Kankakee Community College

ELTR 1223
Survey of Renewable Energy Technology

Unit 6 Intro to Solar-PV

HEARTLAND COMMUNITY COLLEGE

REEC 120 Sustainability and Renewable Energy

Source:

Use Policy

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- Editors/Modifier: Chris Miller Heartland Community College

Source:

Objectives

- Students will be able to describe, in very simple terms, the meaning of the "photovoltaic effect."
- Students will be able to list, and briefly describe (in very simple terms), at least three different application modes for solar-PV technology.
- Students will be able to describe, in very simple terms, three different kinds of solar-PV cell technology.

Objectives

- Students will be able to describe, in very simple terms, the general construction of a solar-photovoltaic module, and how its series-string construction impacts the requirements for properly positioning/locating/mounting the module.
- Students will be able to discuss and describe, in very simple terms, how a solar-photovoltaic module reacts to temperature extremes – how extreme heat and cold affect its output.

Source:

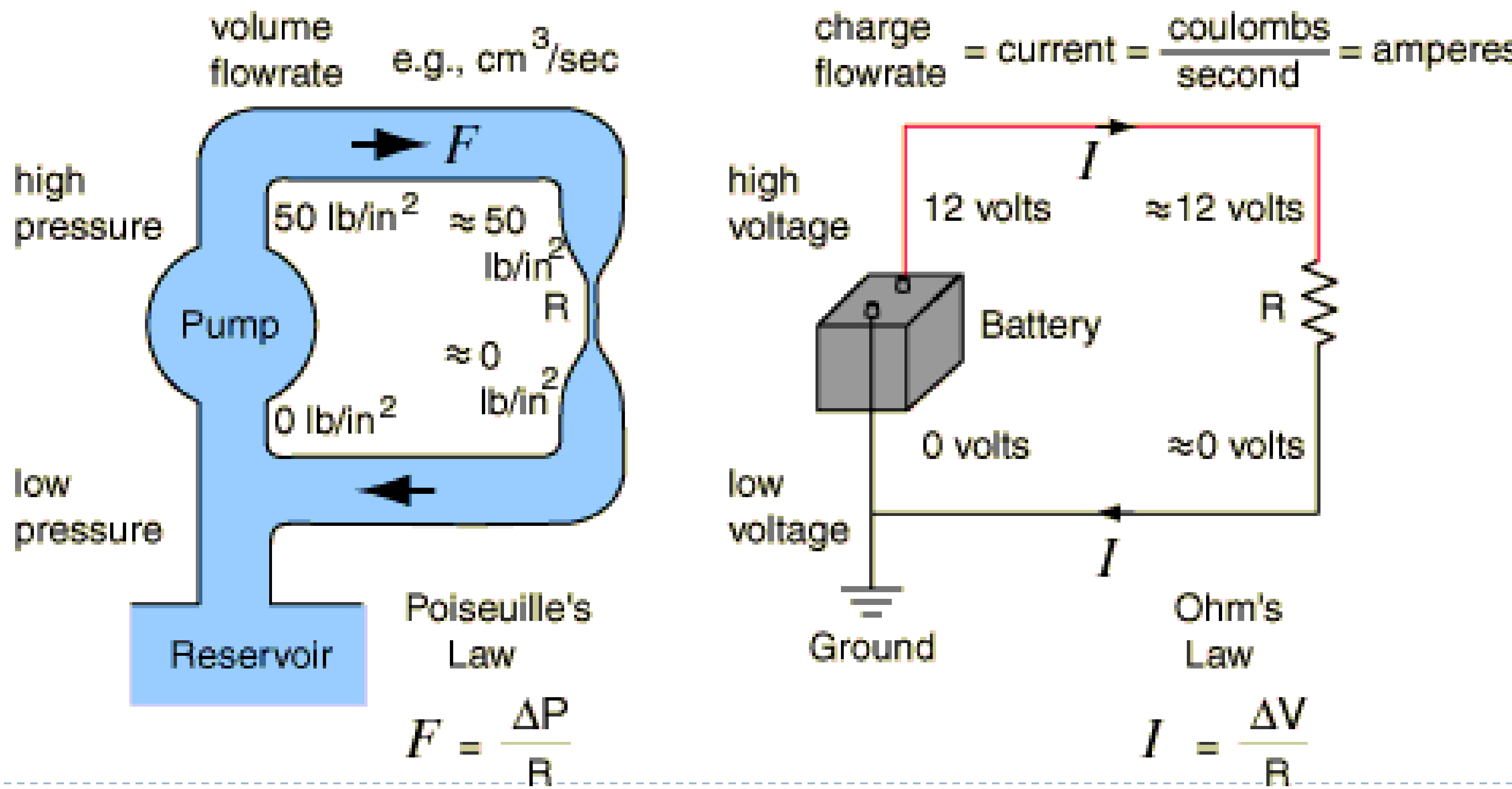
A Brief Introduction to Electricity

Solar-PV is an Electrical Technology

Electricity flows thru wires just like water flows thru pipes…

Water in a Hose	DC in a Wire	Electrical Units
pressure	potential (V)	Volts
volume	current (I)	Amps
friction	resistance (R)	Ohms

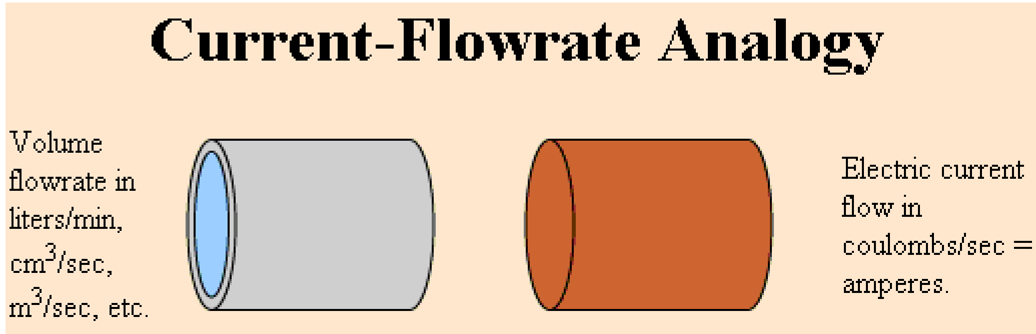
Analogy between a Hose and Electricity in a Wire



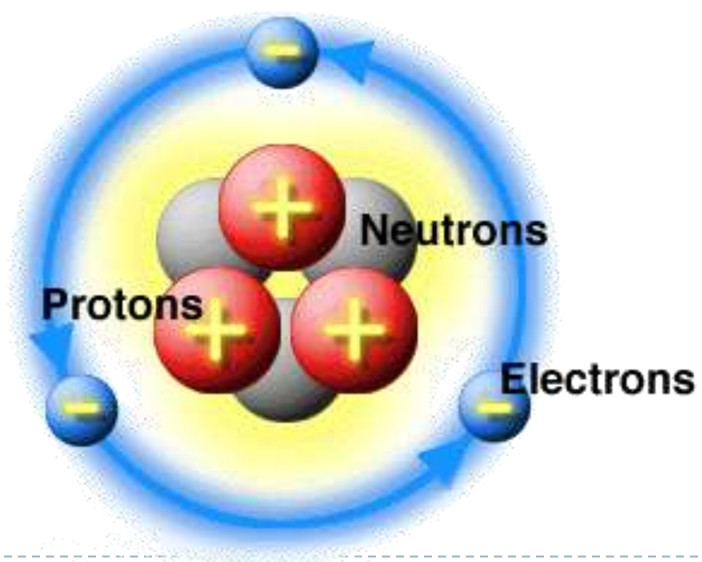
Basic Electrical Definitions

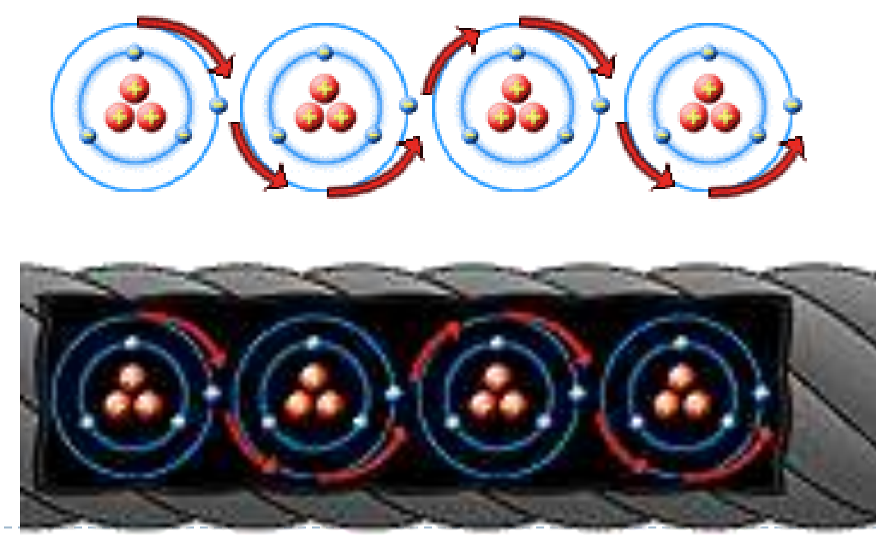
- Voltage (E)
  - Electrical pressure measured in *volts* (V)
  - Pressure required to push one ampere of current through one ohm of resistance ($E = I \times R$)
- Current (I)
  - Electrical flow rate measured in *amperes* or *amps* (A)
  - Flow rate, one amp $\approx 6\times10^{18}$ electrons per second ($I = E / R$)
- Resistance (R)
  - Resists the flow of current, measured in *ohms* (Ω)
  - Resistance necessary to produce one volt of voltage drop with one amp of current flowing ($R = E / I$)
- Power (P)
  - Delivers energy and does work, measured in *watts* (W)
  - 1W of power is consumed by one volt of drop and one amp of current ($P = E \times I$)

Voltage is the pressure that pushes electric current thru a wire, just as hydraulic pressure forces water to flow thru a pipe.



Just like water thru a pipe, electric current flows thru wire…





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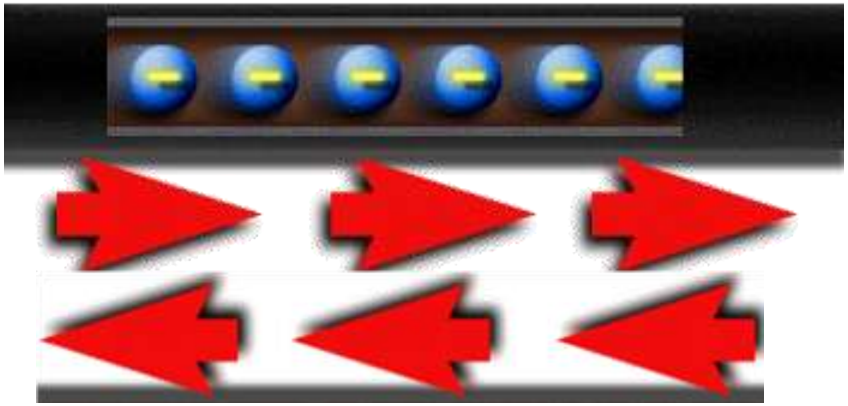
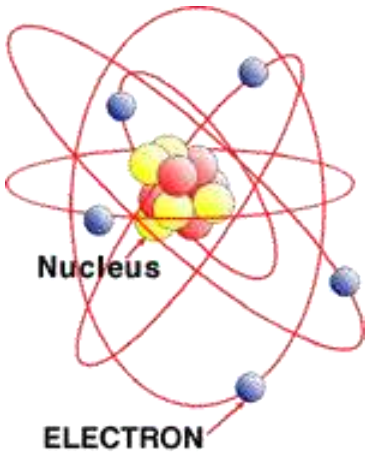
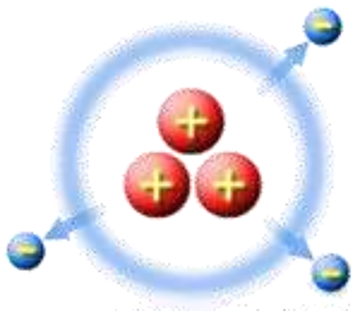
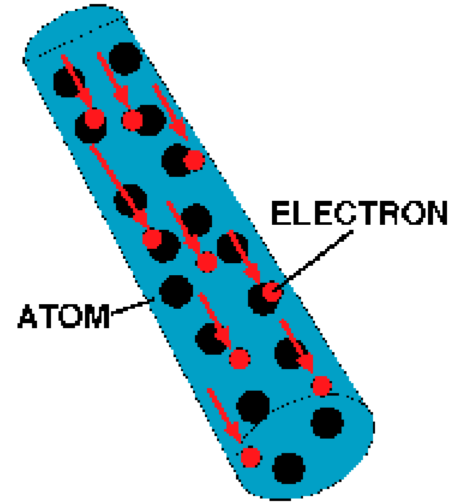






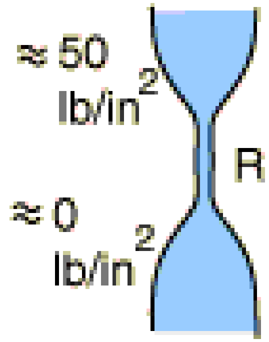


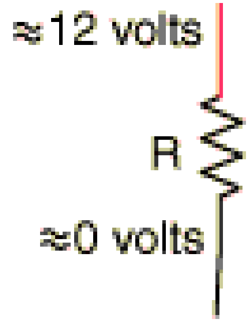
Conductors have loosely held, or free electrons…

Insulators have tightly held electrons…

Source: http://www.energyquest.ca.gov/story/images/chap02_wire_2007.gif

The resistance of a constriction in a large pipe is so great that essentially all the pressure drop will appear across the resistance.

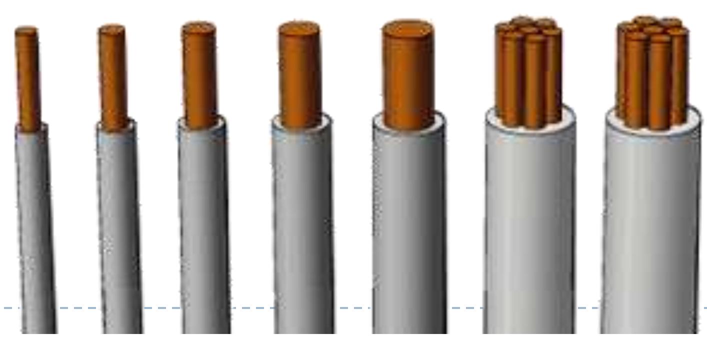


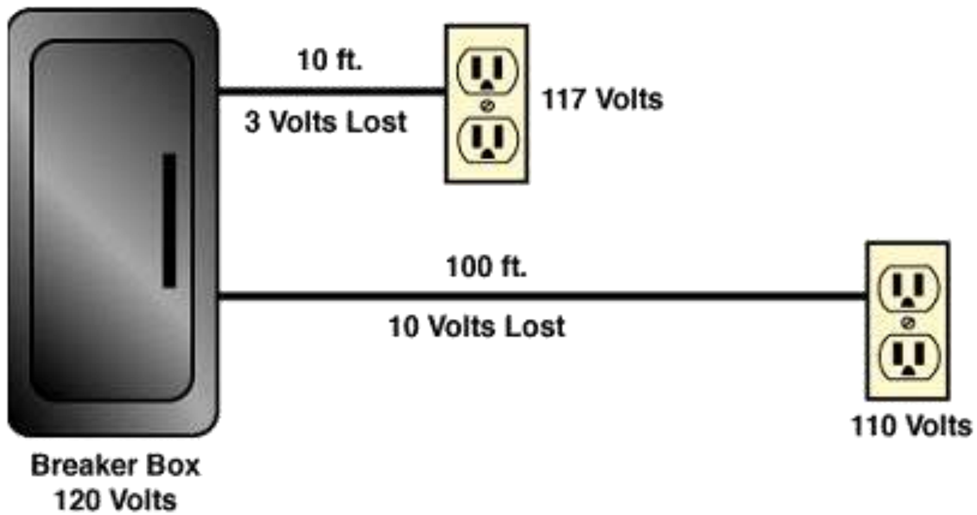


The resistance of a copper wire is so small that essentially all the voltage drop will appear across the resistor (or an appliance).

The thinner the pipe the greater the resistance and the less the water flow…and vice versa

The thinner the wire the greater the resistance and the less the current…and vice versa




10 ft.
3 Volts Lost
117 Volts
100 ft.
10 Volts Lost
110 Volts
Breaker Box
120 Volts

It’s important to know the difference between electric *power* and electrical *energy*!

PV

The Photovoltaic Effect

The Photovoltaic Effect

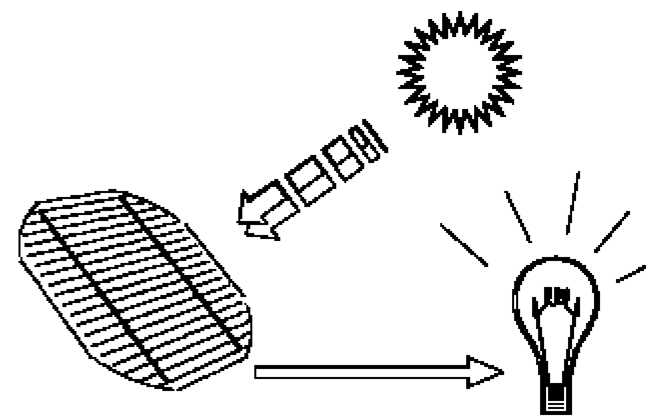
- What is it?
  - The direct conversion of sunlight into electricity.
- When was it discovered?
  - When Abraham Lincoln was President of the U.S.A.!
  - 1839, by Edmond Becquerel

History

- 1839 – Edmond Becquerel, 19 year-old discovered the photovoltaic effect
- 1873 – Willoughby Smith discovered the photoconductive effect (selenium)
- 1883 – Charles Fritz made first "solid-state" solar cell (transparent gold layer over selenium)
- 1954 – Bell labs develop first "practical" solar cell
- 1963 – Wilhelm spent all his paper route savings on a small, single Bell Labs solar cell for his Jr. High science fair!

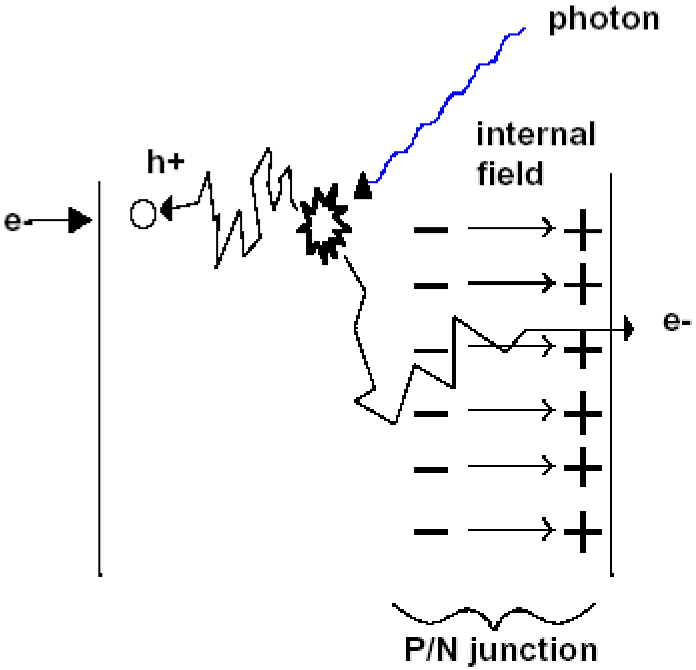
What Are Solar Cells?

- Thin wafers of silicon
  - Similar to computer chips
  - But much bigger and much cheaper!
- Silicon is abundant (sand)
  - Non-toxic, safe
- Light carries energy <u>into</u> cell
- Cells <u>convert</u> sunlight energy into electric current- they do not store energy
- Sunlight is the “fuel”

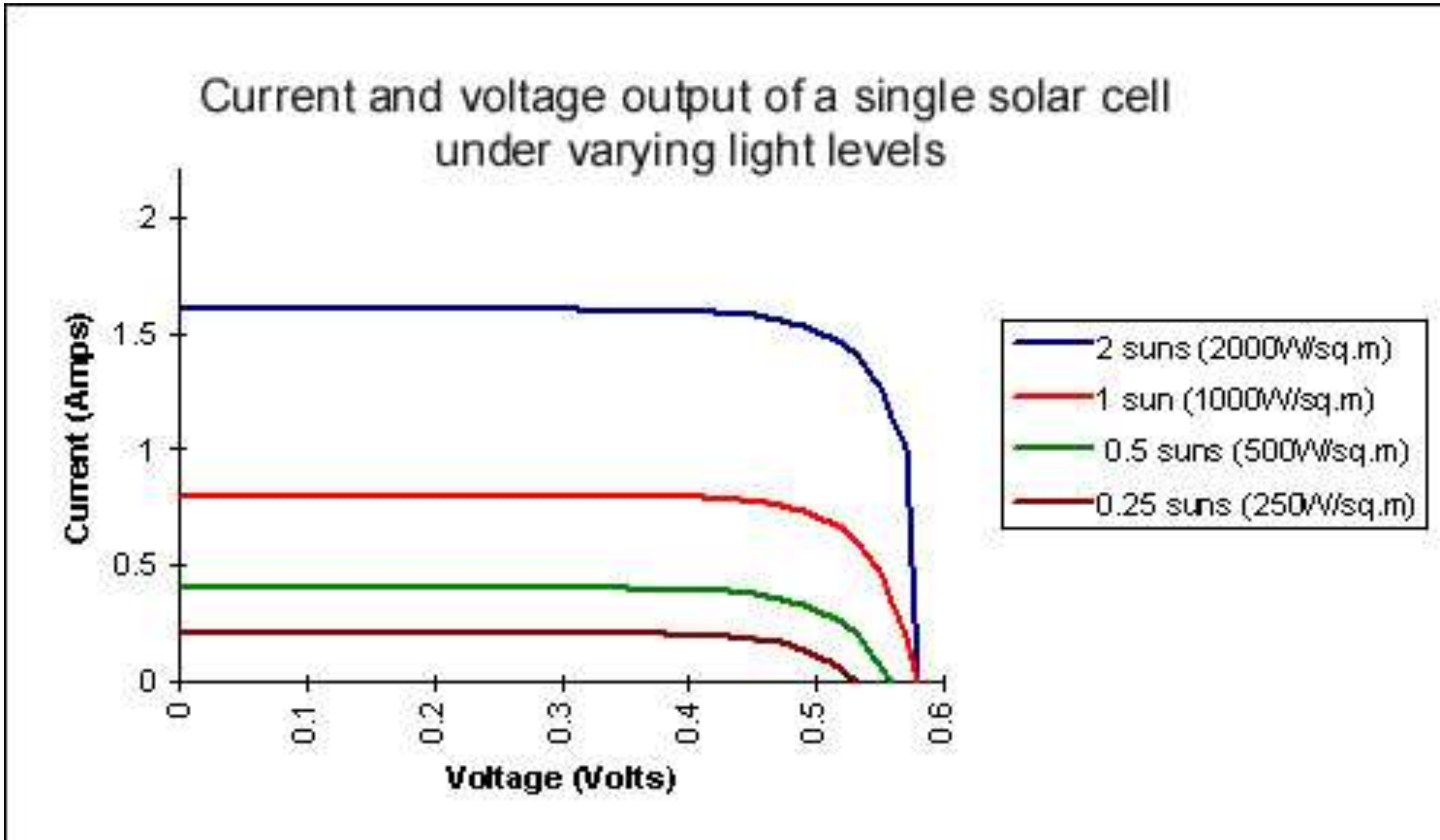


How Solar Cells Change Sunlight Into Electricity

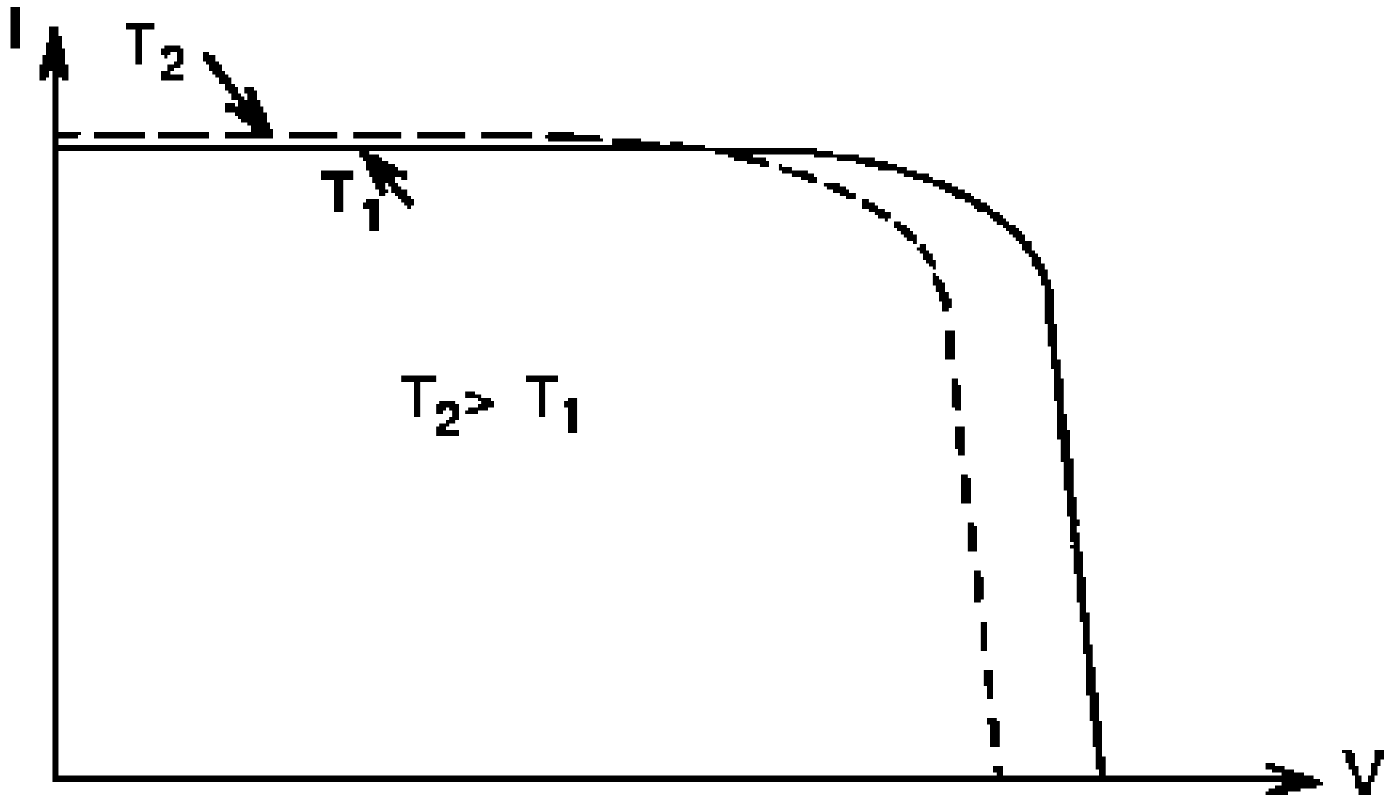
- Light knocks loose electrons from silicon atoms
- Freed electrons have extra energy, or “voltage”
- Internal electric field pushes electrons to front of cell
- Electric current flows on to other cells or to the load
- Cells never “run out” of electrons



Current Changes with Irradiation



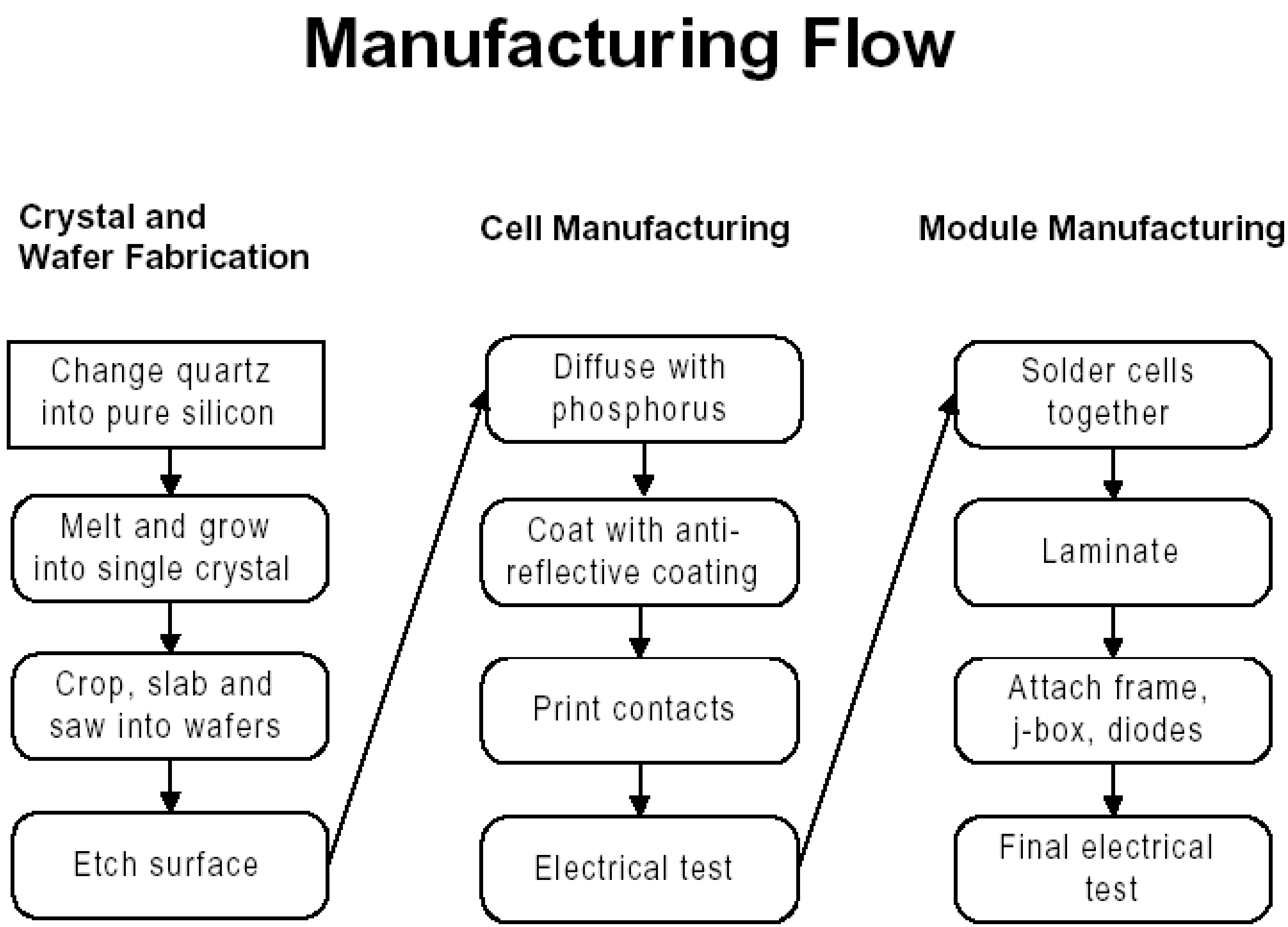
Voltage Changes with Temperature

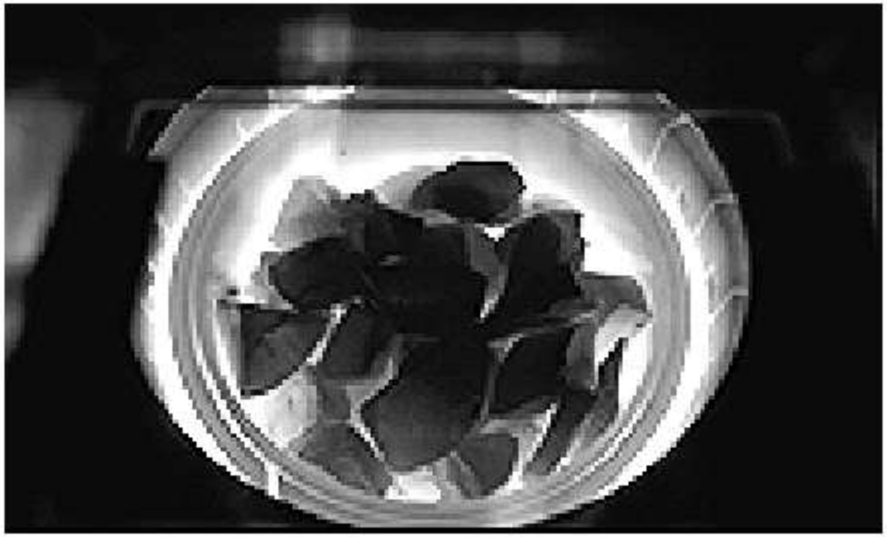


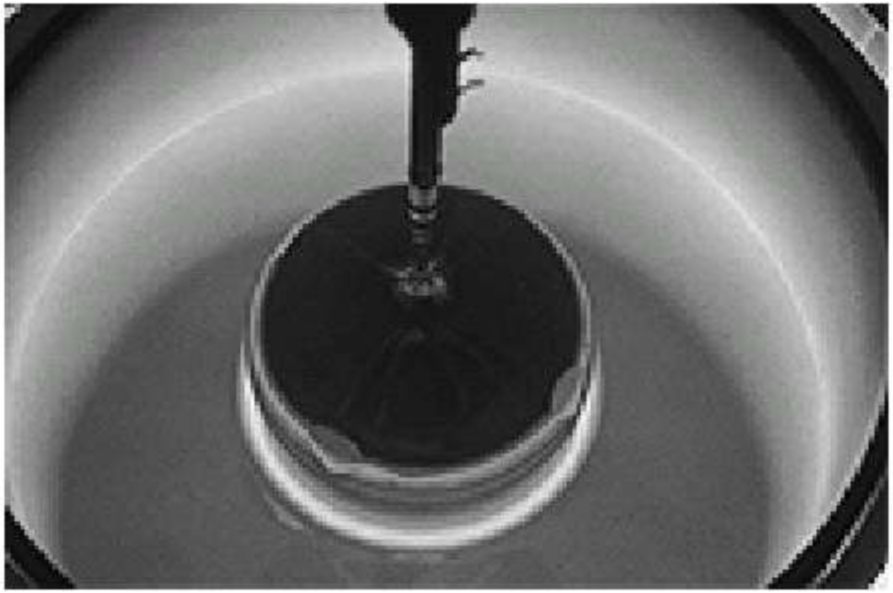
PV

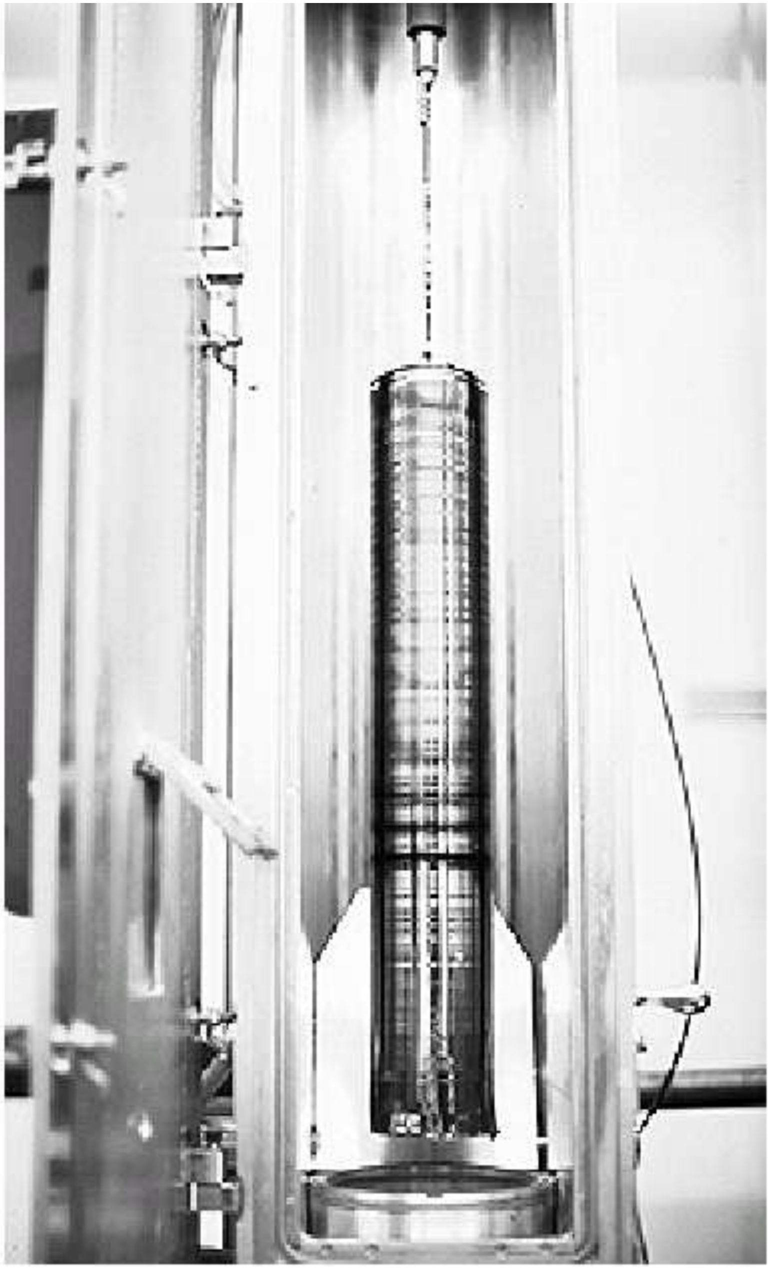
How are Solar Cells Made?

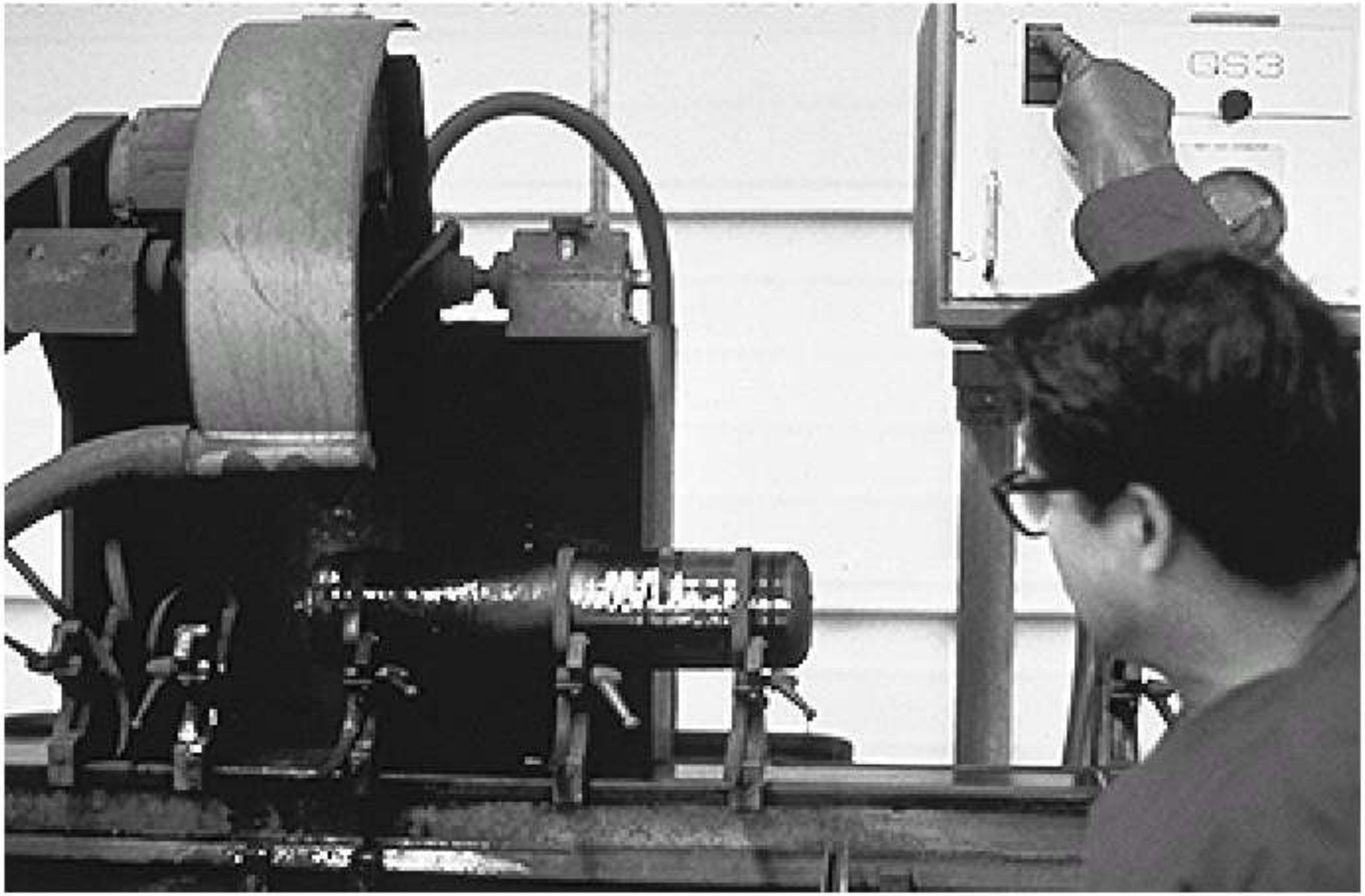
How are Solar Cells Made?







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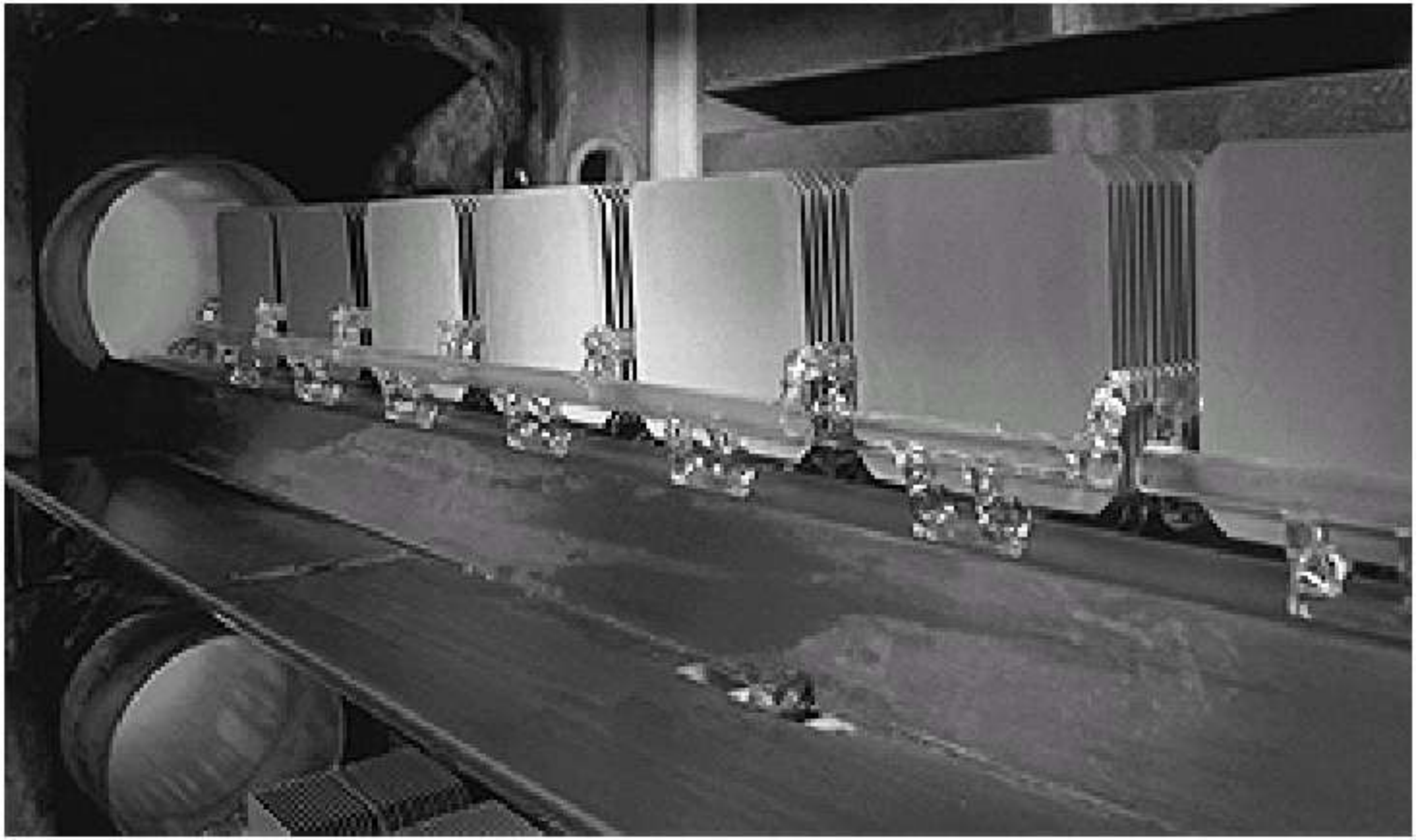
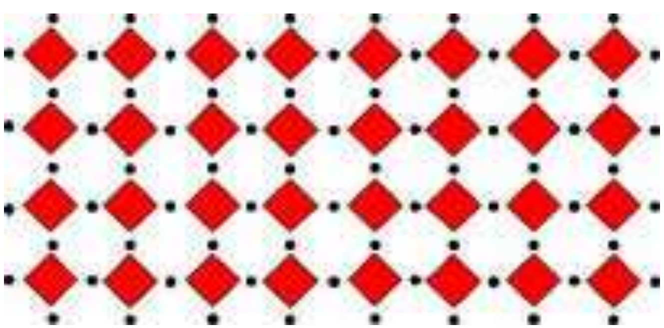


The Doping Process

- Adding an impurity to silicon in order to change its internal properties. Because the production of energy depends on the separation of positive and negative charges, silicon must be modified.
- The charge carrying behavior of the crystal silicon is changed.

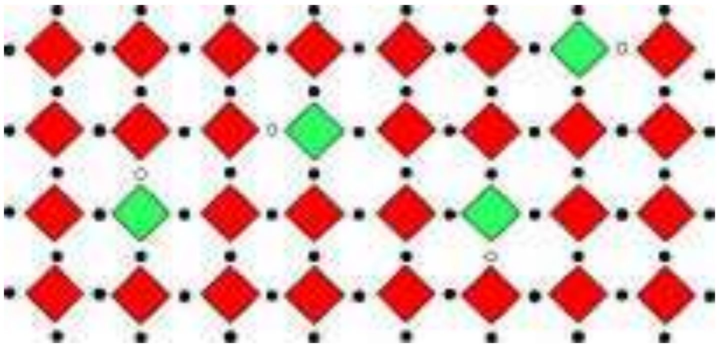


Silicon is very stable in pure crystal form.

Silicon has 4 valence electrons (electrons on the outer shell). To create an impurity between the silicon bonds, boron and phosphorus are added through a heating/vapor process.

Boron's Job (Bottom of Cell)

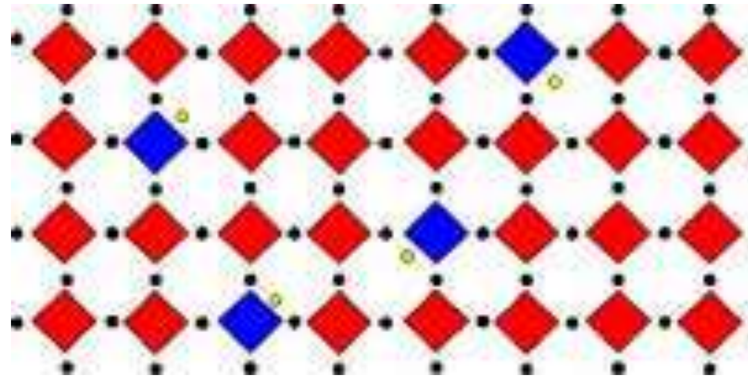
- Boron has 3 valence electrons.
- When boron is introduced a hole or electron vacancy is present.
- The hole is like a positive charge because it attracts electrons.

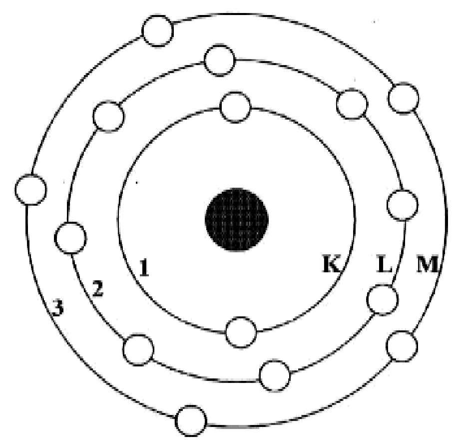


This type of silicon is called P-type due to its positive charge. Acceptor dopant.

Phosphorus' Job (top of Cell)

- Phosphorus has 5 valence electrons.
- Phosphorus adds an extra electron.
- The extra electron causes a negative charge.
- This type of silicon is called N-type due to its negative charge. Donor dopant.

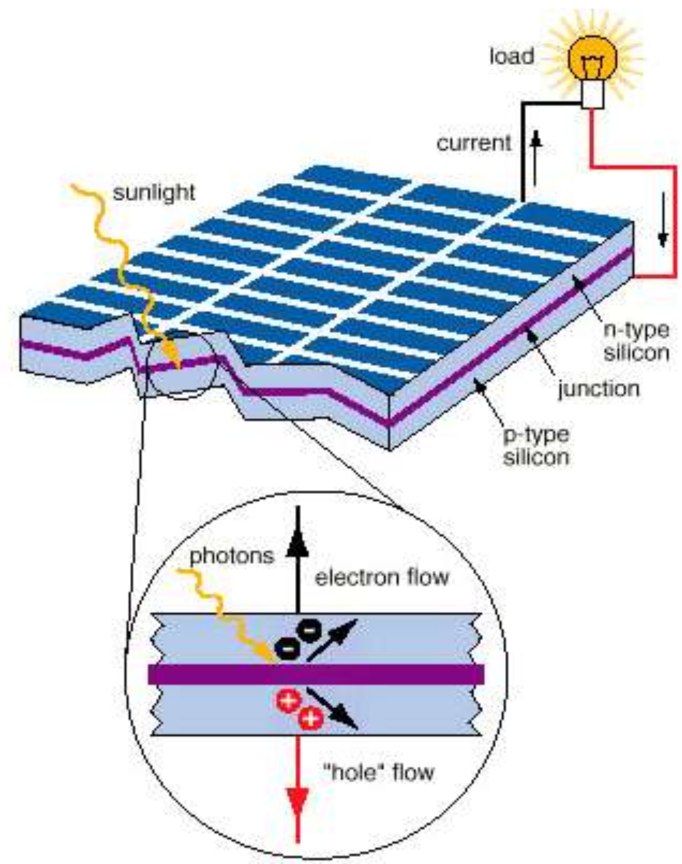




5 valence electrons

How are Solar Cells Made?

- Here is a model of the typical solar cell.
- Notice the split between the two types of silicon.

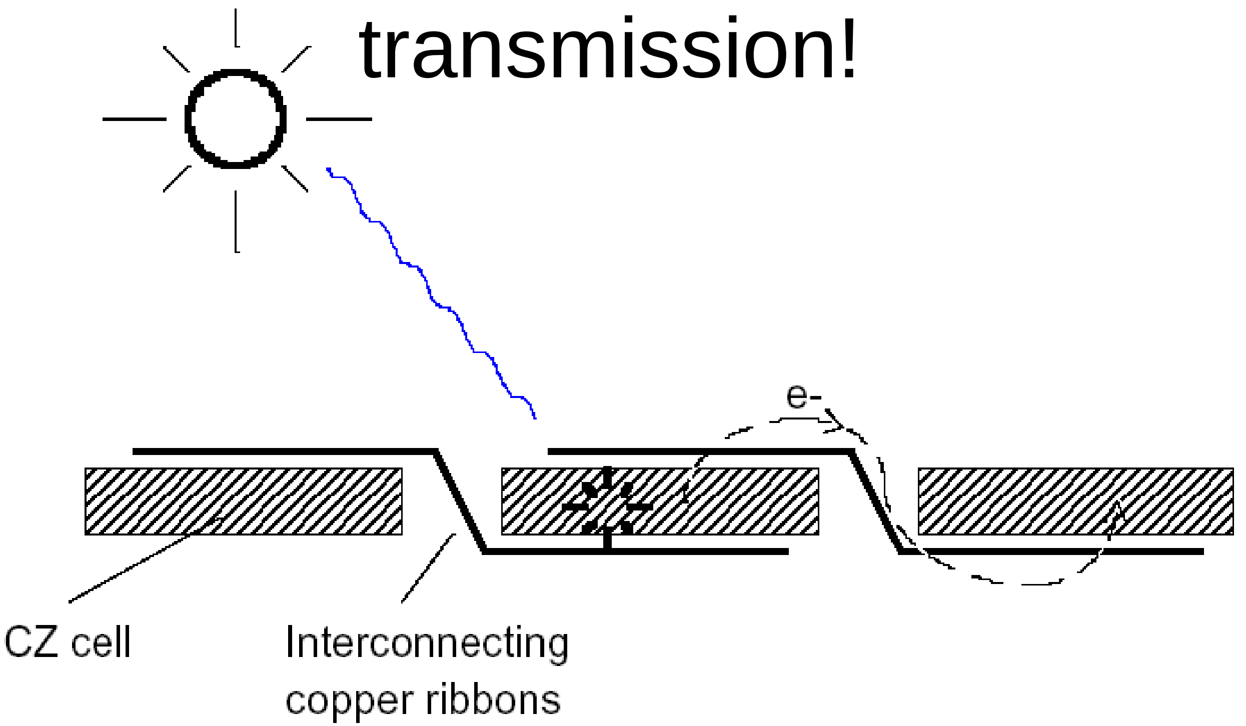


- Source: http://static.squidoo.com/resize/squidoo_images/250/draft_lens9199701module81408401photo_1264529133photo_cells.png

PV

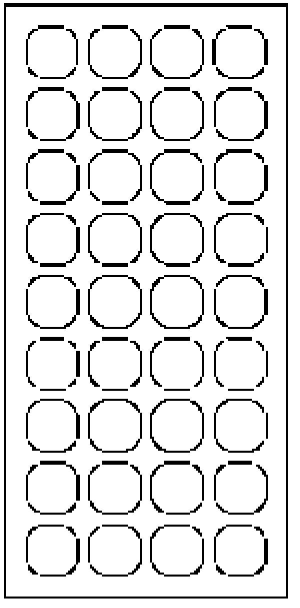
What can you do with only 0.5V?!?!

Solar Cells can be connected in series strings to increase circuit voltage. Cell bottoms can be solid/opaque. Cell tops have to balance connectivity and light transmission!

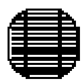


Connect Cells To Make Modules

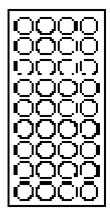
- One silicon solar cell produces .5 volt
- 36 cells connected together have enough voltage to charge 12 volt batteries and run pumps and motors
- Module is the basic building block of systems
- Can connect modules together to get even more power



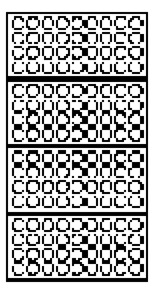
Terms Used



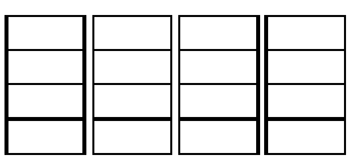
CELL -- basic building block in factory



MODULE -- smallest unit that can do real-world work; building block in the field



PANEL -- physically connected modules on a structure



ARRAY -- all solar generators in one installation

Definitions: PV Module

- **Module:** A group of PV *cells* connected in series and/or parallel and *encapsulated* in an environmentally protective *laminate*.

Solarex MSX60
60 watt polycrystalline

Siemens SP75
75 watt single crystal

Definitions: PV Panel

- **Panel:** A group of *modules* that is the basic building block of a PV *array*.

Definitions: PV Array

- **Array:** A group of *panels* that comprises the complete PV generating unit.

Types of Solar Cells
(silicon based)

- Solar cells are made as:
  - single crystal wafers,
  - poly-crystalline wafers, or
  - thin-film technology.

Source: http://www.rise.org.au/info/Tech/pv/image001.jpg

- Single Wafer: sliced to the millimeter from a large single crystal ingot. Very expensive, but the silicon is much purer and therefore more efficient.

Solar Cell Types Cont'd

- Polycrystalline Wafers: made by a casting process in which molten silicon is poured into a mould. It is allowed to set, and then cut into wafers. Not as energy efficient. About half the silicon is lost to dust in the cutting process.

- Thin-Film Technology: (amorphous silicon) made by depositing silicon onto substrate from a reactive gas. Substrates are normally glass or plastic. Thin film has ease of deposition, low cost, is mass producible, and suitable for large applications.

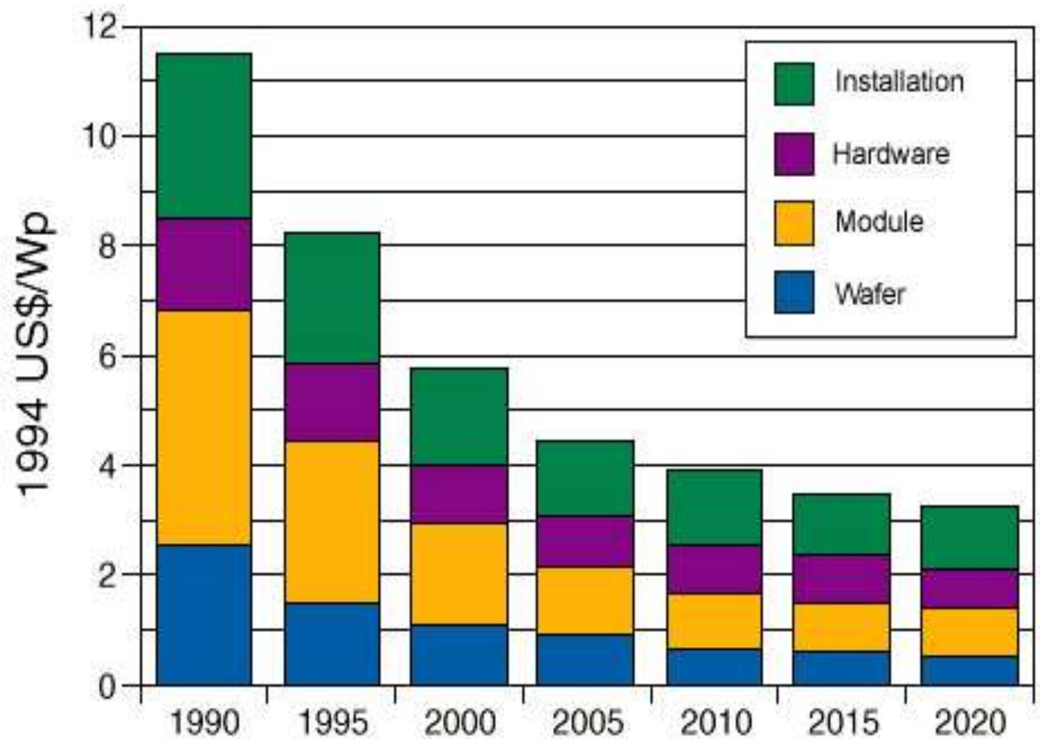
Cell Technology Comparison Chart

Cell Type	Best Cell Efficiency	Module Area Efficiency	Advantages	Weaknesses
Silicon	22.7 %	12-15 %	Well understood; Receiving renewed attention	Indirect band gap limits efficiency; How thin?
CdTe/CdS	15.8 %	6-8 %	Low cost; High deposition rates possible	Cd liability; Needs more development
Amorphous Silicon	13.2 %	4-9 %	Low cost	Looses power over time; Low efficiency
CuInSe2	16.9 %	10%	23% potential; Low cost	Manufacturing yields are low; Needs more development
Single Junction Concentrator	28.7 %	NA	Hybrid PV / thermal; central power generation	Lacks production economy of scale; Complex BOS
Multijunction Concentrator	35 %	NA	Hybrid PV/thermal Space	Lacks production economy of scale; Complex BOS

Reliability of Solar Cells

- Most solar-PV modules carry a manufacturer's warranty of 20 years, or more.
- Solar cells are very durable.

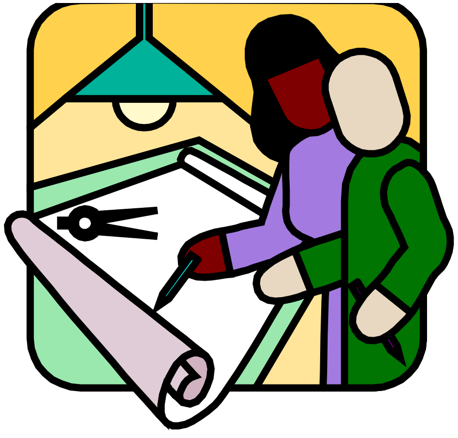
Right: shows the decreasing cost of solar revolution.



http://www.acre.murdoch.edu.au/refiles/pv/text.html

Future Prospects

- Solar cell manufacturing has become a growing industry.
- Demand for cells is increasing.
- Much Japanese/Australian/Chinese/Indian development.



PV

Solar-PV Applications

PV Applications

- Corrosion Protection
- Electric Fences
- Remote Lighting
- Telecommunications
- Solar powered water pumping.
- Water treatment.

Source: http://www.mercadolibre.com.ve/jm/img?s=MLV&f=6934475_8041.jpg&v=P

Different PV applications have different circumstances and different requirements…

- Near Utility Power, or Remote?
- Daytime Only, or Anytime?
- Photovoltaic Only, or Hybrid Generation?
- Centralized or Decentralized?
- Batteries/Stand-Alone, or Utility-Tied/No Batteries?

Roadside Flashers

Bus Shelters

Garden Lights

Portable Lanterns

Microwave, TV or Radio Repeaters

Telemetry Stations

Radio and Telephones

Railroad Signals

Buoys

Airport Approach Systems

Offshore Oil Platforms

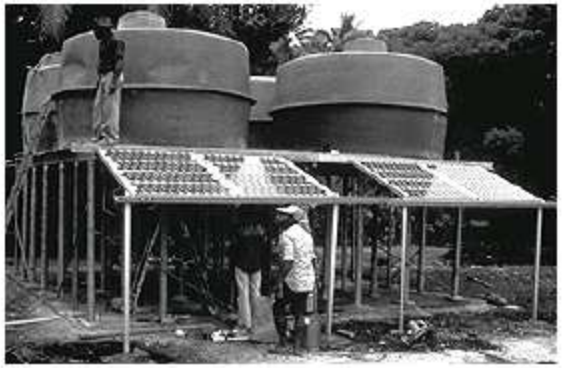
Well Heads

Oil and Gas Pipelines

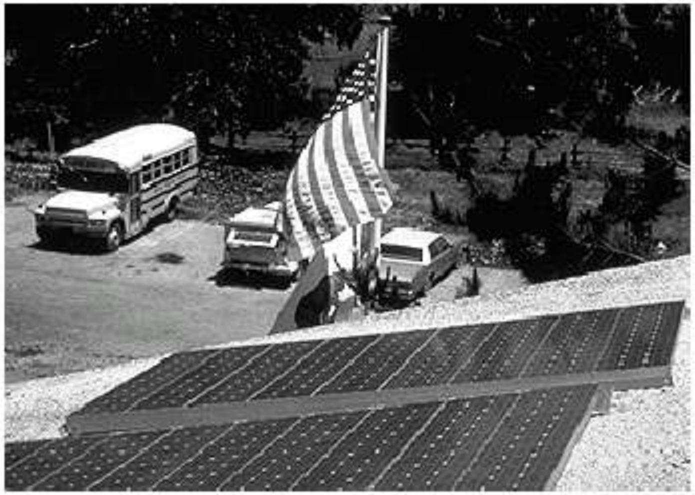
Livestock Watering

Irrigation

Village Drinking Supply



Schools



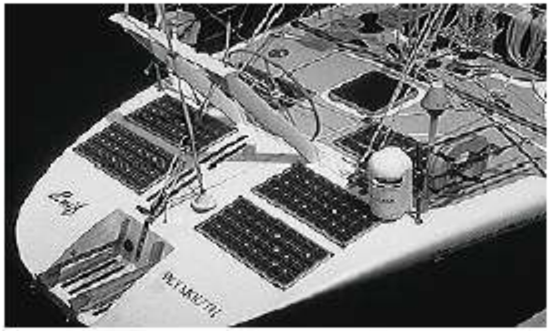
Rural Home Lighting System

Hospitals and Clinics

Electric Vehicle Charging Station

Recreational

Boats / Vehicles



Commercial Farm DSM Facility System

Individual Home Rooftop

Simple PV Power System Overview

Considerations and Examples

System Design Involves Tradeoffs

- Choices based on budget, remoteness, how critical is load

Efficiency	⟷	Simplicity and Reliability
Initial Cost	⟷	Lifetime Cost
Centralized Generation	⟷	Distributed Generation

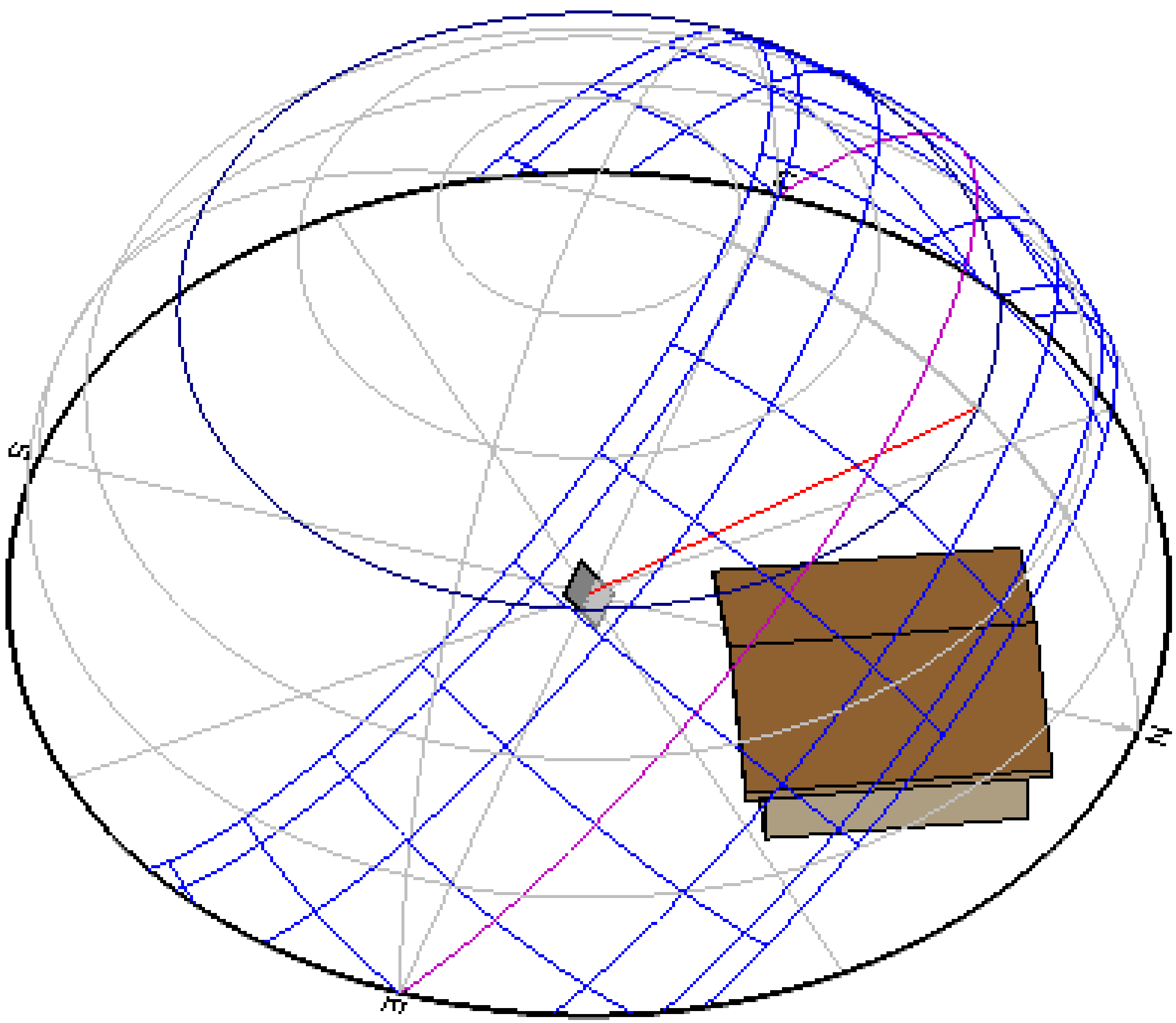
Gather Information About the Application

- Load requirements
- Load profile
- Surges
- Power quality
- DC or AC
- Critical loads
- Ease of access to site

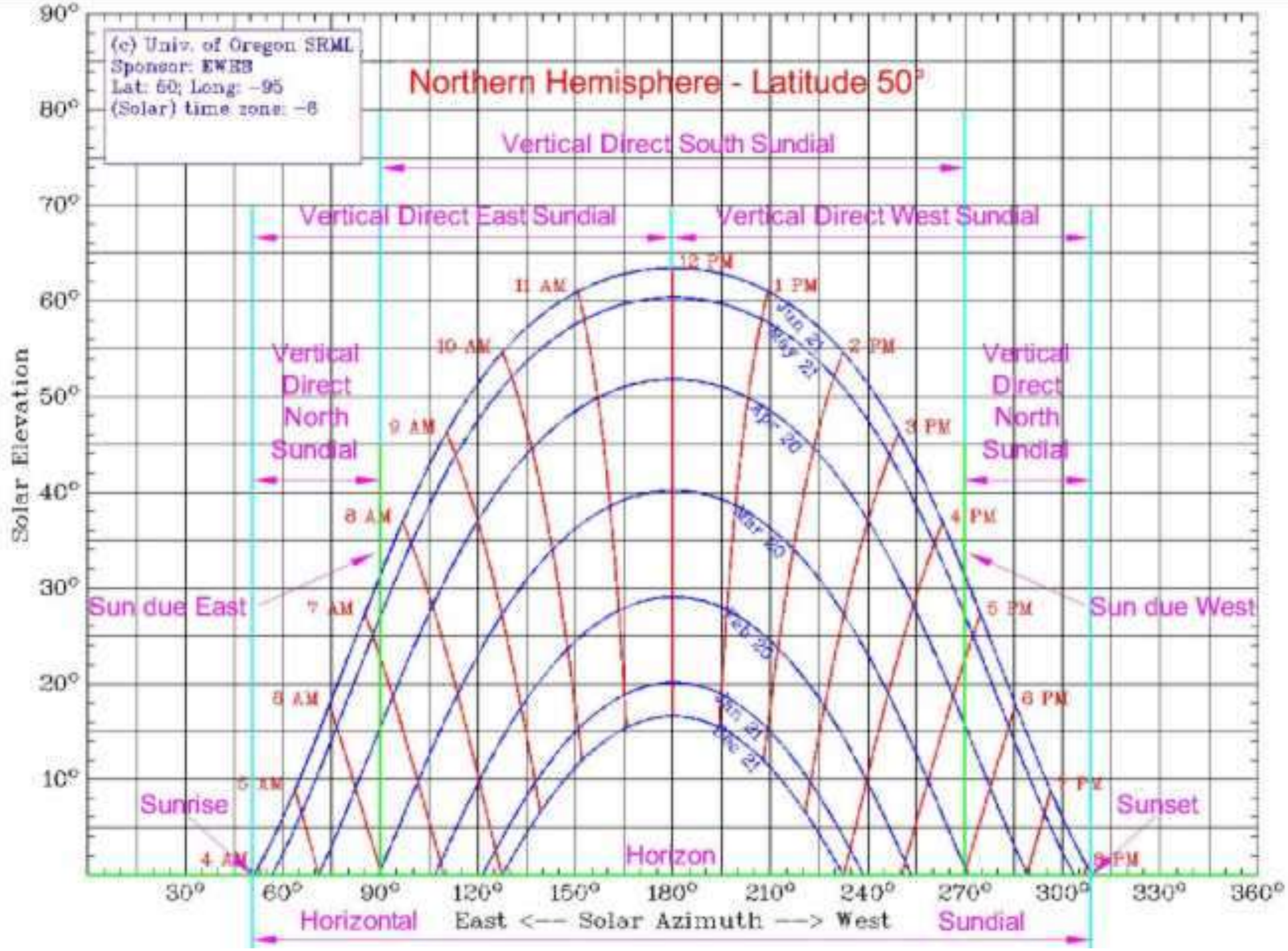
Gather Information About the Climate

- Latitude, longitude
- Insolation
- Temperature
- Variability of weather
- Harshness

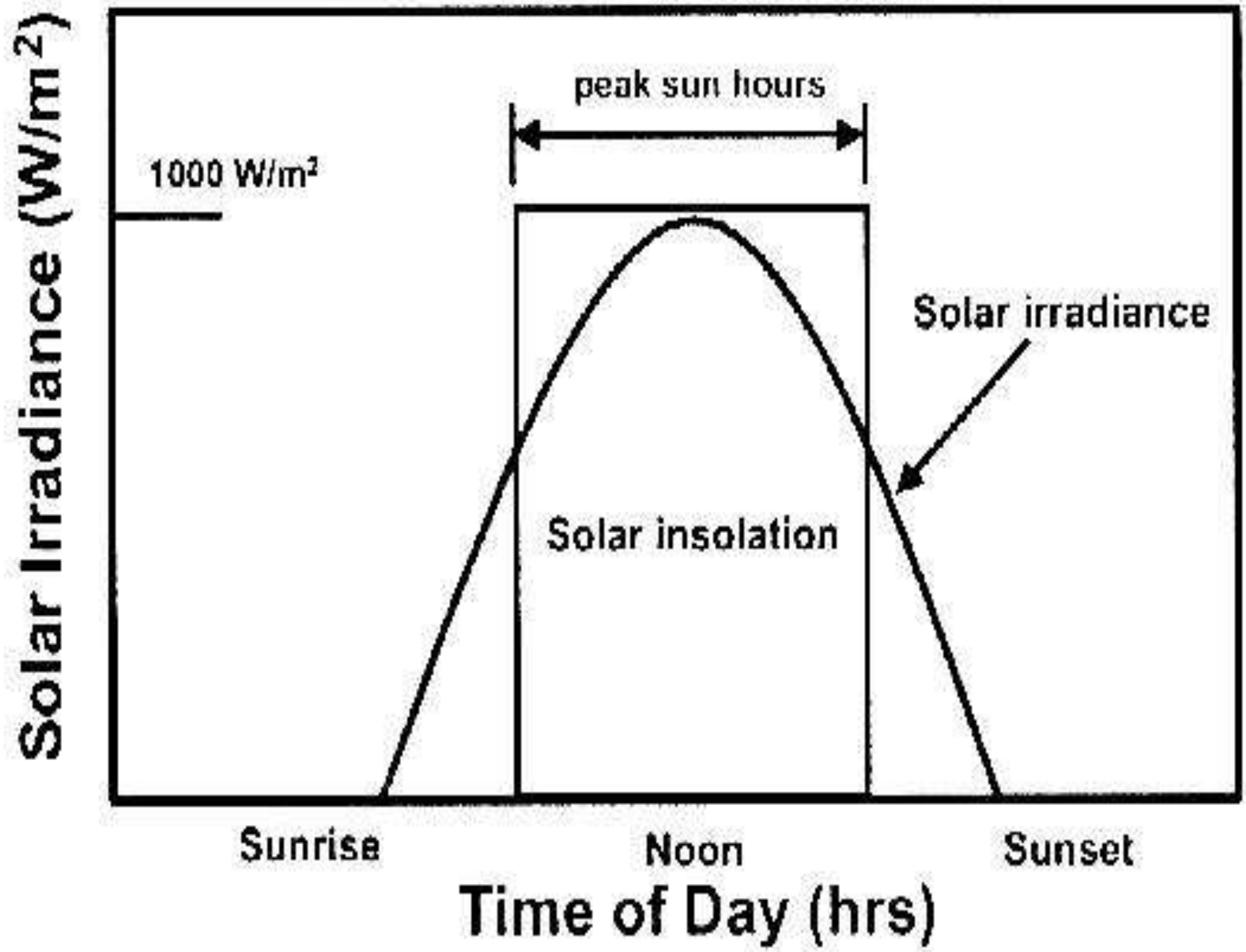
The Sun's Wandering Path



Cartesian Coordinate Sun Map

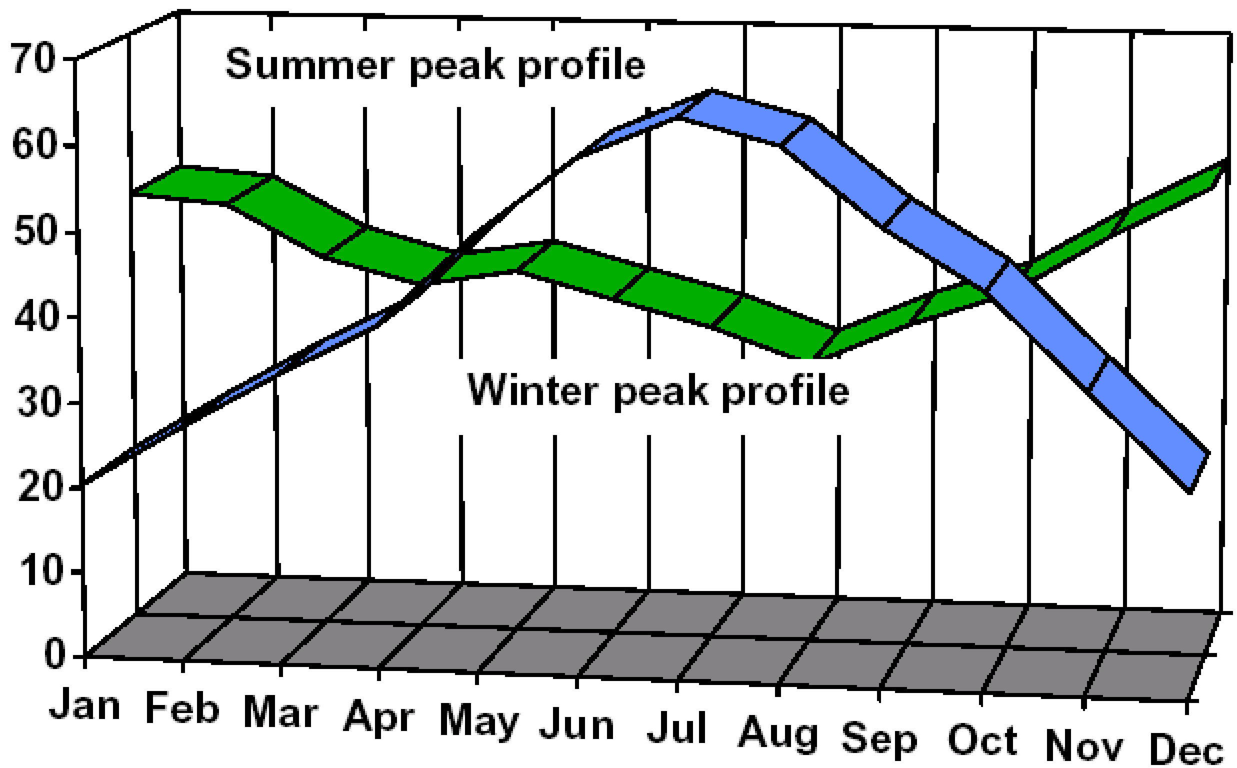


Source: http://www.mysundial.ca/tsp/images/sun_chart_sundials.jpg



Solar Irradiance (W/m²)
1000 W/m²
peak sun hours
Solar irradiance
Solar insolation
Sunrise
Noon
Sunset
Time of Day (hrs)

Seasonal Load Profiles



Design the System

- Array sizing
- Battery bank sizing
- Wiring
- Safety components
- User feedback
- DC or AC or Hybrid
- Mounting
- Accomodate future growth

PV

Types of Solar-PV Systems

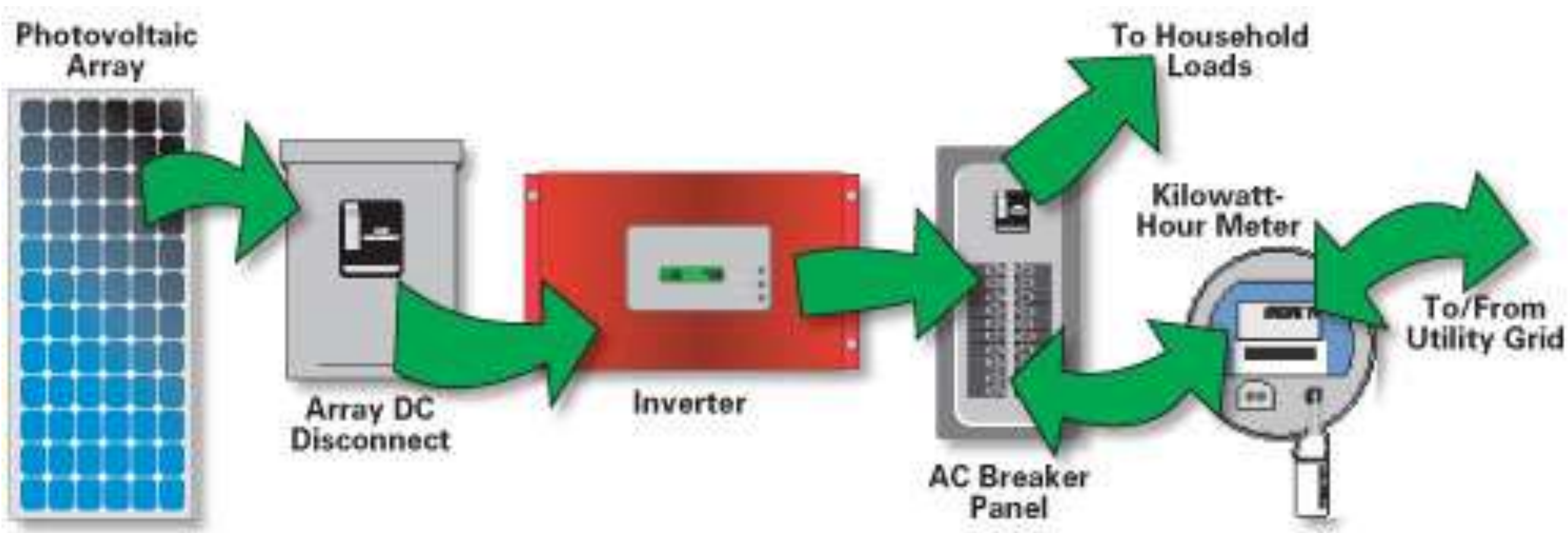
PV System Modes

- Direct-Power of DC Loads
- Simple Utility-tied
- Simple, battery-based, Stand-Alone
- Stand-Alone / Utility-Tied Hybrid
- Hybrid System Inputs…
  - PV with Wind
  - PV with GenSet

Direct PV-Powered Loads

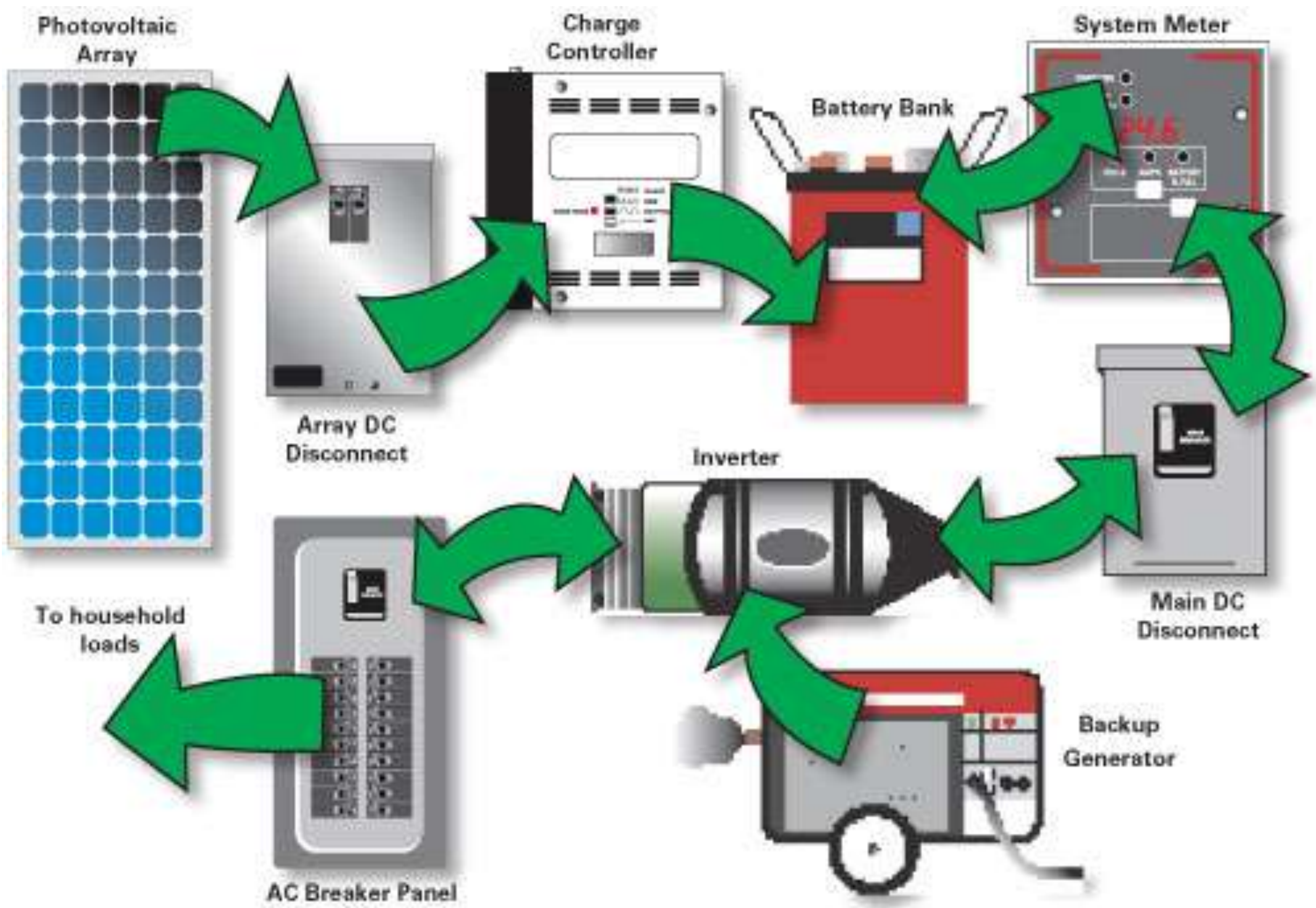
Source: http://www.rise.org.au/info/Applic/Solarpump/image002.jpg

Simple Utility-Tied System



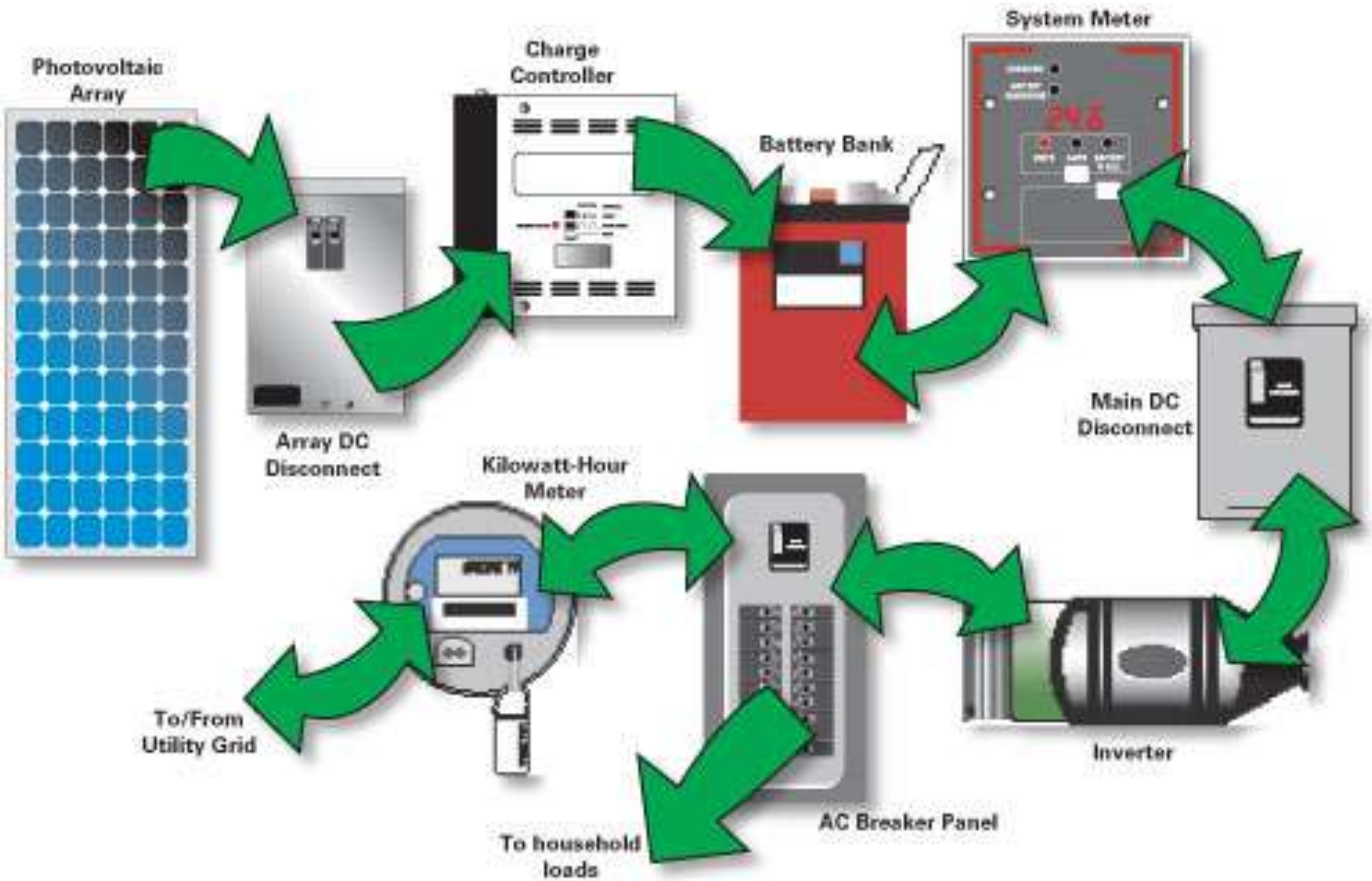
Source: http://www.rhoduselectric.com/images/10-14-08/Solar_Electric_Systems.jpg

Simple Stand-Alone System



Source: http://homepower.com/images/basics/Basics_SolarElect_OffGridFlow.jpg

Grid-Tied with Batteries



Source: http://homepower.com/images/basics/Basics_SolarElect_GridBBFlow.jpg

PV System Electrical Design: Common Problem Areas

- *Insufficient* conductor ampacity and insulation
- Excessive *voltage drop*
- *Unsafe* wiring methods
- *Lack of or improper* placement of overcurrent protection and disconnect devices
- *Use of unlisted*, or improper application of listed equipment (e.g. ac in dc use)
- *Lack of or improper* equipment or system grounding
- *Unsafe* installation and use of batteries

PV

An Example Solar-PV System – Report to Client

Final Project Report

To: Alan and Susan *Xxxxx*

Your 5KW Solar-Photovoltaic

Power System

Wilhelm Engineering
June, 2003

General System Description

- PV array consists of 48, *ShellSolar* **SM-110**, 110 watt photovoltaic modules.
- PV array roof-mounting rack is the *UniRack* **SolarMount** system.
- The PV series-string combiner is from *OutbackPower*. The string combiner is located in the attic, above the garage.
- The entire PV array is divided into two sub-arrays. Each sub-array is controlled by an *OutbackPower* **MX60** charge controller.
- The battery bank consists of eight *Concorde* **PVX-258**, sealed, AGM batteries. The batteries are housed in a cabinet made by *OutbackPower*.
- The system inverter is a *Xantrex* **SW5548**.
- The inverter, the charge controllers, the PV ground-fault protection, the main DC disconnect and OCP, the AC bypass switch, and other necessary disconnects and metering are all mounted and assembled on an *OutbackPower* power panel.
- 240 VAC is provided for the well pump via a *Xantrex* **T240** autotransformer.

System Photos
PV mounting rack

All rails are carefully spaced and aligned to allow proper mounting of the PV modules.

All mounting feet are lag-screwed into roof trusses and are thoroughly sealed with polyurethane roof sealant.

System Photos
PV Array

System Photos
PV array details

PV series strings penetrate into the attic through flashed and sealed, outdoor-rated boxes.

All PV-module frames are bonded together with tinned and braided grounding straps, attached with stainless-steel tek screws. The entire frame and rack system is tied into the house lightning protection system with 4AWG stranded copper ground wire.

System Photos
PV combiner box

The PV series-string combiner is located in the attic, above the garage, and directly below the PV array.

The string combiner includes over-current protection and disconnect means for each of the 12 series strings of PV modules. Six series strings of PV modules are combined into a single sub-array. There are two sub-arrays of 24 modules each.

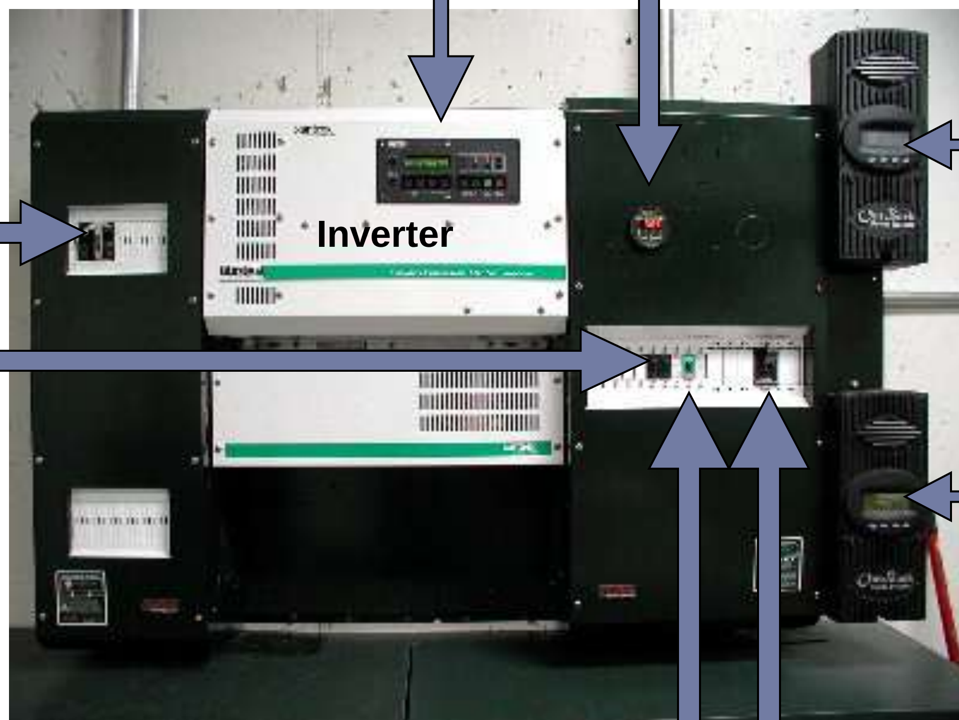
System Photos
Power Control Center

The Power Panel contains the charge controllers, inverter, grid-tie interface, disconnects, etc.

Note the DC lightning-surge arrestors hidden behind the charge controllers.

The sealed batteries are housed in the vented steel cabinet below the Power Panel.

Power Center Details



Power Center Details

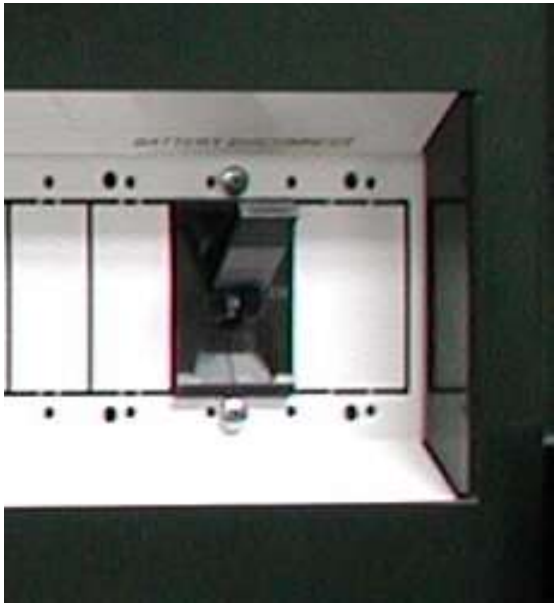
The By-Pass Switch

- This is the "emergency" switch. In its normal position, the loads in the sub-panel are powered by the inverter. If for any reason the inverter shuts down, or malfunctions, flipping the positions of the ganged switch will allow the sub-panel loads to be powered by the main utility panel.

Power Center Details

Main DC Disconnect

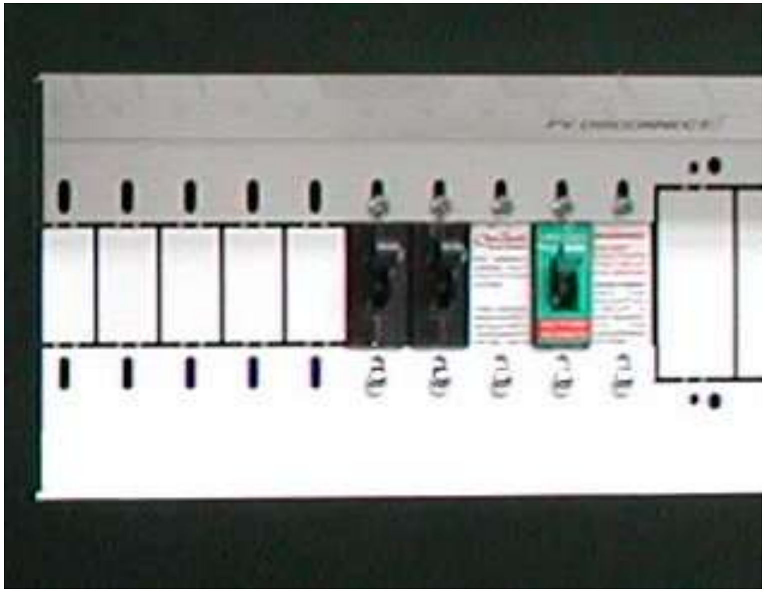
- This switch should not be turned off unless necessary for safety reasons. If this switch is opened, the battery will be disconnected from the inverter, the inverter will completely power down, and all of the inverter's set points will revert to their factory-default values.



Power Center Details

Charge Controller Disconnects

- The switch with the green label (on the right) is positioned between the PV sub-arrays and the charge controllers. It can be used as a manual switch, or it may "trip" open if there is a ground fault in the PV array.
- The two black switches (on the left) are positioned between the charge controllers and the batteries. If these are turned off, the charge controllers may lose their programmed set-points, reverting to factory defaults.



Power Center Details

The Battery E-Meter

- This is the main battery-monitoring meter. It defaults to reading the battery voltage. When full, the batteries will read near 56.5 volts. During a power outage, the batteries will be drained of stored energy, and their voltage will drop. As the voltage drops toward 48 volts, energy conservation will be necessary to extend inverter operating time.

Power Center Details

Charge Controllers

- The function of the charge controllers is to prevent the PV array from over-charging the batteries. It has been programmed to match your specific batteries and system requirements: **Bulk voltage = 56.8V; Float voltage = 53.4V.** If it needs to be re-programmed, you will need to enter the *password* "141." You should read the owners manual carefully before attempting to re-program the charge controller.

Power Center Details

Inverter Controls

- The inverter is actually a microprocessor-controlled inverter/charger. The operating parameters of the inverter are "programmed" via the control pad on the face of the inverter. The inverter has been programmed to match your system requirements. If it looses DC power, and reverts to factory defaults, it will need to be re-programmed with the proper values.

Source:
http://www.magnet4less.com/images/sw_image.jpg

Inverter Control Details

The six black buttons on the control panel are divided into three pairs. The pair of black buttons on the right (next to the green button) are used to move from menu-heading to menu-heading. There are 20 total menus, as shown in the following two pages.

Once a menu heading has been selected, the pair of black buttons on the far left are used to scroll down thru the items contained within that specific menu (see the menu map on the following two pages).

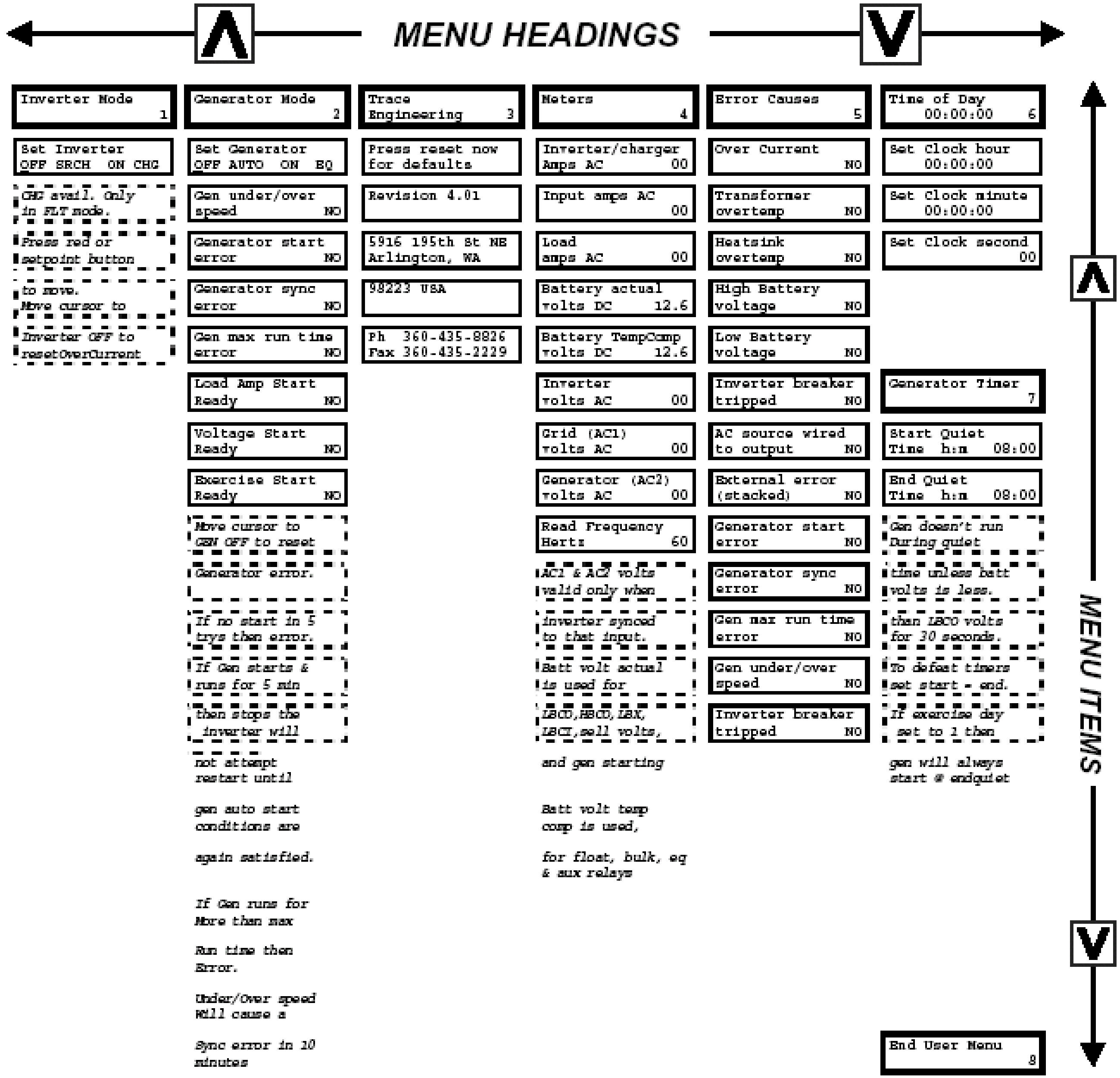
After a menu item has been selected, the center pair of black buttons – labeled “set points” – are used to change the values assigned to that item. These programmable options include such things as Bulk Charge Voltage, Float Voltage, Maximum Charging Current, etc.

Pressing the green button takes you to the generator control menu. In your system, this menu will not be used.

Pressing the red button takes you to the main, on/off menu. Within this menu, the set point buttons will be used to turn the inverter off and on.

Please read the owner’s manual before attempting to program the inverter.

See User Manual, Page 34.



MENU HEADINGS

(Λ ← MENU HEADINGS → V; MENU ITEMS ↑ Λ / V ↓)

Inverter Setup 9
- Set Grid Usage FLT SELL SLT LBX
- Set Low battery cut out VDC 11.0
- Set LBCO delay minutes 10
- Set Low battery cut in VDC 13.0
- Set High battery cut out VDC 16.0
- Set search watts 48
- Set search spacing 59

Battery Charging 10
- Set Bulk volts DC 14.4
- Set Absorption time h:m 02:00
- Set Float volts DC 13.4
- Set Equalize volts DC 14.4
- Set Equalize time h:m 02:00
- Set Max Charge amps AC 20
- Set Temp Comp LeadAcid NiCad

AC Inputs 11
- Set Grid (AC1) amps AC 60
- Set Gen (AC2) amps AC 30
- Set Input lower limit VAC 108
- Set Input upper limit VAC 132

Gen Auto Start setup 12
- Set Load Start amp AC 20
- Set Load Start delay min 5.0
- Set Load Stop delay min 5.0
- Set 24 hr start volts DC 12.3
- Set 2 hr start volts DC 11.8
- Set 15 min start volts DC 11.3
- Read LBCO 30 sec start VDC 11.0
- Set Exercise period days 30
- Set Maximum run time h:m 08:00

Set Max Run time to 0 to defeat.

Set Exercise to 0 to defeat.

See menu 9 to to set LBCO.

Gen starting details 13
- Set RY7 Function GlowStop Run
- Set Gen warmup seconds 60
- Set Pre Crank seconds 10
- Set Max Cranking seconds 10
- Set Post Crank seconds 30

Auxiliary Relays R9 R10 R11 14
- Set Relay 9 volts DC 14.5
- R9 Hysteresis volts DC 01.0
- Set Relay 10 volts DC 14.8
- R10 Hysteresis volts DC 01.0
- Set Relay 11 volts DC 15.0
- R11 Hysteresis volts DC 01.0

Close on batt > setpoint.

Open on batt < setpoint - Hys

Relays have 2 second delay on

Close, 0.1 sec delay on open

Bulk Charge Trigger Timer 15
- Set Start Bulk time 00:00

To disable timer set to 00:00

If grid timer active set bulk

time after start charge time.

In SLT mode don't disable this

timer. It is the daily chg time.

Low Battery Transfer (LBX) 16
- Set Low Battery TransferVDC 11.3
- Set Low battery cut in VDC 13.0

See menu 9 to enable LBX mode.

Make sure LBX is above LBCO volts.

Battery Selling 17
- Set Battery Sell volts DC 13.4
- Set Max Sell amps AC 30

See menu 9 to enable SELL mode.

Make sure LBX is above LBCO volts.

Grid Usage Timer 18
- Start Charge time 21:00
- End Charge time 21:00

After Start Charge time:

SELL mode charges battery.

FLT mode charges battery

After End Charge time:

SELL mode sells battery to AC1.

FLT mode drops AC1 and inverts

Timer on when start < > end;

timer off when start = end

Sell and float modes use timer

SLT and LBX mode ignore timer

Information file battery 19

Batt temp comp changes battery

voltage reading away from actual

HBCO resets at: 6v/48, 3v/24 and

1.5v/12v under HBCO.

LowBattTransfer used in LBX, FLT

Modes only. Goes back to battery

at LowBattCutIn (aka LBCI).

For LBX mode set below LBCI so

charger won't cycle batteries

up and down and set LBCO below.

End Setup Menu 20

See User Manual, Page 35.

Inverter Set Points

- **The following set points have been programmed into your inverter, different from the factory default settings:**
  - To access menus 9 through 20 you must push the red and green control buttons, simultaneously.
  - Menu 9, Inverter Setup…
    - Low battery cut out = 46.4V
    - Low battery cut in = 51.0V
    - High battery cut out = 60.0V
    - Search watts = 16
  - Menu 10, Battery Charging…
    - Bulk voltage = 56.6V
    - Float voltage = 53.2V
    - Max AC charge amps = 25
  - Menu 11, AC Inputs…
    - Input lower limit = 105V
    - Input upper limit = 136V
  - Menu 17, Battery Selling…
    - Battery sell voltage = 53.2V

Manufacturer and Warranty Information

- All of the major components of your system are warranted by their manufacturers. Manufacturer warranty and contact information can be found in the equipment user manuals. For your convenience, contact information is also on the following pages.
- Your system was sold and installed by: Wilhelm Engineering, 149 Sun Street, Stelle, IL 60919; 815-256-2284

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Your Photovoltaic Modules

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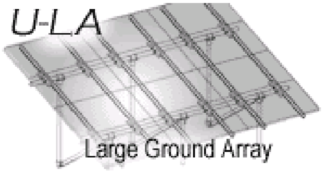

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USA

Phone 505-242-6411
Fax 505-242-6412

Welcome

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On-site product photos

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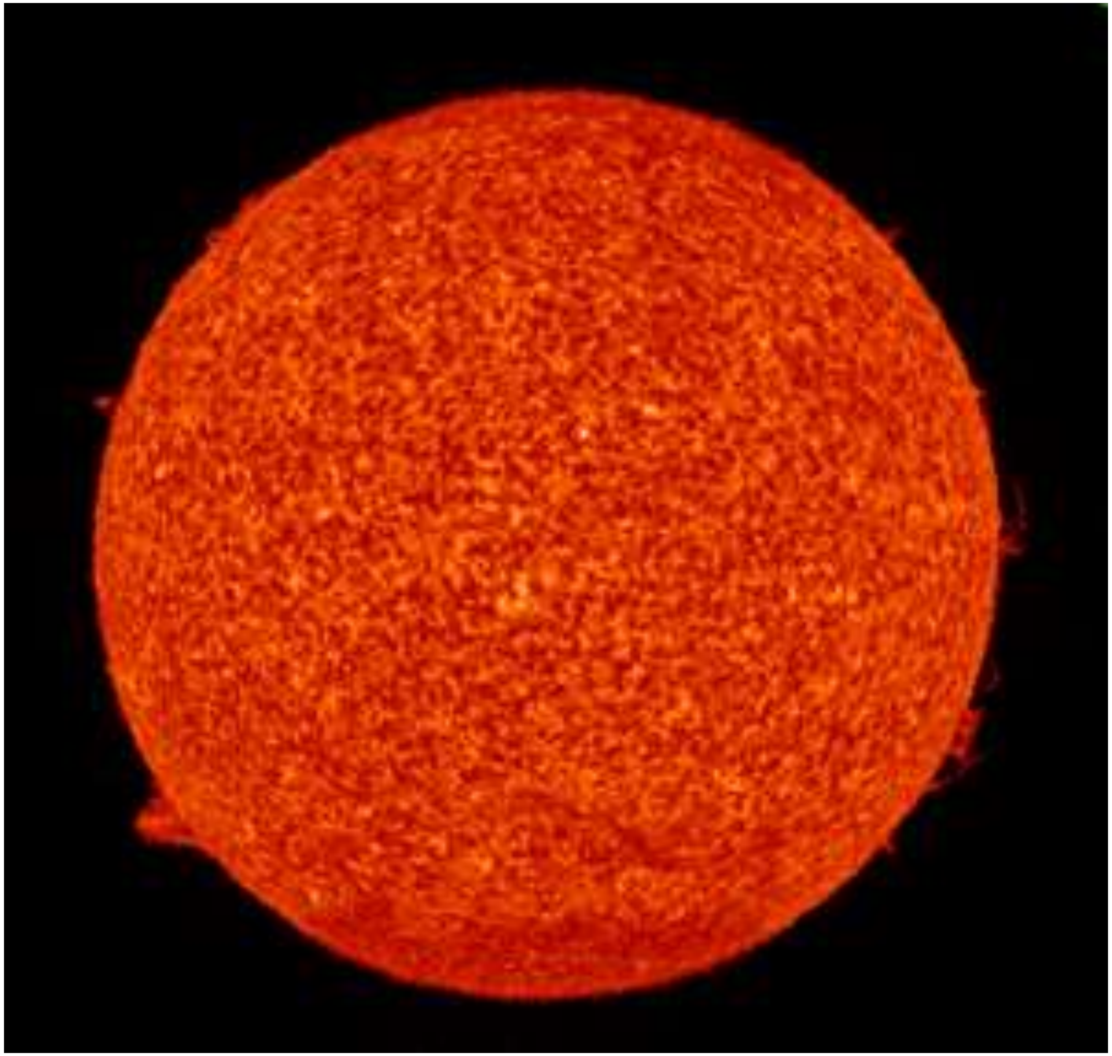
Next Week…

- Re-visit solar-PV
  - A little review
  - A little more detail
- Electrical Generator Technology
  - Converting mechanical energy into electrical energy

Finis



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