Solar Test Yard Volunteer Handbook

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Solar Yard Purpose Statement

1. Evaluate grid-tied PV systems and their components.
2. Test new PV technology.
3. Educate the public about PV systems.

Solar Yard History/ Goals and Objectives

The TEP solar test yard has been established on TEP property, at TEP’s expense, in order to study the performance of several different photovoltaic (PV) systems. Grid-tied PV systems have been operating in the test yard continuously, measuring AC power every five minutes, since September 2003. Computerized data acquisition with AC power, DC power, irradiance, and temperature measurements every one second, facilitated by University of Arizona researchers, began in October 2008. Today over 600 photovoltaic modules from 20 different manufacturers are operating at the TEP solar test yard, with 23 inverters in strings similar to residential systems. This diverse set of PV hardware supplies 90 kWpeak to the grid (Per day?).

With data from the TEP solar test yard we will answer the following questions:

- How well do photovoltaic systems perform in the field?
- How quickly do photovoltaic systems degrade?
- What are the temperature coefficients of efficiency for each type of panel?
- What are the annual, daily, and 1 Hz energy yields of each PV system?
- How do PV modules and inverters perform compared to their specifications?
- How can we best forecast the annual PV energy yield for any given system?
- How do aerosols, winds, clouds, and other weather conditions affect PV systems?
- How can we predict the statistics of PV energy production at any given site?
- How well do various low-concentration-radio PV systems perform?

This work will inform utility companies, homeowners, PV panel installers, and researchers about the performance of existing and new types of photovoltaic systems in the Arizona environment.
Solar Yard Safety (Visitors and Researchers)

- Visitors should understand this is an outdoor, working industrial laboratory. It’s not a museum!

1. **Sun exposure and heat.**
The solar panel test yard is outdoors, on an un-shaded asphalt parking lot. Expect to be hot.
Visitors should wear closed-toed shoes. Visitors may wish to carry a water bottle, wear a hat, long sleeved shirts, long pants, sunglasses and slather on sunscreen.

2. **Trip hazards, sharp edges, uneven terrain and walking distance.**
The tour will be on an asphalt surface, which is at times uneven. There are loose wires and electrical conduit on the ground. Some conduit is 4” above ground, which requires careful attention to where and how one walks. The solar panel frames have some sharp edges, so care must be taken not to walk closely around corners.

3. **Electrical hazards.** (Electrical wiring and boxes.)
Visitors should not, under any circumstances, touch any wiring, and therefore, should not contact any electricity.

Visiting engineers who may wish to view electrical connections should NOT open any boxes which have been closed with tools and must never touch wiring. The voltages from a string of solar panels varies with the sun, but often exceeds 200Vdc. The utility side of the inverters is 220Vac, 60Hz, contact with which can be fatal.

- Any researchers working on the electrical connections must:

1. Have clearance from Dr. Alex Cronin.

2. Have schematics of how the circuitry is supposed to be wired, knowledge that in a laboratory situation the schematic may not match what’s on the ground.

3. Tools with which to confirm that open circuit breakers are actually open, and that hazardous voltages and hazardous energy conditions do not exist.

Researchers are encouraged to log which circuits were taken down and for approximately how long, so zero output readings can be understood.

**Solar Energy Collection Process:**

I’m not sure that we want to keep this section in the handbook, but think it might be helpful to map out (in words or with a picture) the process of solar energy from photon of light to flicking on a light.
Current Research:

Again, I don’t know if we should include this section, but I think that the research aspect of the solar test yard will be very interesting to many of the visitors. We wouldn’t have to include anything too complex, just an overview.

Solar Test Yard Questions:

General Solar Questions:

1. What is Solar Power?

The sun creates energy every second of every day by converting hydrogen to helium in the process of nuclear fusion. The sun produces so much energy that in one day it provides enough power to meet human consumption needs for a quarter of a century. That is of course, if we knew how to harness it all.

There are two ways to use solar energy, passive, and active. Passive solar energy collection relies directly on the sun's rays and is often used by architects to design green buildings. For instance a building may be built with specially placed windows, heat-absorbing construction materials, and surrounded by strategically placed plants in order to keep it cool in the summer and warm in the winter. Active solar energy collection is the use of technological devices to collect and store solar energy. All of the solar panels at the test yard are examples of this type of energy collection.

2. How Do Photovoltaic Cells Collect Energy?

Photovoltaic (PV) cells are able to collect energy because of the photovoltaic or photoelectric effect, which causes a flow of electrons between two metal plates within the PV cell when struck by light. This flow creates direct current (DC), which can be changed to alternating current (AC) for residential use. Basically, electrical current is made of moving electrons. When light (photons) come in, electricity is generated because the photoelectric effect causes electrons to move when light is absorbed.

3. Why Use Solar Energy?

Scientists estimate, the sun will burn four to five billion years into the future. This makes solar energy a sustainable and renewable alternative to nonrenewable fossil fuels. As mentioned before, energy from the sun is also abundant enough to meet all of our needs, without harmful effects such as greenhouse gas and other air pollutants. Solar panels are also quite and safe, unlike nuclear energy options.
4. Why are solar panels ideal?
   Sunshine is an ever-abundant resource. In fact, the Sun provides Earth with as
   much energy every hour as human civilization uses every year!

6. Why are there different designs?
   A variety of photovoltaic materials exist.
   Different designs serve different purposes.
   Manufacturing cost is always a variable.
   Chemistry and different coatings make them look different.

7. What are those panels that are all blue and shiny when you look at them from
   different angles?
   Most of the blue panels are polycrystalline silicon that have an anti-reflection coating.

8. Why are the panels at an angle?
   Most panels at this yard do not move.
   They are fixed facing south at a tilt of 32 degrees (latitude of Tucson).
   The idea is to capture the most sunlight (kWh) each year from the modules by
   insuring that the sun hits the panels as directly as possible.

9. What kinds of places would be best for solar panels?
   Sunny and away from potential shaded areas.
   Rooftops, parking garages, patios.
   Basically a moderate temperature climate like Flagstaff is ideal.

10. Why do solar panels work better when they are cooler?
    HEAT KILLS! Almost all electronics work better when they are cool.

11. At what temp do the panels become inefficient?
    “PV performance decreases when the cell temperature exceeds a threshold of 25
    °C (~77°F) (Jacobson) For most crystalline silicon solar cells the reduction is
    about 0.50%/°C.”

12. If heating is such an issue why has no one tried to incorporate a cooling device?
    It’s not cost effective!
    There have been a few studies done with cooling solar panels, the main method is
    by spraying water periodically or by misting the cells so the heat is dissipated by
    evaporative cooling. Results have varied. Cooling the cells by passive cooling
    has proven not “feasible for Si cells over 100 suns concentration for 4 sq cm cells,
    and 150 suns for 1 sq cm cells” (Smithsonian). Additionally, misting or spraying
    down panels consumes water and risks cracking the hot glass.

13. Who uses solar panels?
    Satellites have used solar panels since the 1950’s.
    Remote offices (off-grid) have used solar panels.
    In 2009 there were over 1100 houses with large solar panels (1 Kw or more).
Utility companies, businesses, schools, military, and homeowners all use them.

14. What other types of renewable energy are there –
83% of our energy consumption was from fossil fuels.
The largest source for electricity is coal and natural gas combustion, Hydroelectric, wind, and solar electricity generating stations are examples.

According to http://www.eia.doe.gov/, in the U.S. in 2008, we consumed 100 Quad Btu of energy. That is equal to $10^{30}$ Joules, or 27 trillion kWh. The breakdown by source is:

<table>
<thead>
<tr>
<th>Source</th>
<th>Portion of our energy use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>37.0 %</td>
</tr>
<tr>
<td>Coal</td>
<td>22.0 %</td>
</tr>
<tr>
<td>Natural gas</td>
<td>24.0 %</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>8.0 %</td>
</tr>
<tr>
<td>Biomass</td>
<td>3.8 %</td>
</tr>
<tr>
<td>Hydro</td>
<td>2.4 %</td>
</tr>
<tr>
<td>Wind</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Solar</td>
<td>0.1 %</td>
</tr>
</tbody>
</table>

15. How much energy does one solar panel generate compared to something they know about (such as a AA battery) and how that is calculated?
In 25 years you would get as much energy from single PV module as from a million (1,000,000) AA batteries.

A typical solar panel produces 100 Watts max and it does this for about 5 hours per day. At the end of a year this amounts to 182 kWh.

A typical cell phone battery holds 3.6 watt hours. During a typical day you could charge a cell phone battery 130 times with one PV module that is ratted at 100 Watts. In a year you could charge 50,000 cell phones with one panel. And the panels should last 25 years.

The average amount of usable sun hours per day in Tucson AZ is 6.3 sun hours/day. Depending on the time of year the range is 4.3 to 7.7.

16. What new discoveries have been established by this data?
Degradation rates of panels.
The effects of dust and particulate matter on panels.

17. What are the current projects that are being done at the solar test yard?
One project that is being done currently is the temperature coefficients of efficiency for each solar string.

18. What kind of crystals are the cells made out of?

Monocrystalline is composed of silicon that has one crystal lattice throughout the whole material, which usually provides efficiency 10-15% greater than polycrystalline due to the near absence of impurities.

Polycrystalline on the other hand is cheaper than monocrystalline. It consists of multiple crystal lattices that are oriented differently and have different sizes. Due to those features, light is less efficient in promoting electrons into the conduction band, relative to the monocrystalline structure.

Thin film, the least efficient of them all. It is made by applying a thin layer of photovoltaic material, ranging in thickness from several nanometers to tens of microns. This technology is by far the cheapest, and is becoming rapidly cheaper than poly and mono crystal lattices.

By far, the most prevalent bulk material for solar cells is crystalline silicon (abbreviated as a group as c-Si), also known as "solar grade silicon". Also used is a cadmium telluride solar cell made with cadmium telluride, an efficient light-absorbing material for thin-film cells. Compared to other thin-film materials, CdTe is easier to deposit and more suitable for large-scale production. (Solar Cells) The materials based on CuInSe2 that are of interest for photovoltaic applications include several elements from groups I, III and VI in the periodic table. These semiconductors are especially attractive for thin film solar cell application because of their high optical absorption coefficients and versatile optical and electrical characteristics which can in principle be manipulated and tuned for a specific need in a given device.

19. Why are the cells linked in series instead of parallel?

The main reason that the cells are linked in series is because of cost. To link the cells in parallel would require more time and wire to construct along with the added disadvantage the heat generated from the extra wire would decrease the efficiency of the panel.

20. What is the efficiency per panel?
Monocrystalline:  11.51% - 19.32%
Polycrystalline:  5.93% - 16.84%
Thin Film:  5.14% - 17.67%

21. What are the current methods being tested to reduce the cost and increase the efficiency of the cells?
   - One way of reducing the cost is to develop cheaper methods of obtaining silicon that is sufficiently pure...at current efficiencies, it takes one to two years for a conventional solar cell to generate as much energy as was used to make the silicon it contains. Another approach is also to reduce the amount of silicon used and thus cost, is by micromachining wafers into very thin, virtually transparent layers that could be used as transparent architectural coverings (Solar cells). Research projects in Tucson are examining ways to concentrate the solar energy, to optimize the wavelengths collected. Volume manufacturing always brings costs down.
   Single and dual axis tracking.

22. Can we use other wavelengths of light or will only the visible spectrum work?
   Traditional solar cells can only use visible light, rendering them idle after dark.

23. Is there a benefit to using mirrors/lenses to concentrate the sunlight on a smaller row of panels?
-Yes. There are a few ways to concentrate the light onto the solar panels. By increasing the quality of the panel by using a better crystalline for example gallium arsenide then the amount of light that is concentrated will have more effect. (Photovoltaic Module) Overall the increase in power generated is about 30%.

Questions from Potential Buyers:

1. What is the cost per watt of a solar system?
   - Overall cost of installation? $16,500 (Typical 3 watt system)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost per watt</th>
<th>PV Module</th>
<th>Inverter</th>
<th>Mounting Wires</th>
<th>Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>$8.00</td>
<td>$5</td>
<td>$1.00</td>
<td>$1.00</td>
<td>$1.00</td>
</tr>
<tr>
<td>2010</td>
<td>$5.50</td>
<td>$3</td>
<td>$0.50</td>
<td>$1.00</td>
<td>$1.00</td>
</tr>
</tbody>
</table>

2. What are all the government rebates and incentives?
   NOTE: Tax credits apply to the year that the solar system actually goes into operation
   • Federal tax credit : 30%
     • No cap on residential federal tax credit
   • State tax credit : up to $1000
   • Utility rebates
     • Tucson Electric Power offers $3 per watt up to 60% of the system cost, or 0.2¢/kWh. TEP also offers up to $1,750 for a solar hot water system

3. How long does it take to install?
   - Under 6 hours to install, and about 4-6 months from picking an installer, depending on the amount and type of panel (very approximate).

4. Will I still need to buy power from the electric company?
   - If you use more power than you are producing, then, yes, you will need to buy power from the electric company.

5. What happens if the solar panels produce more electricity than I need?
   - You have entered into a contract with TEP to sell your energy to them for the going rate.

6. How long does it take to pay it off?
   - About 10-12 years

7. How long do the solar panels last?
   - Panels 25 years, Inverter 10-15 years (heat kills)

8. What other equipment is needed (inverter, etc.) and what does it look like (size, where it goes, etc.)?
   - The inverter is housed in a metal box, the size of two to three shoeboxes. The box is shut so that you cannot access its interior and goes on the size of your
house. The net meter calculates how much energy you are putting in and how much you’re taking out.

9. What type of roof works best?
   -White roof, facing south at 30 degrees, with no shade.

10. What about just getting a solar water heater?
    -Best bang for the buck. Great investment if you don’t have enough money to buy a whole PV system.

11. What happens when it’s not sunny?
    -Depending on the weather conditions and type of panels less energy is produced, and need to use energy from T.E.P.

12. How useful would solar be in areas where it’s not as sunny as it is here?
    -Still useful, ex) Germany, although not being the sunniest country has become the number one PV installer in the world! In fact, Germany alone accounted for almost half of the solar market in 2007.

13. Overall question: will it save me money?
    -Depends, long term, yes.
    -Insulating people from rising utility rates.
    -AzRISE has an analysis comparing a solar panel plant with money sitting in a CD at 1% or losing money in the stock market.

14. How many square feet can a single solar unit be expected to produce power for?
    -An average 3 kW system might provide power for a 2,000 square foot home, but it all depends on the efficiency of the users and the home.

15. What kind of maintenance is involved with the units?
    -None, except replacing the inverter in 10 years (5 year extended warranty available in some cases).

16. Does solar cost more or less than traditional energy sources?
    -On a kwh basis it cost more.
    -Coal is 8 cents per kwh
    -Solar is 15 cents per kwh.
    -The average US residential price for electricity is $.1133/kWh during November 2009.
    -The average $ value per watt for PV solar is hard to determine because the value can change based on system size and incentive programs.

17. Can you do this?
    -YES!
Tour Tips:
Wisdom gained from giving tours that may help new volunteers.

Middle and High School Lesson Plans:

PART ONE:
Introduction: What is solar energy? How does it work?
Discuss: The three most commonly encountered types of silicon material used for solar cells:

1. Mono Crystalline Cells
2. Poly Crystalline Cells
3. Amorphous (thin film) Silicon Cells

Activity: Have students identify the various types of solar cells (designated by system number e.g. PV1).

PART TWO:
Tour of test yard

PART THREE:
Introduction: How do we measure output? What is a digital multi-meter?
Discuss: Digital multi-meter and electrical measures

1. Voltmeter/Voltage/Volts (V)
2. Ammeter/Current /Amperes (A)
3. \( V \times A = \text{Power/Watts} \) (W)
4. Direct Current
5. Alternating Current

Demonstrate: Use of digital multi-meter
Activity: Testing Current and Voltage of a solar panel.
Equipment: 1 – solar panel, 1- multi-meter, 2- connecting wires (e.g. alligator clips).
Procedure: Solar panel lying flat, panel at 45 degrees and at 90 degrees.
Data Analysis: Chart/graph your results.
Conclusions: Explain your findings and what you learned about the solar panel.
Glossary of Terms:

**Alternating Current (AC):** An electric current where the direction reverses at regular intervals or cycles. AC currents are used for commercial energy because the voltage can easily be controlled.

**Amp/Ampere:** A unit measuring the rate of flow of an electric current. High currents require thicker wire to minimize losses when cable temperatures rise.

**Concentrating Solar Power (CSP):** Technology that uses mirrors to reflect and concentrate sunlight onto receivers that collect the solar energy and convert it to heat. This thermal energy can then be used to produce electricity via a steam turbine or a heat engine driving a generator.

**Conductor:** The material through which electricity is transmitted such as a wire or distribution line.

**Direct Current (DC):** A type of current where the electricity flows in one direction only. It usually involves low voltage and high current. Solar panels produce DC, which must be converted to alternating current (AC) before it can be used by most appliances.

**Electric Current:** The flow of electricity in a conductor, which is measured in amperes.

**Feed-in Tariff:** A policy-based system under which utilities pay participants per kilowatt-hour of renewable electricity generated. Feed-in tariffs affect where, when, and how much renewable energy generating capacity is installed. Feed-in tariffs are also known as electricity feed laws, feed-in laws, feed-in tariffs (FITs), advanced renewable tariffs (ARTs), renewable tariffs, and renewable energy payments.

**Inverter:** A device that converts direct current (DC) electricity to alternating current (AC), either for stand-alone systems or to supply power to an electricity grid.

**Kilowatt hour (kWh):** The amount of electricity it takes to run a 100-watt light bulb for 10 hours. The average household uses around 11,000 kilowatt hours (kWh) per year.

**Megawatt (MW):** A standard measure of electric power plant generating capacity, equivalent to 1,000 kilowatts or 1,000,000 watts.

**Net Metering:** Enables renewable energy customers to “save” excess energy that they generate to offset later energy consumption. This is done with electric meters that turn backwards when excess electricity is generated. “Net” refers to the deduction of energy
outflows from metered energy inflows. This offset means that customers receive retail prices for excess electricity generated. This encourages customer investment in renewable energy technologies. Implementation of net metering is determined by state legislation.

**Photovoltaic (PV):** Photovoltaic (PV) cells convert light from the sun into usable energy.

**Real-Time Pricing:** Real-time pricing differs from time-of-use rates in that it is based on actual (as opposed to forecasted) energy prices, which may fluctuate unpredictably throughout the day and are weather-sensitive.

**Smart Grid:** A nickname for an ever-widening palette of utility applications that enhance and automate the monitoring and control of electrical distribution. Smart meters provide detailed information on energy consumption for use in the smart grid.

**Smart Meter:** Refers to a general class of meter which will not only measure kilowatt hours but also power quality, which is based on quality of the voltage. It is capable of being read remotely.

**Solar Thermal:** A form of power generation using concentrated sunlight to heat water or other fluids that may then be used to drive a motor or turbine.

**Tariff:** The price paid per kilowatt-hour of electricity.

**Time-of-Use (TOU):** Time-of-use rates describe the pricing of electricity based on forecasted supply and demand during particular time blocks. Time-of-use rates are usually divided into three or four time blocks per 24 hour period (on-peak, mid-peak, off-peak and sometimes super off-peak) and can vary from summer to winter.

**Volt:** The unit measuring electrical pressure. High voltage requires increased insulation and clearances.

**Watt:** The rate of energy transfer equivalent to one ampere under an electrical pressure of one volt. One watt = 1/746 horsepower, or one joule per second. It is the product of voltage and current (amperage).

**Resources**
Finding a Solar Installer
• Arizona Solar Energy Industries Association:
  www.arizonasolarindustry.org/members.html
• Tucson Electric Power:
o Electric: www.greenwatts.com/Docs/ListingSolarInstallers.pdf
• Trico Electric Cooperative: www.trico.coop/index.php/renewable-energy

News and Information
• American Solar Energy Society : www.ases.org
• Database of State Incentives for Renewables and Efficiency : www.dsireusa.org
• World Solar Energy News Headlines: www.solarbuzz.com
• Home Power Magazine: www.homepower.com
• Solar Energy International: www.solarenergy.org
• Solar Energy Industries Association: www.seia.org
• Solar Electric Power Association: www.solarelectricpower.org
• Renewable Energy Access: www.renewableenergyaccess.com

Research
• National Renewable Energy Laboratory : www.nrel.gov
• Sandia National Laboratory : www.sandia.gov/ERN/index.html
• Union of Concerned Scientists: www.ucsusa.org
• Developing State Solar PV Markets: www.americanprogress.org/issues/2008/01/solar_report.html

Arizona Resources
• Arizona Department of Commerce:
• Arizona Research Institute for Solar Energy (AzRISE): www.azrise.org
• Arizona Solar Center : www.azsolarcenter.com
• Arizona Solar Energy Industries Association: www.arizonasolarindustry.org
• Arizona Solar Electric Roadmap Study:
• City of Tucson Energy Office, Solar America City : www.tucsonaz.gov/energy/sac.html
• S. AZ Solar Partnership:
• Solar Institute: www.solarinstitute.org

Local Utilities
• Tucson Electric Power : www.tep.com
• Arizona Public Service: www.aps.com
• Trico Electric Cooperative: www.trico.coop
• Sulphur Springs Valley Electric Cooperative: www.ssvec.org
• Salt River Project: www.srpnet.com

Recycling
• Tucson Clean and Beautiful: www.tucsonaz.gov/tcb
• Pima County Household Hazardous Waste (including compact fluorescent light bulbs): www.deq.pima.gov/waste/householdhaz.html