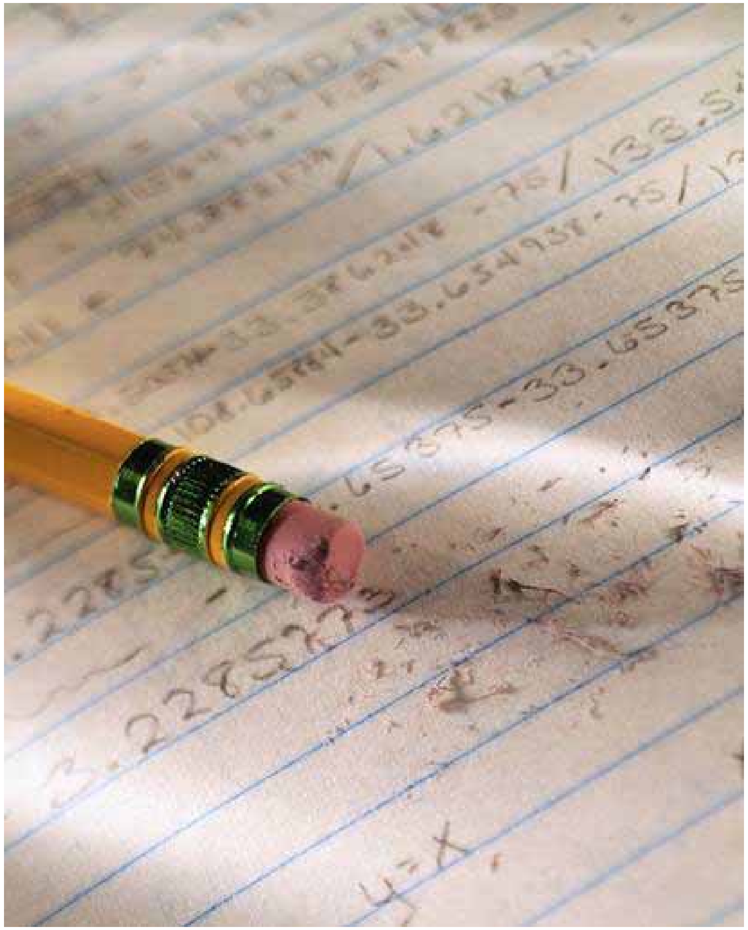
- Solar Pathfinder: www.solarpathfinder.com
- Solmetric: www.solmetric.com

Sizing the System

Introduction

The process of determining the optimal size solar system for a project involves several steps.

In this section of the course we will discuss the key criteria that are used to facilitate a successful installation.



Steps 1 and 2

- **Step 1: Estimate annual kilowatt hour usage**
  - Review the client's utility bills of the past twelve months; if unavailable, then prepare an estimate based on similar sized dwellings.
  - Determine the following:
    - How many kWhrs were used?
    - How many kWhrs were used at each tier?
    - What was the price per kWhr at each tier?
    - What was the total expense for each tier?

- **Step 2: Determine what the client wants to achieve**
  - Through discussions with the client, establish their goals.
    - Eliminate electric bill entirely?
    - Reduce higher priced electricity usage from top tiers? (this provides the best payback)
    - "Fill the roof" with as much solar as possible.
    - Specific system size, specified by customer.

Step 3

- **Step 3: Determine number of kWh the system is required to generate**

  Based on the objectives of the client, calculate the necessary system output, e.g.,

Baseline:	227 kWhrs @ $0.114 = $25.88
Tier 2:	68 kWhrs @ $0.130 = $ 8.84
Tier 3:	159 kWhrs @ $0.226 = $35.93
Tier 4:	227 kWhrs @ $0.315 = $71.51
Tier 5:	275 kWhrs @ $0.349 = $95.98
Total Usage	956 kWhrs avg $0.249 = $238.14

To eliminate the most expensive tiers (3, 4, 5) the customer would need a solar system that produces 661 kWhrs/month (159+227+275=661). A 5.3 kW (DC) system, costing $32,000-$45,000 installed, would produce roughly 661 kWhrs/month, resulting in $203.42 (85%) in monthly electric savings.

Step 4

- **Step 4: Measure available roof area, orientation, and tilt.**
  - System size is often limited by available roof space
  - Consult the solar panel manufacturer for assistance

Step 5

- **Step 5: Calculate system size**

  Rule of Thumb: 1 kW DC = approx 1,500 kWh per year

CITY	kWh / kWstc (Range)
Arcata	1,092 - 1,365
Shasta	1,345 - 1,681
San Francisco	1,379 - 1,724
Sacramento	1,455 - 1,819
Fresno	1,505 - 1,881
Santa Maria	1,422 - 1,778
Barstow	1,646 - 2,058
Los Angles	1,406 - 1,758
San Diego	1,406 - 1,758

Annual Energy Production by City per kW STC (DC)

Resources for Predicting PV Energy Output – PV Watts

Developed by the National Renewal Energy Lab, PV Watts is a neutral third party resource that allows non-experts to quickly obtain performance estimates for grid-connected PV systems.

Features of PV Watts:

- Inputs
  - Location
  - Tilt, Azimuth
  - DC watts,
  - Derate factor (default .77, for BIPV systems .75 is recommended)
  - Cost of energy
- Outputs
  - Kwh per month
  - Value of PV energy
  - Average sun-hours
  - http://rredc.nrel.gov/solar/calculators/PVWATTS/

Resources for Predicting PV Energy Output – Clean Power Estimator™

Clean Power Estimator™ is an economic evaluation software program the California Energy Commission (CEC) is licensing for use from Clean Power Research. The program provides estimates of the costs and benefits of a PV solar system for both residential and commercial applications.

Features of Clean Power Estimator™:

- Database of all U.S. utility rates and PV incentives
- Detailed inputs
- Output full financial analysis

Refer to the link provided on Slide 66 for further information.

Solar Rating Systems

STC or Nameplate

- "Best Case" DC module rating

PTC - PVUSA Test Condition

- "Real World" DC module rating, listed on CEC web site

CEC AC System Rating

- AC rating of entire system that is used to determine rebates and compare PV systems
- PTC x # of panels i efficiency (also listed on CEC web site)

Example

- 68 34 watt tiles, 2500 kW Inverter (94.5% efficiency)
- STC = 68 x 34 = 2,312 watts
- CEC = 68 x 29.3 x 94.5% =1,883 watts

Note: When evaluating systems, be sure you are comparing the same watt ratings.

Solar System Applications

Introduction

Solar modules are available in different sizes, shapes and colors to suit a variety of residential and commercial applications.

Rack-Mounted Residential System

Rack-Mounted Commercial System

Membrane Commercial Systems / Ground-Mounted Systems


Commercial Membrane System


Ground-Mounted System

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Building Integrated Photovoltaics (BIPV)

Building Integrated Photovoltaics (BIPV) systems are installed along with the roofing material (concrete tile, clay tile, etc.) instead of being mounted on stanchions above the existing roof. Appropriate for use in new construction or reroof, BIPV systems can be installed on residential, commercial or institutional pitched roofs.

Features of BIPV Systems

BIVP systems offer long-term reliability combined with several favorable features:

- lightweight and can be easily installed by an authorized roofer, electrician and/or solar integrator
- maintains natural look and aesthetic appeal of the roof
- significantly reduces or eliminates monthly energy costs
- low maintenance system, designed to prevent leaks

Examples of BIPV Installations

References and Resources

- Database of State Incentives for Renewable Energy
  www.dsireusa.org
- Internal Revenue Service
  www.irs.gov
- Solar Pathfinder
  www.solarpathfinder.com
- Solmetric
  www.solmetric.com
- PV Watts
  http://rredc.nrel.gov/solar/calculators/PVWATTS
- Clean Power Estimator™
  http://www.consumerenergycenter.org/renewables/estimator/index.html

Conclusion of This Program

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