SOLAR ENERGY

Saswat Sourav Panda

Outline

- Why Renewable Energy?
- The Science of Photovoltaics
- System Configurations
- Principle Design Elements
- Energy Efficiency
- The Solar Scholars program at Bucknell (walking tour)

What's wrong with this picture?

- Pollution from burning fossil fuels leads to an increase in greenhouse gases, acid rain, and the degradation of public health.

- In 2014, India emitted 2,513,609 metric tons of carbon dioxide, 10,340 metric tons of sulfur dioxide, and 3,961 metric tons of nitrogen oxides from its power plants.

Why Sustainable Energy Matters

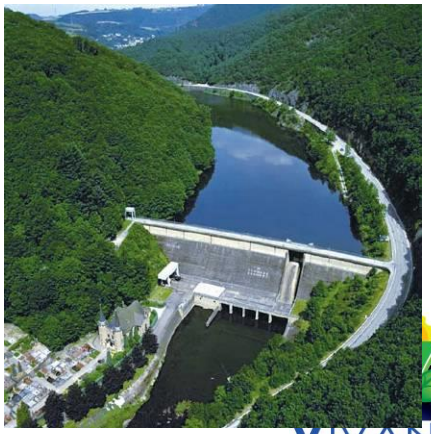
- The world's current energy system is built around fossil fuels
  - Problems:
    - Fossil fuel reserves are ultimately finite
    - Two-thirds of the world' s proven oil reserves are locating in the Middle-East and North Africa (which can lead to political and economic instability)

Why Sustainable Energy Matters

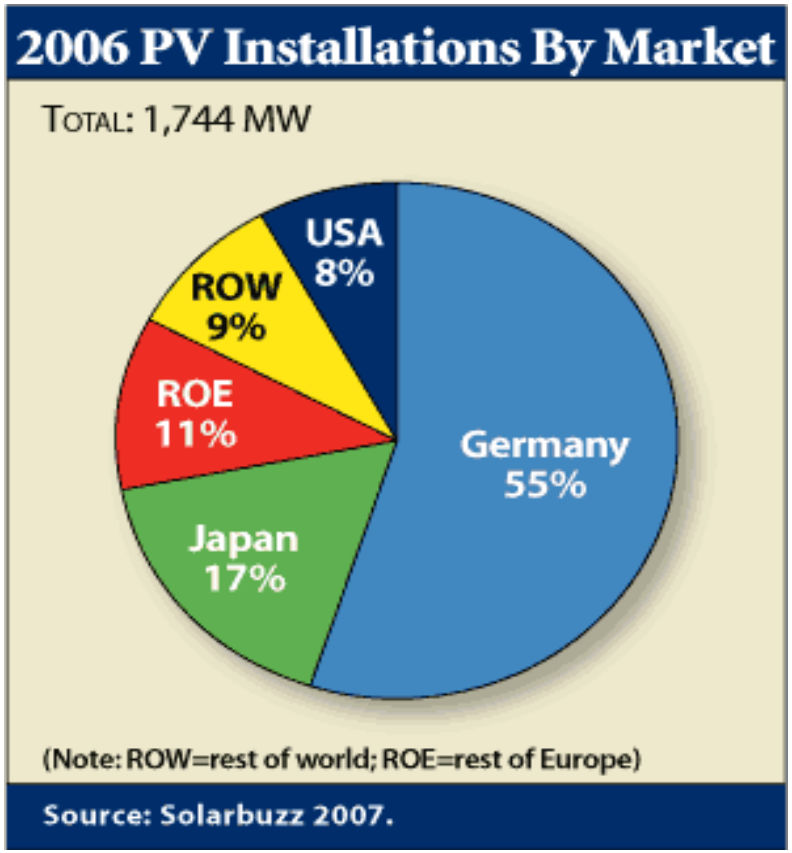
- Detrimental environmental impacts
  - Extraction (mining operations)
  - Combustion
    - Global warming

Making the Change to Renewable Energy

- Solar
- Geothermal
- Wind
- Hydroelectric



Today's Solar Picture



Financial Incentives

- Investment subsidies: cost of installation of a system is subsidized
- Net metering: the electricity utility buys PV electricity from the producer under a multiyear contract at a guaranteed rate
- Renewable Energy Certificates ("RECs")

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Solar in India

- India is fast growing renewable energy market in the world.
- Installation target for India by IRENA
  - 2016-14GW
  - 2022-100GW
  - 2022-175GW(Recent announcement)
  - 40%-roof top solar

New and Renewable Energy Department

- INR 7000 Cr for Renewable Energy and Energy Efficiency
- The India Solar Program -provide Rs 180 Cr in grants to large and small businesses to purchase and install solar photovoltaic (PV) and solar hot water systems.

Deregulation and Grid Parity

- Current cost of electricity – Rs 8.58/kWh
- 2019 PA electricity prices will be uncapped
  - Est. 33+% increase projected by PPL
- The Solar India Initiative
  - goal of bringing solar to grid parity by 2015

Electricity

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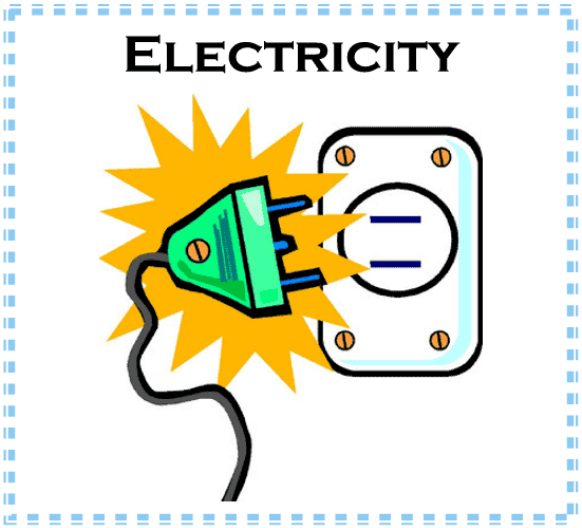
The Idea



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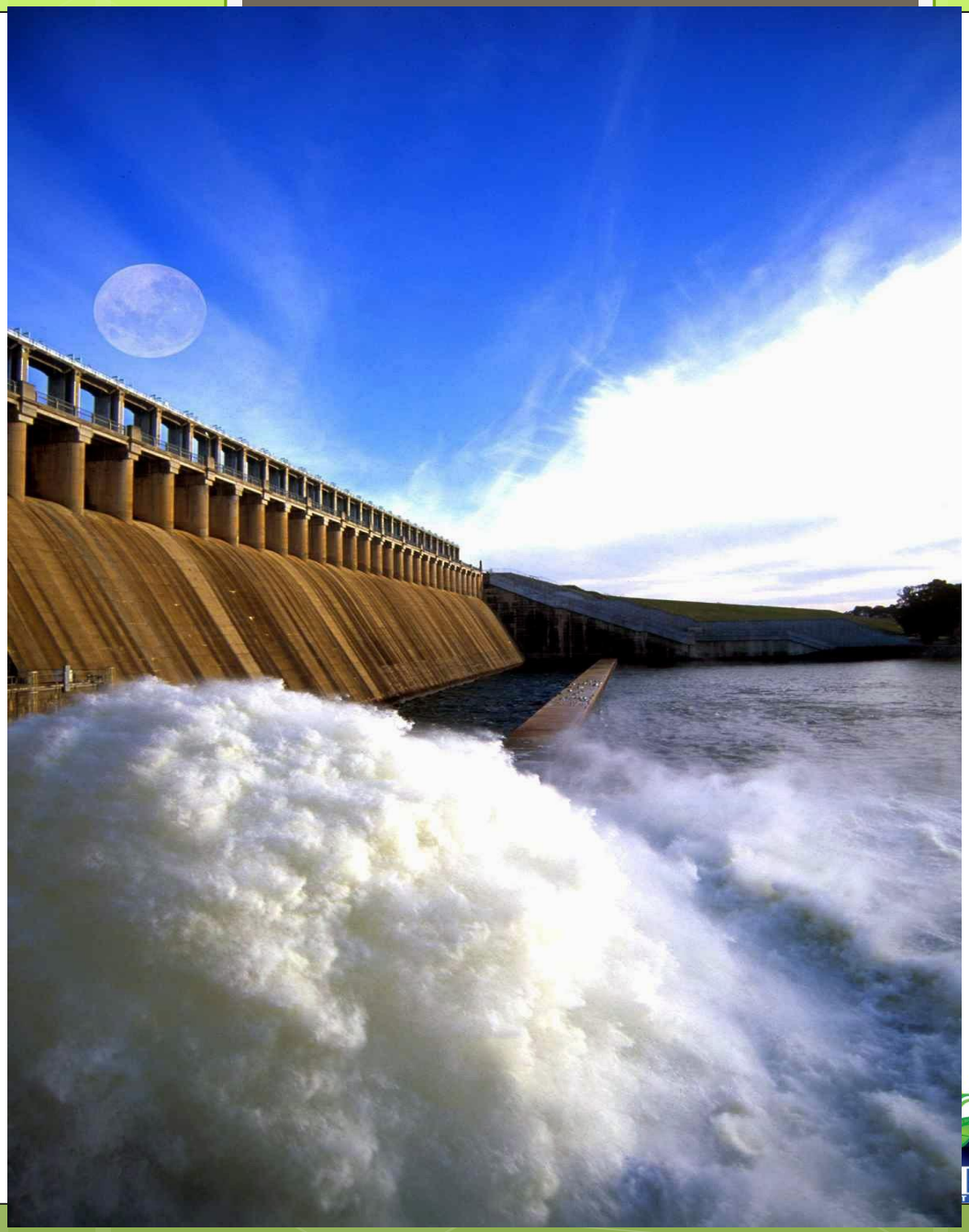
The Idea



The Idea

Terminology

- Voltage
  - Measured in Volts
  - Electrical potential
  - "Height" of water on one side of a dam compared to the other side
- Current
  - Measured in Amps
  - Rate of electron flow
  - "Speed" at which water flows through the dam

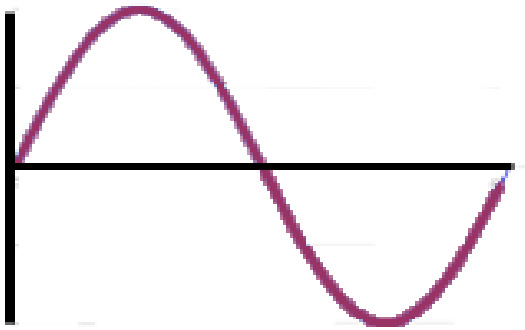
Terminology

- Resistance
  - The opposition of a material to the flow of an electrical current
  - Depends on
    - Material
    - Cross sectional area
    - Length
    - Temperature

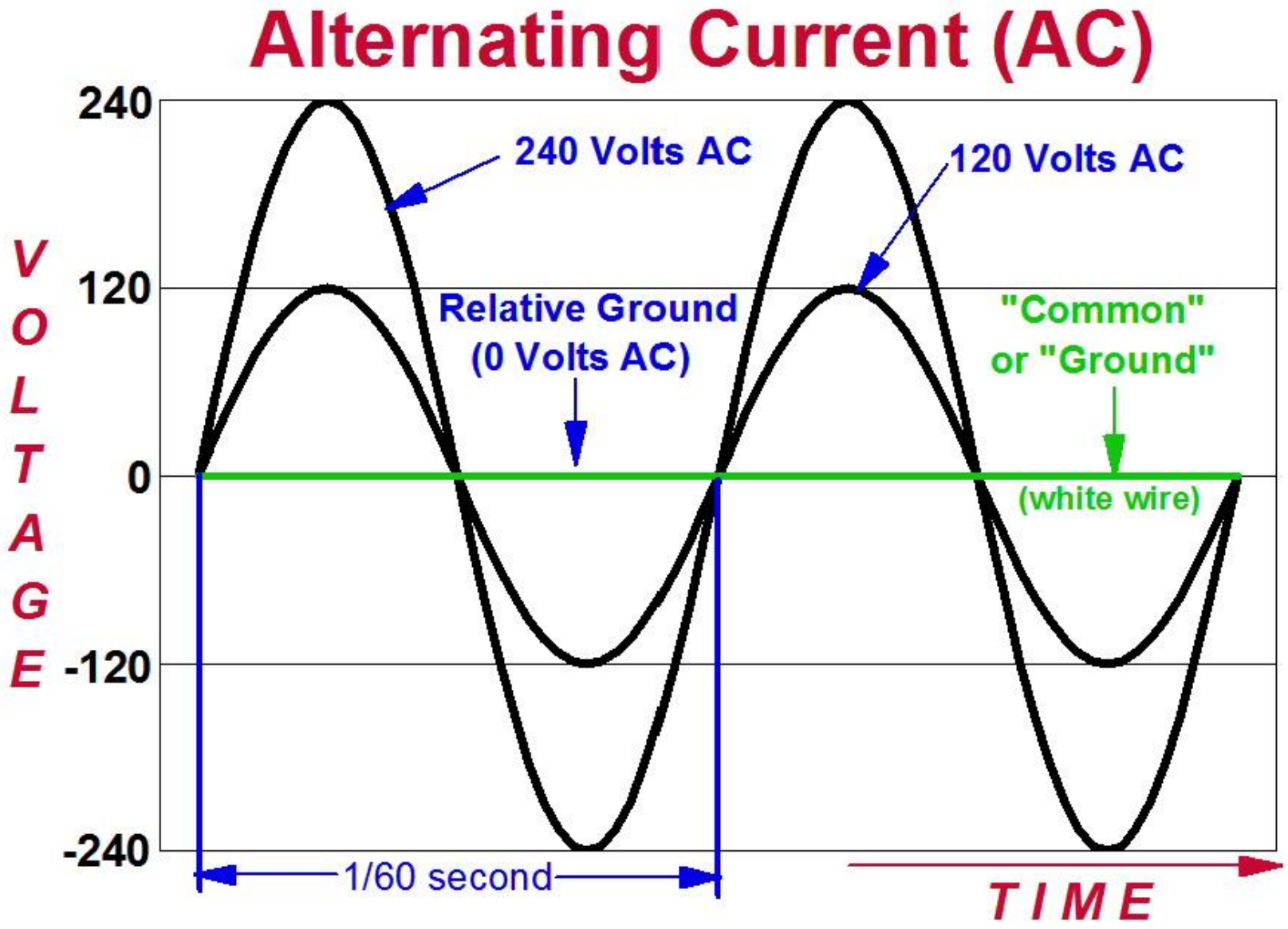
Types of Current

- DC = Direct Current
  - PV panels produce DC
  - Batteries store DC
- AC = Alternating Current
  - Utility power
  - Most consumer appliances use AC
  - Electric charge changes direction

Direct Current



Alternating Current


Alternating Current (AC)
240
120
0
-120
-240
VOLTAGE
240 Volts AC
120 Volts AC
Relative Ground
(0 Volts AC)
"Common"
or "Ground"
(white wire)
1/60 second
TIME

Terminology

- Watt
  - Measure of **Power**
  - Rate of electrical energy
  - Not to be confused with Current!

Typical Wattage Requirements

Appliance	Wattage
CFL Bulb	15, 20, 30
TV (25 inch)	130
Fan	70
Refrigerator	130-180
Hair Dryer	1000
AC 1.5 ton	1500

Terminology

- Watt(W) is the power of an appliance.
- Watt-hour (Wh) is a measure of energy
  - Unit quantity of electrical energy (consumption and production)
  - Watts x hours = Watt-hours
- 1 Kilowatt-hour (kWh) = 1000 Wh
- 100W X 10hr = 1000kWh= 1unit off electricity

Symbols and Units

Voltage: E or V (Volts)

Current: I or A (Amps)

Resistance: R or Ω (Ohms)

Watt: W (Watt)

Solar Energy Overview

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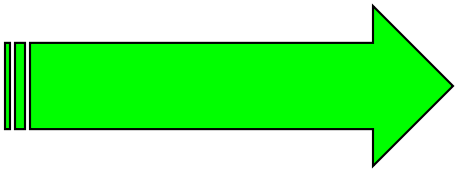
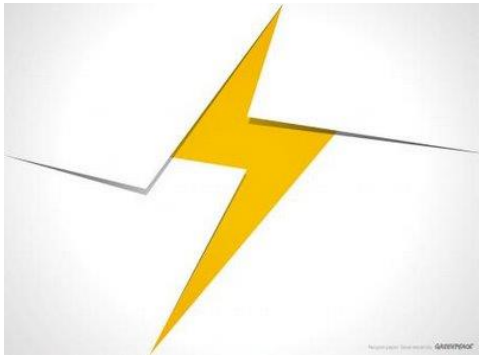
Harnessing the Sun





- Advantages
  - Clean & Green Energy
  - Easy to install (less components)
  - Grid can supply power
  - Low O&M cost
  - No sound or pollution
- Disadvantages
  - Requires energy storage for night use
  - No power if grid goes down
  - Requires space

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Solar Energy Harnessing

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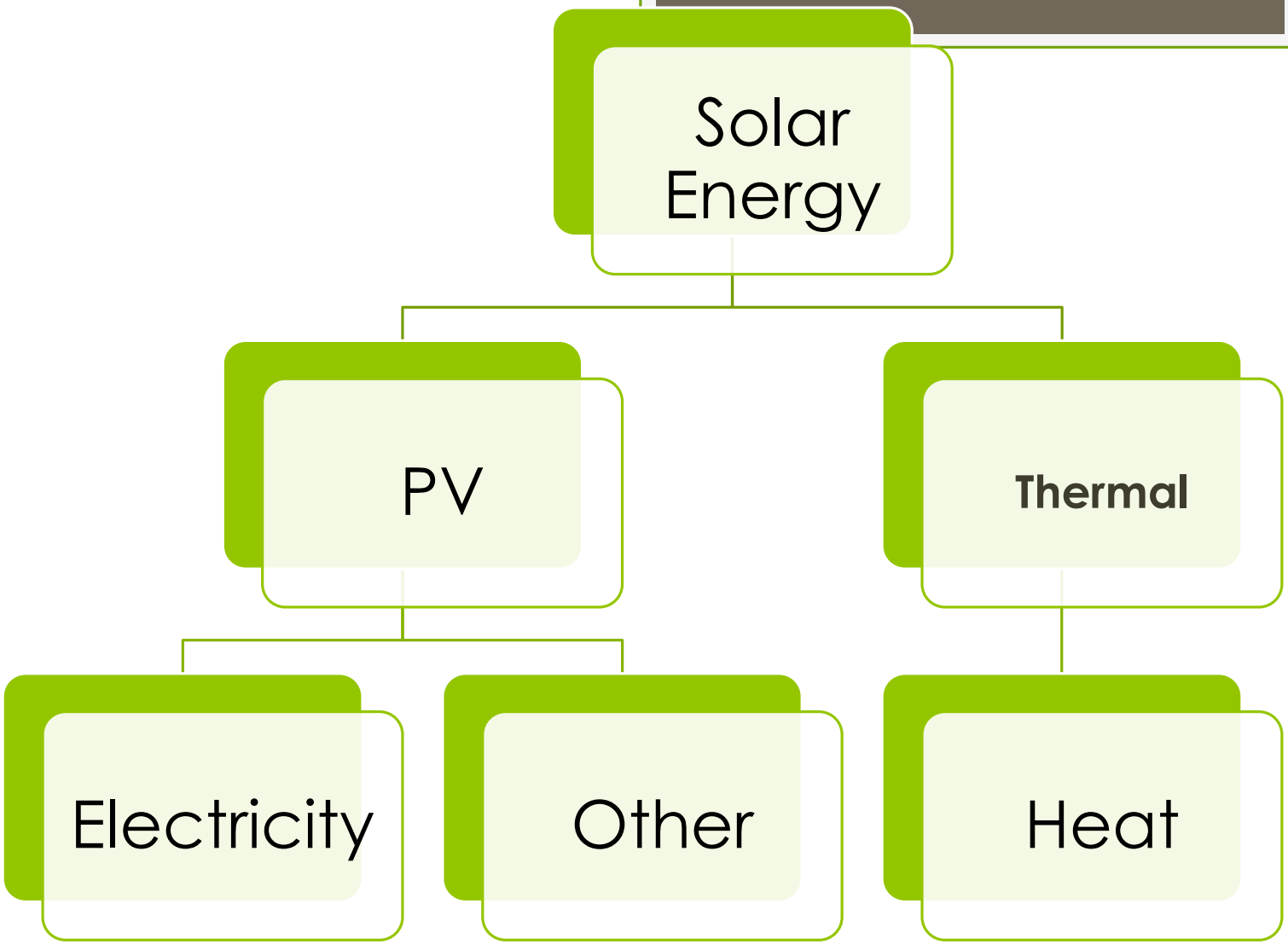
Solar Energy
PV
Thermal
Electricity
Other
Heat

Two Main Categories:

Solar Thermal

Water heating and cooking

Solar Photovoltaic (PV)

Electricity production

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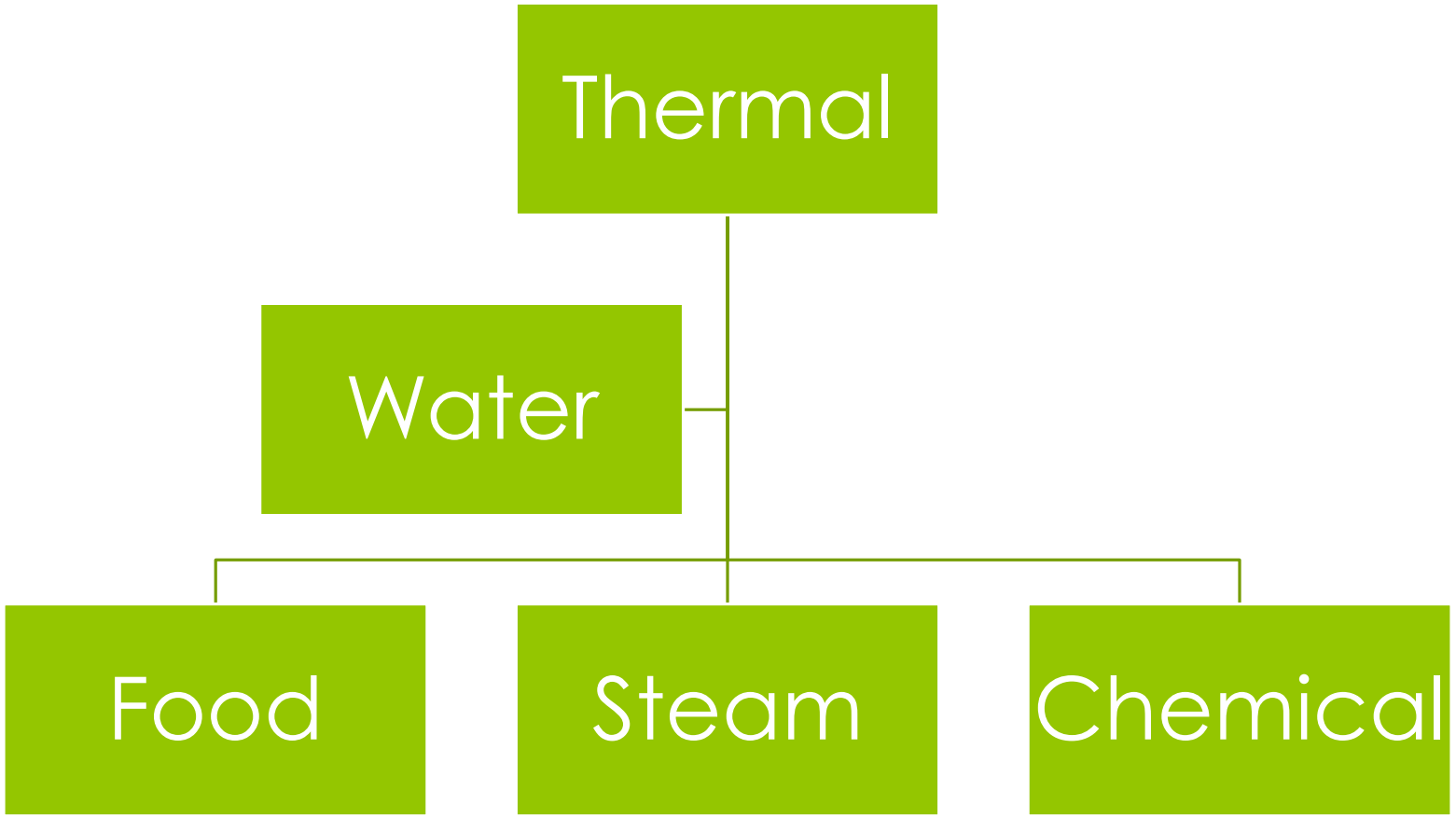
Thermal
Water
Food
Steam
Chemical

Solar Thermal Energy

Cooking

Water Heating

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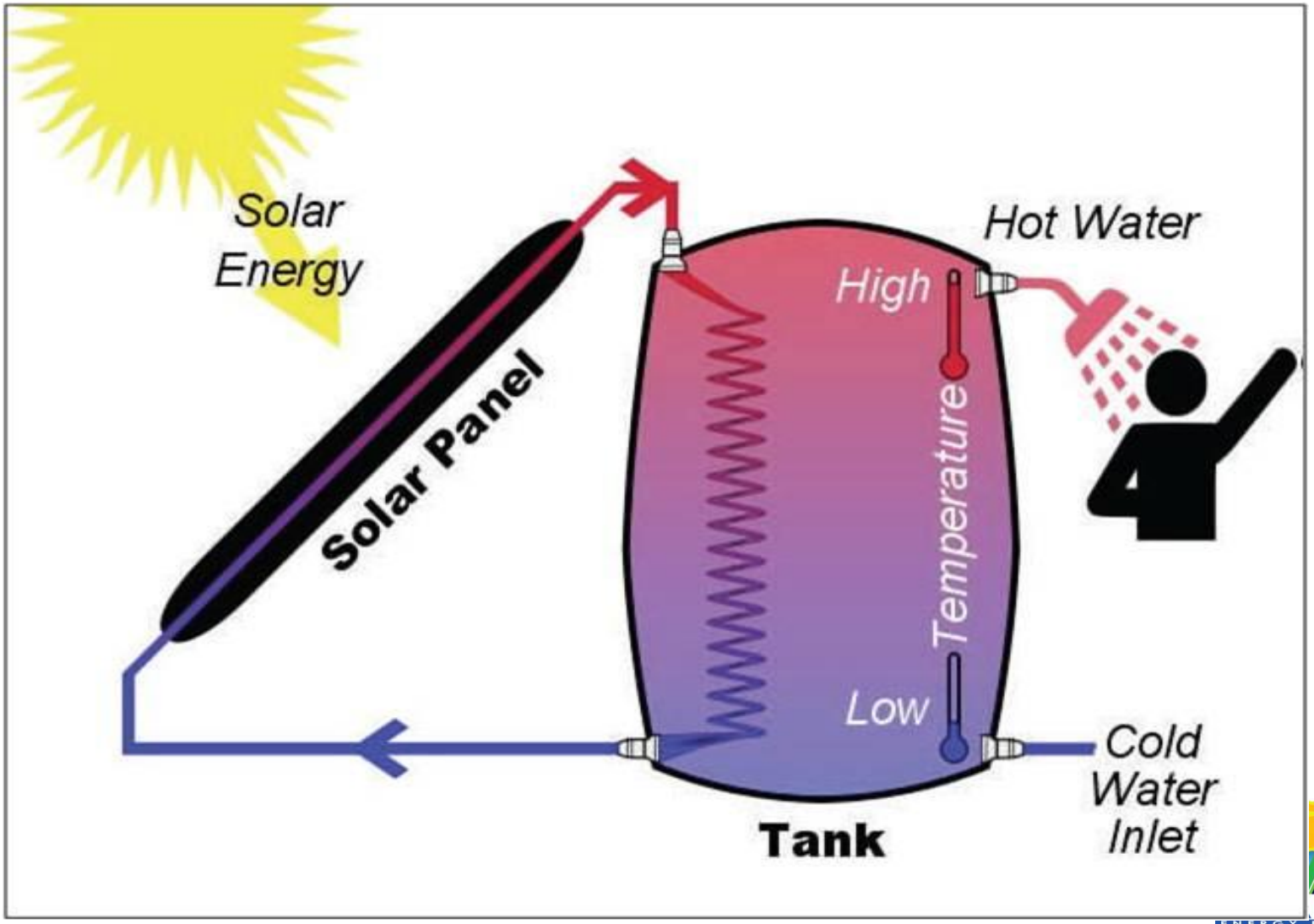
Solar
Energy
Solar Panel
Hot Water
High
Temperature
Low
Cold
Water
Inlet
Tank

Solar Water Heating

Solar water heating is the most efficient and economical use of solar energy

Residential systems start at 15000

Savings of 150-250 per month, lasting 20+ years

Tax credits and state rebates available

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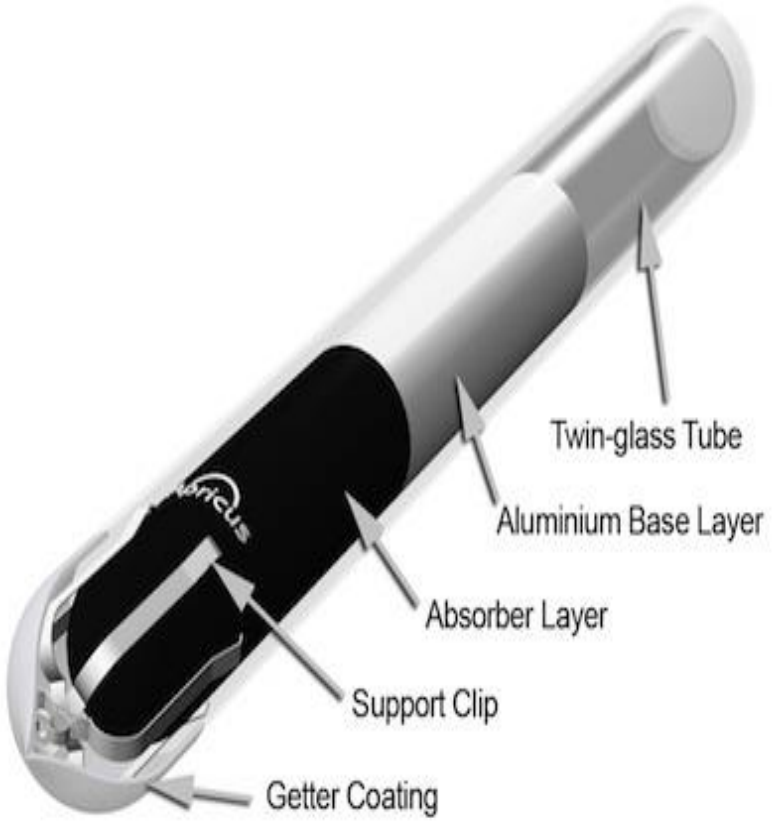
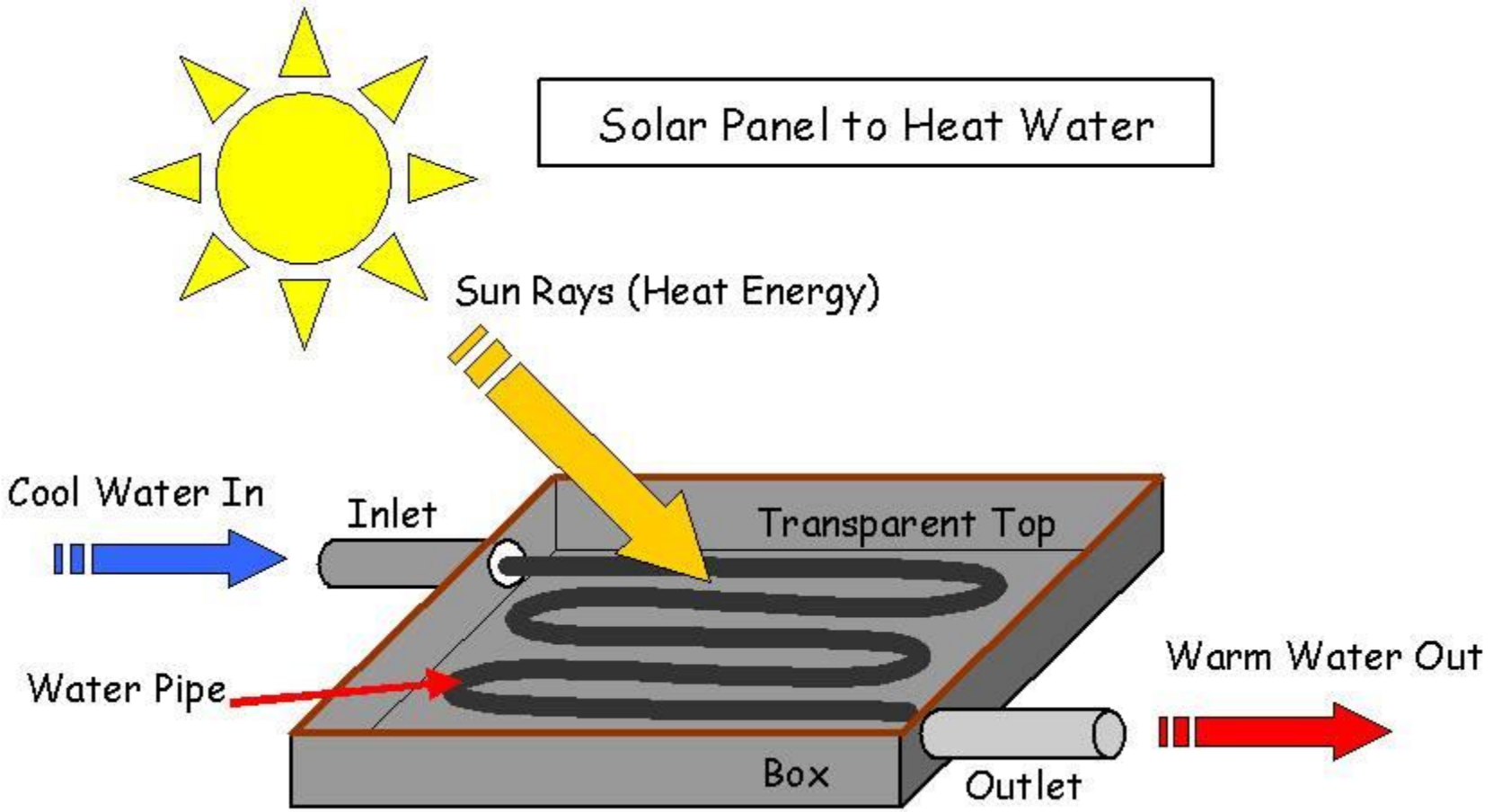
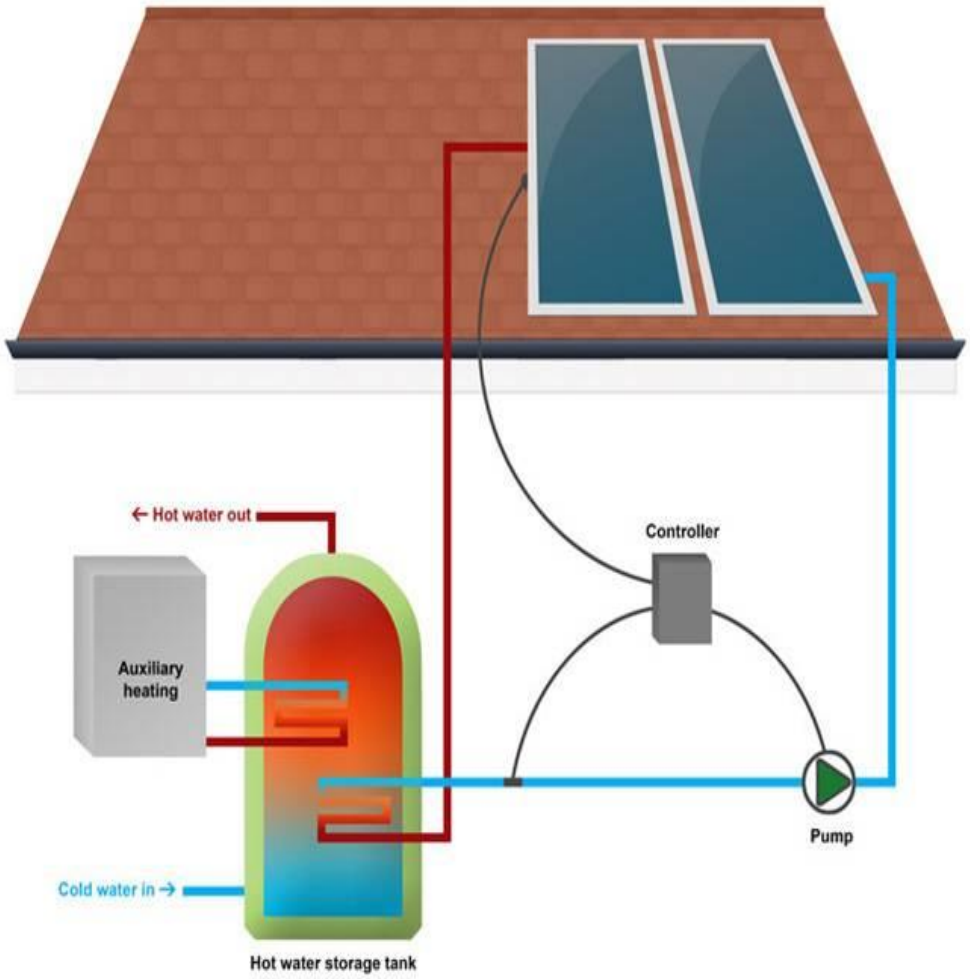
AUXILIARY VENT
VENT
HIGH-TECH INSULATION MATERIAL
OUTER TANK
FUBBER SEAL
VACUUM TUBE
TUBE HOUSING
COLD WATER
SMALL TANK FOI
AUTOMATIC WAT
SUPPLY
INNER TANK
O RING
HOLDER FOR
VACUUM TUBE


Twin-glass Tube
Aluminium Base Layer
Absorber Layer
Support Clip
Getter Coating

How Does it Work?



How Does it Work?



- Systems can be *passive* or *active*
- Passive systems only found in warmer climates, as they are prone to freezing
- Active: Roof-top collectors heat glycol which then passes through a heat exchanger in the storage tank to heat water
- Electric pump can be run on solar PV

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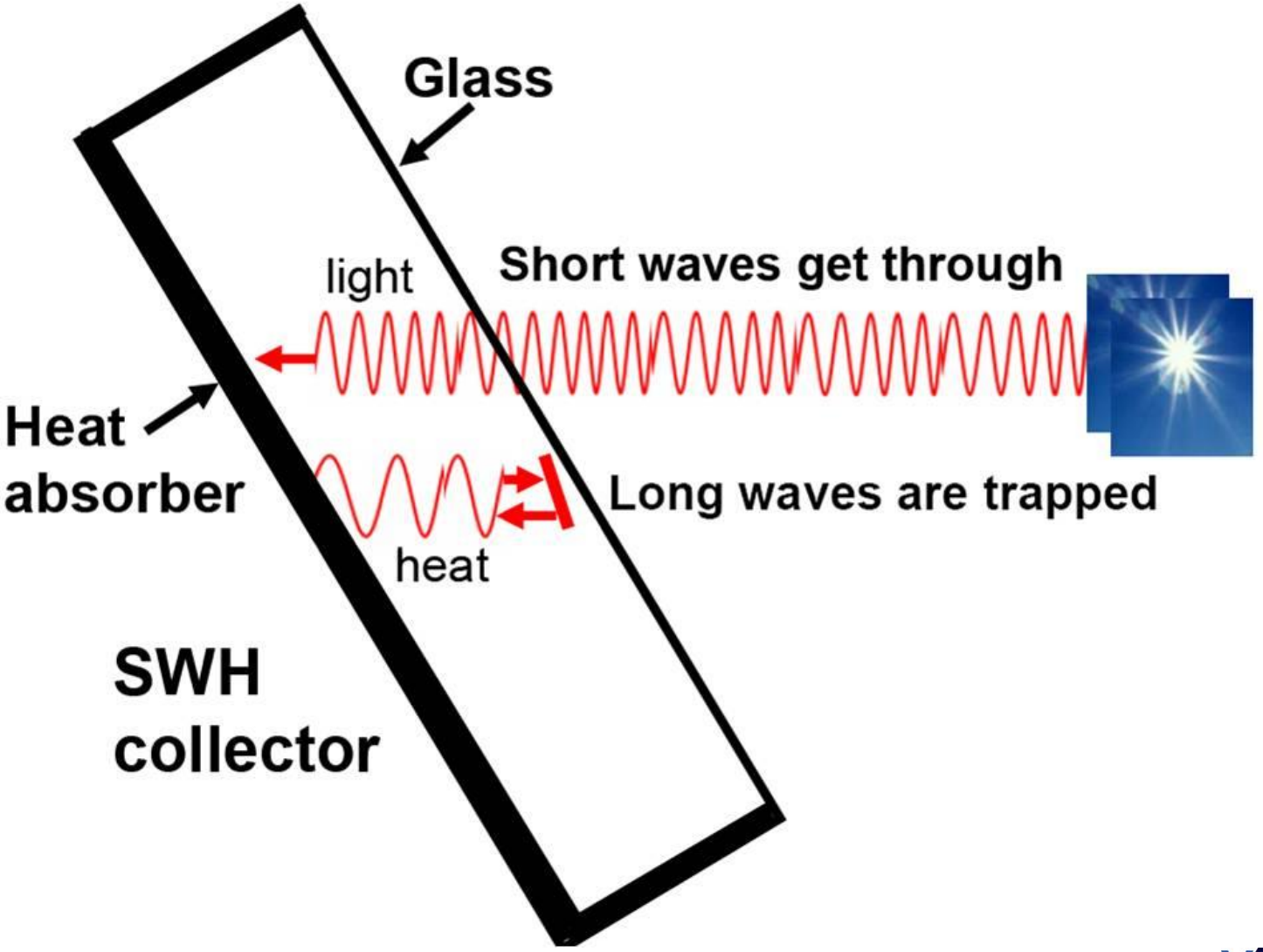
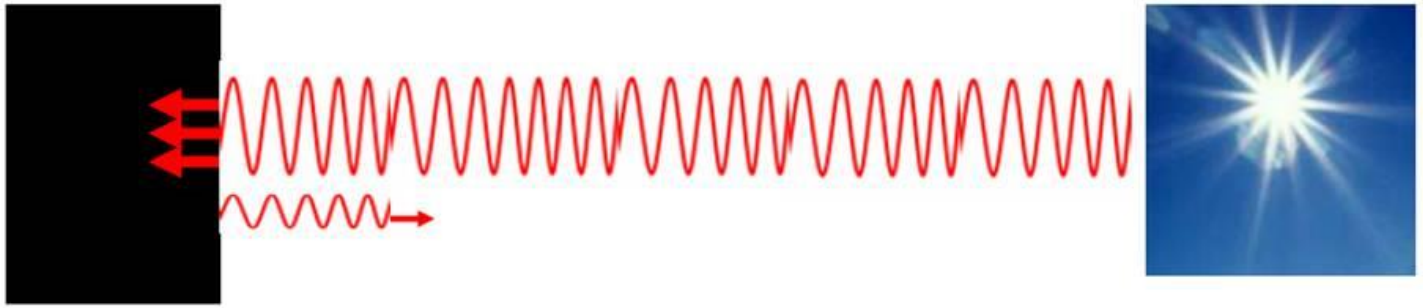
Greenhouse Effect

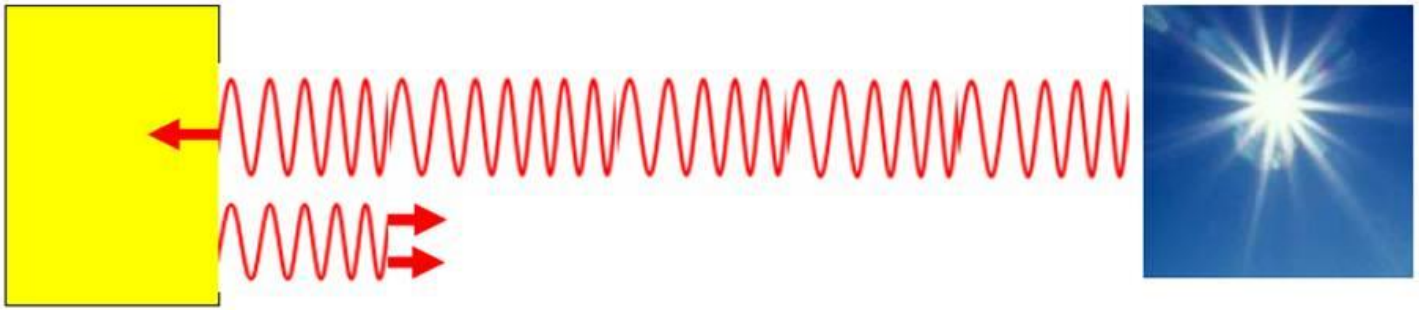


Color Absorption

Dark colors absorb a lot, reflect little



Light colors absorb little, reflect a lot



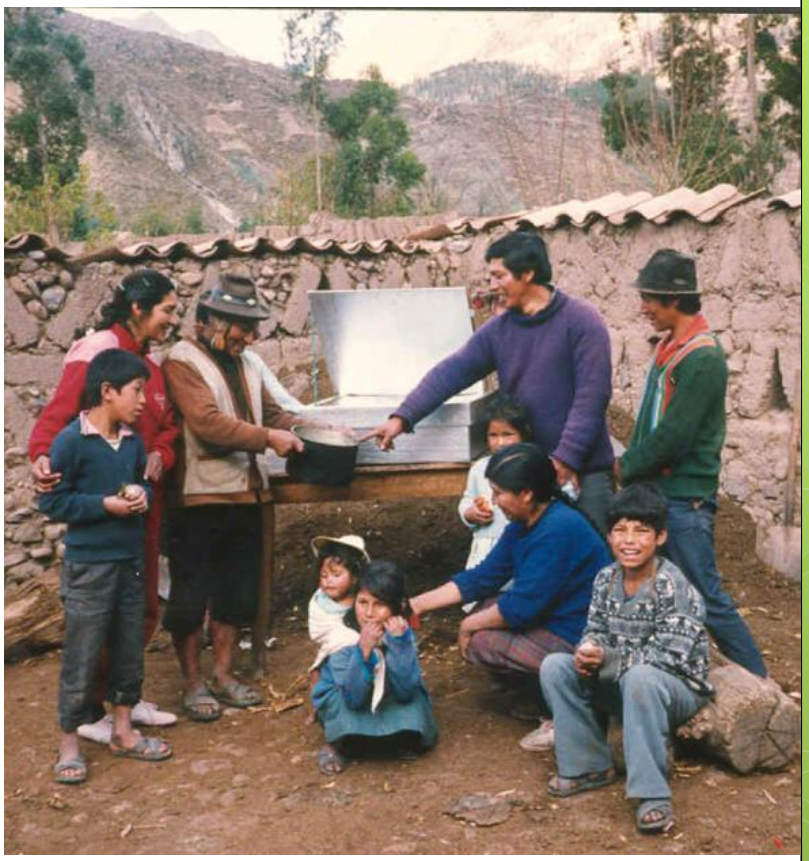
Metal Conductivity

Some metals transfer more heat than others.

Solar Cooking

Benefits of Solar Cooking

- Consumes no fuels/wood
  - No loss of trees & habitat
  - Trees sequester carbon
- Generates no air pollution
- Generates no greenhouse gases
- Produces no smoke
  - Cooking smoke kills over 1.6 million people each year, mostly women & children, according to a recent report
- Eliminates fire dangers



More Benefits of Solar Cooking

- Eliminates work
  - No daily search for firewood
    - 2 Billion people rely on wood for cooking fuel!
  - No risks to women and children
  - Frees time for other activities
  - No need to stir food
  - Helps to liberate women

Solar Cooking

How Long Does it Take?

- Vegetables: 1.5 hrs
- Rice/wheat: 1.5-2 hrs
- Beans: 2-3 hrs
- Meats: 1-3 hrs
- Bread: 1-1.5 hrs

CSP

- Concentrated Solar Power
- Concentrates Solar Infra-Red radiation
- Types
  - Parabolic
  - Tower
  - Dish
  - Fresnel

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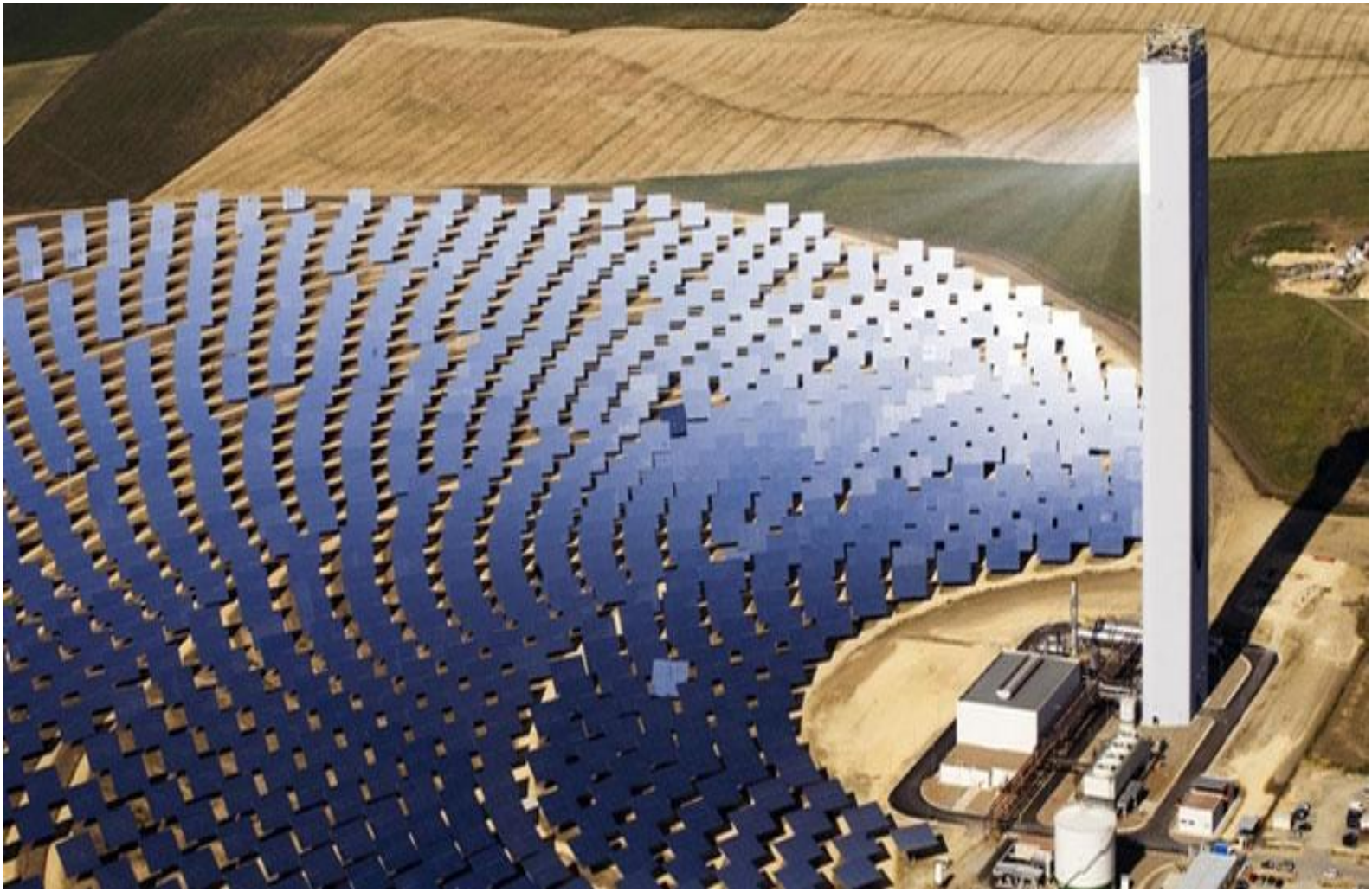

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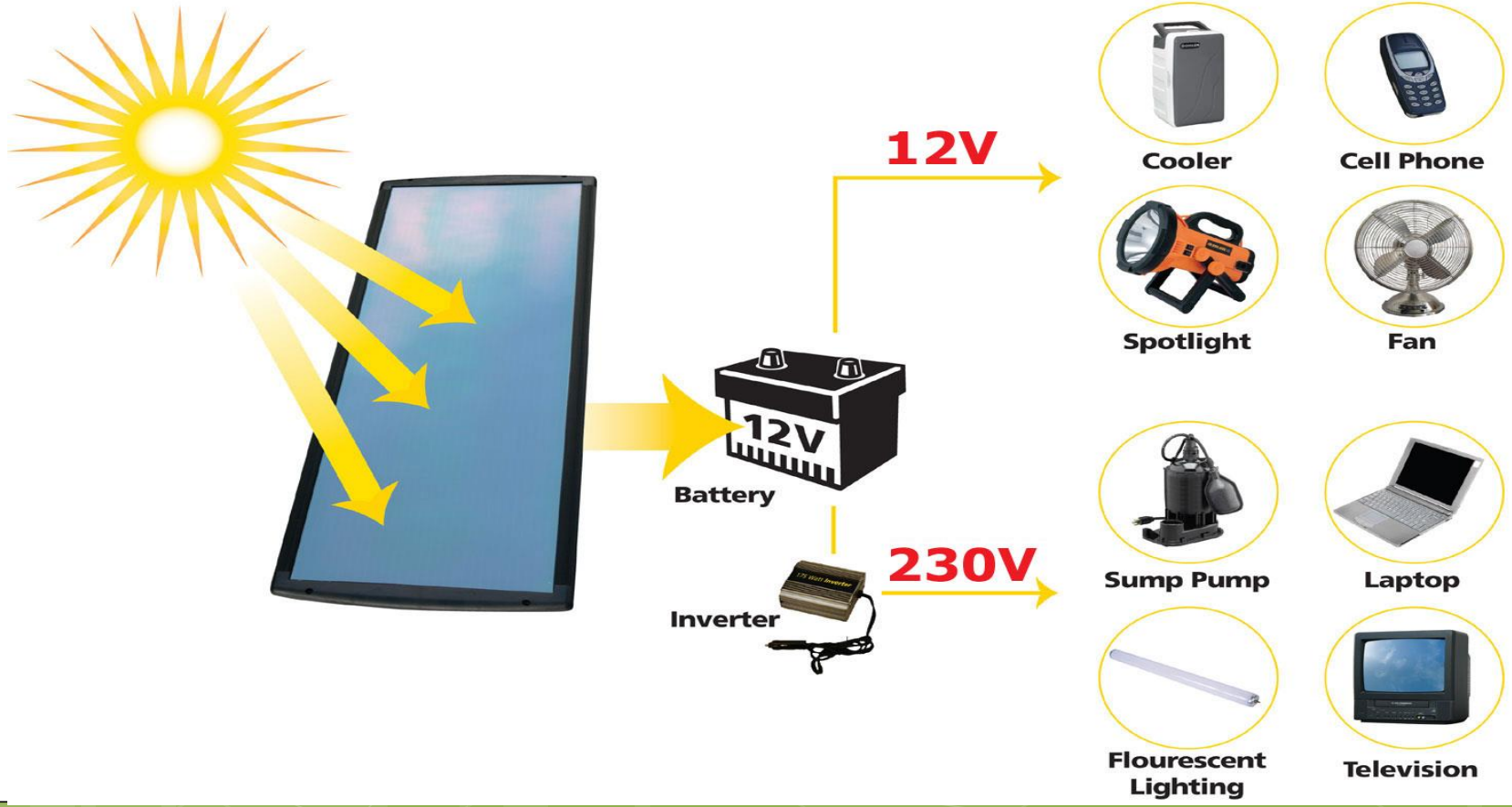
Solar PV

- Uses Photons from and convert it into electricity.
- Produces DC power
- Off Grid and on grid applications

Solar Electric (Photovoltaic)



Solar Electric Systems

- Photovoltaic (PV) systems convert **light energy directly into electricity.**
- Commonly known as "**solar cells**."
- The simplest systems power the small calculators we use every day. More complicated systems will provide a large portion of the electricity in the near future.
- PV represents one of the most promising means of maintaining our energy intensive standard of living while not contributing to global warming and pollution.

How Does it Work?

- Sunlight is composed of **photons**, or bundles of radiant energy. When photons strike a PV cell, they may be reflected or absorbed (transmitted through the cell). Only the absorbed photons generate electricity. When the photons are absorbed, the energy of the photons is transferred to electrons in the atoms of the solar cell.

How Does it Work?

- Solar cells are usually made of **two thin pieces of silicon**, the substance that makes up sand and the second most common substance on earth.
- One piece of silicon has a small amount of **boron** added to it, which gives it a tendency to attract electrons. It is called the **p-layer** because of its **positive tendency**.
- The other piece of silicon has a small amount of **phosphorous** added to it, giving it an excess of free electrons. This is called the **n-layer** because it has a tendency to give up negatively charged electrons.

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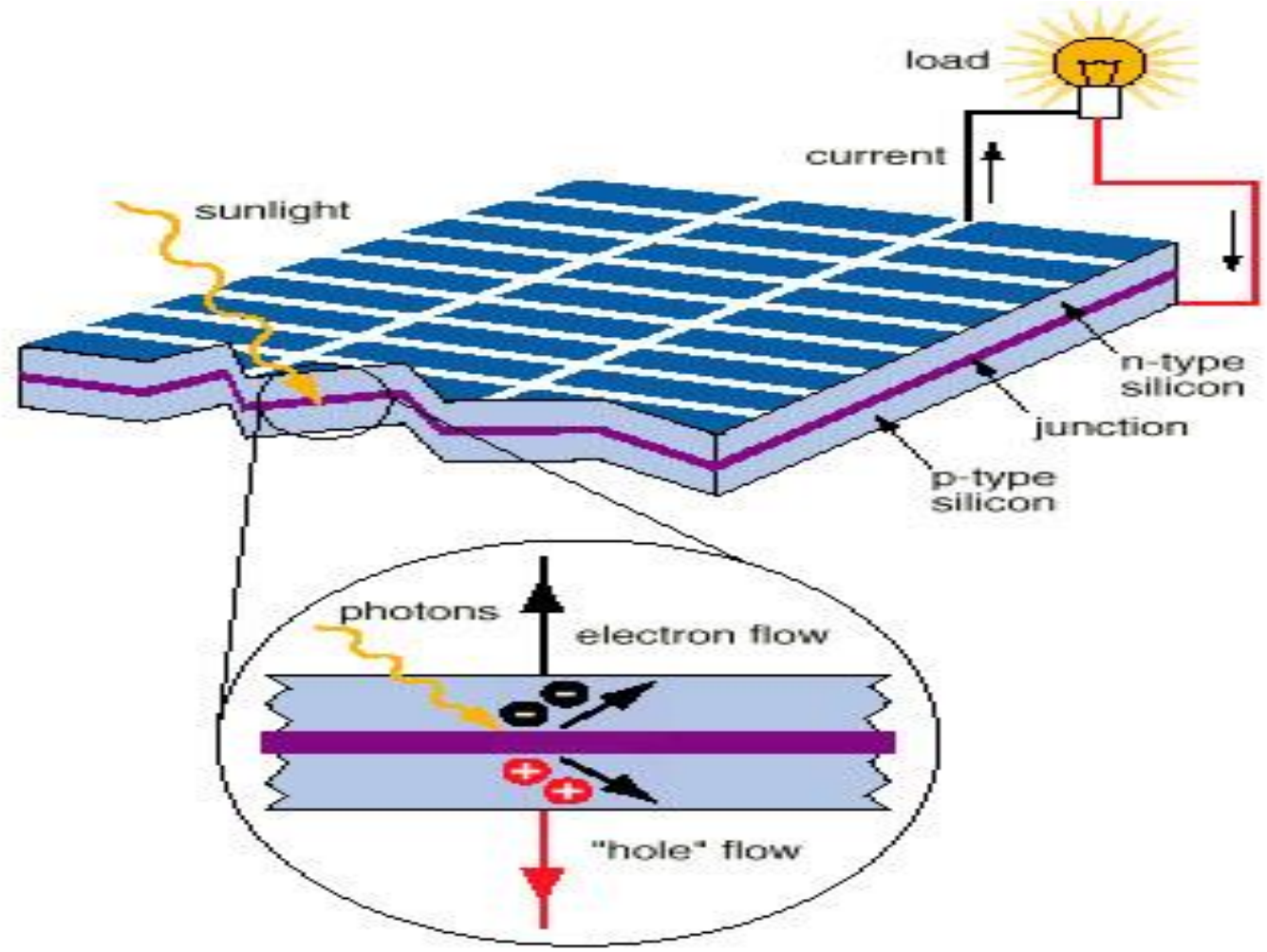
How Does it Work?



Inside a PV Cell

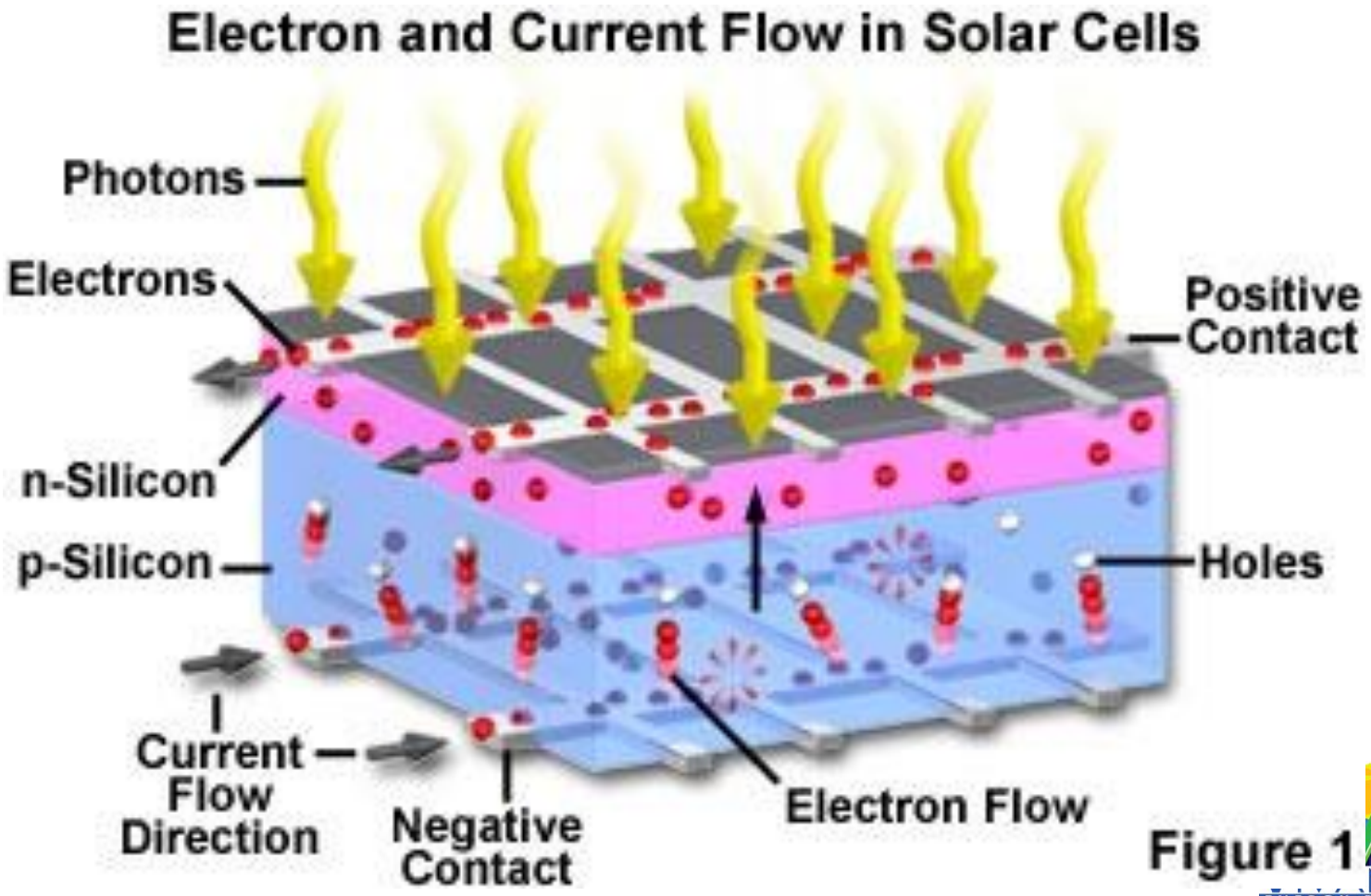
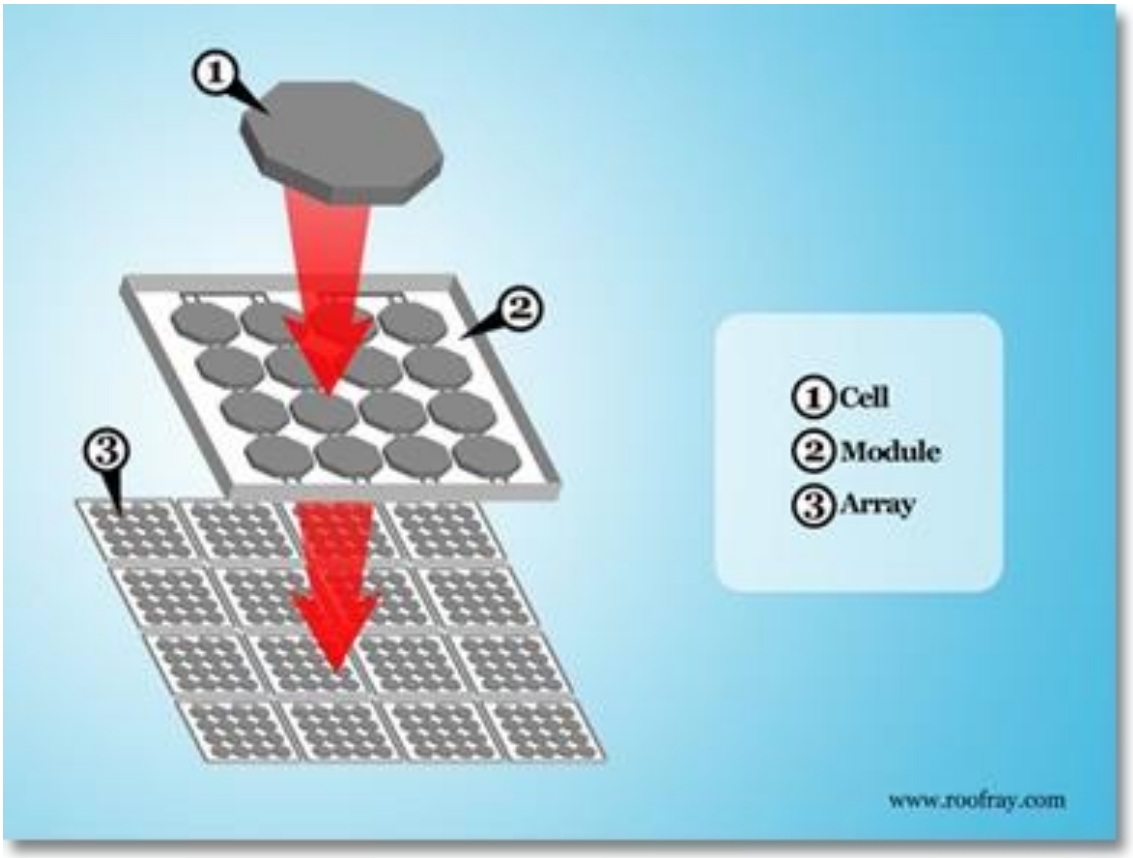


Figure 1

Photovoltaic (PV) Hierarchy

- Cell < Module < Panel < Array



Available Cell Technologies

- Single-crystal or Mono-crystalline Silicon
- Polycrystalline or Multi-crystalline Silicon
- Thin film
  - Ex. Amorphous silicon or Cadmium Telluride

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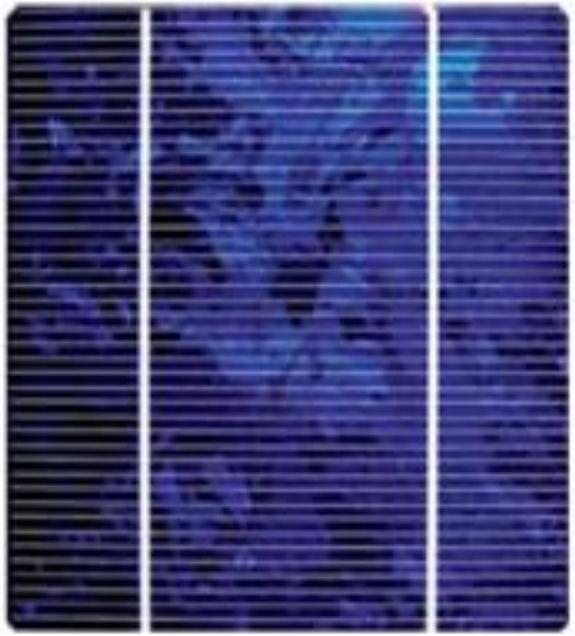
Mono



Poly

Thin Film

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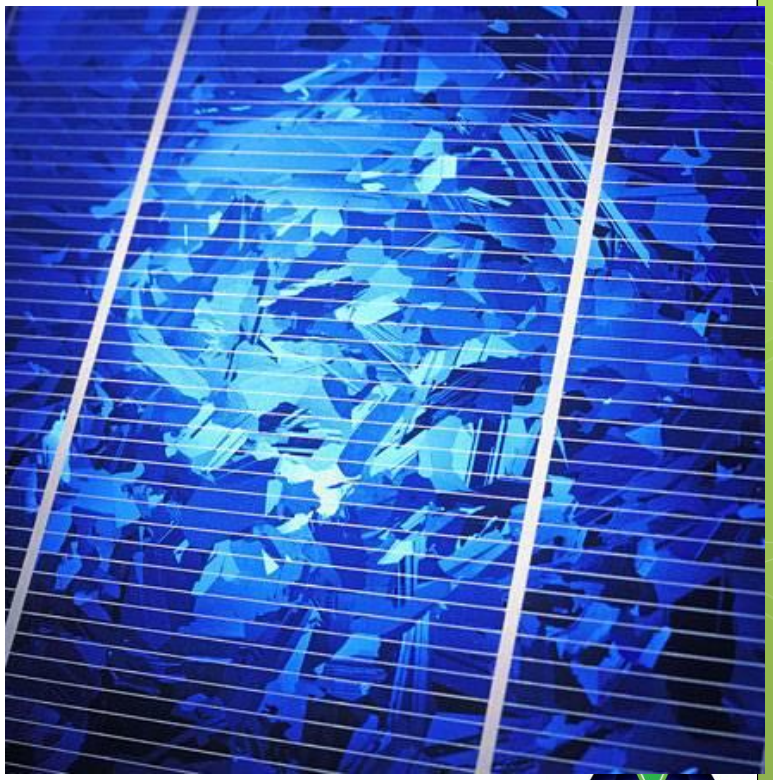
Monocrystalline Silicon Modules

- Most efficient commercially available module (12% - 18%)
- Most expensive to produce
- Circular (square-round) cell creates wasted space on module

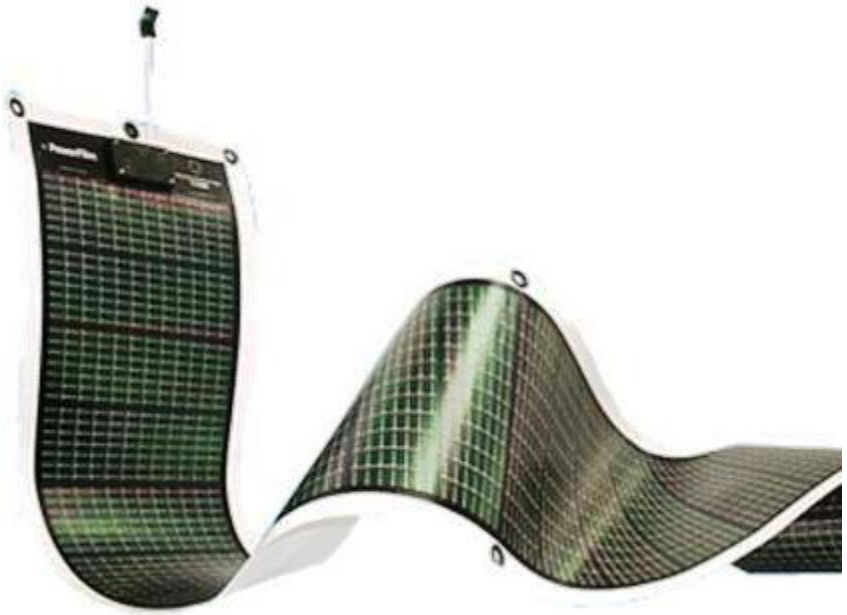
Polycrystalline Silicon Modules

- Less expensive to make than single crystalline modules
- Cells slightly less efficient than a single crystalline (10% - 16%)
- Square shape cells fit into module efficiently using the entire space



Amorphous Thin Film

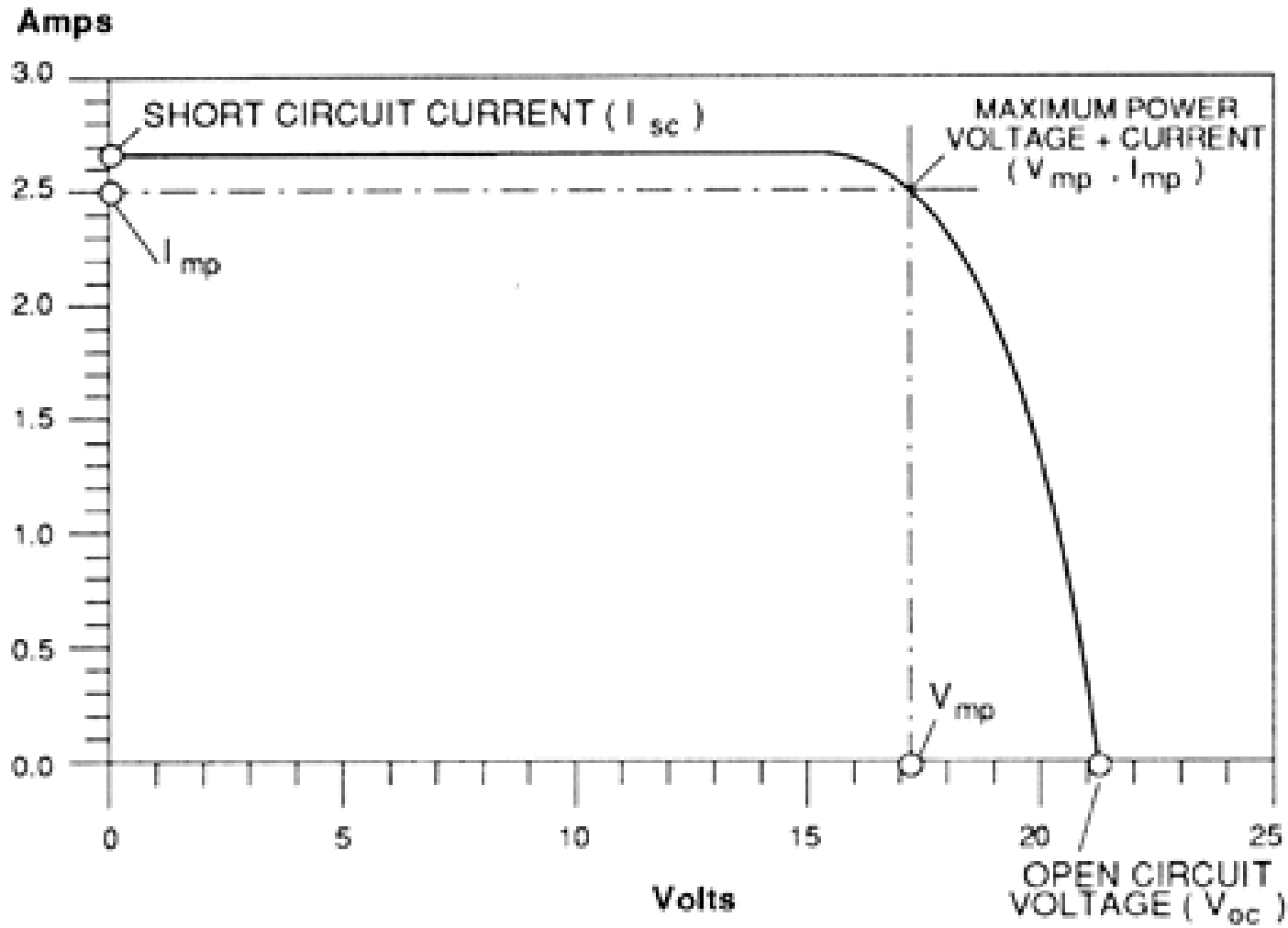
- Most inexpensive technology to produce
- Metal grid replaced with transparent oxides
- Efficiency = 6 – 8 %
- Can be deposited on flexible substrates
- Less susceptible to shading problems
- Better performance in low light conditions that with crystalline modules



Selecting the Correct Module

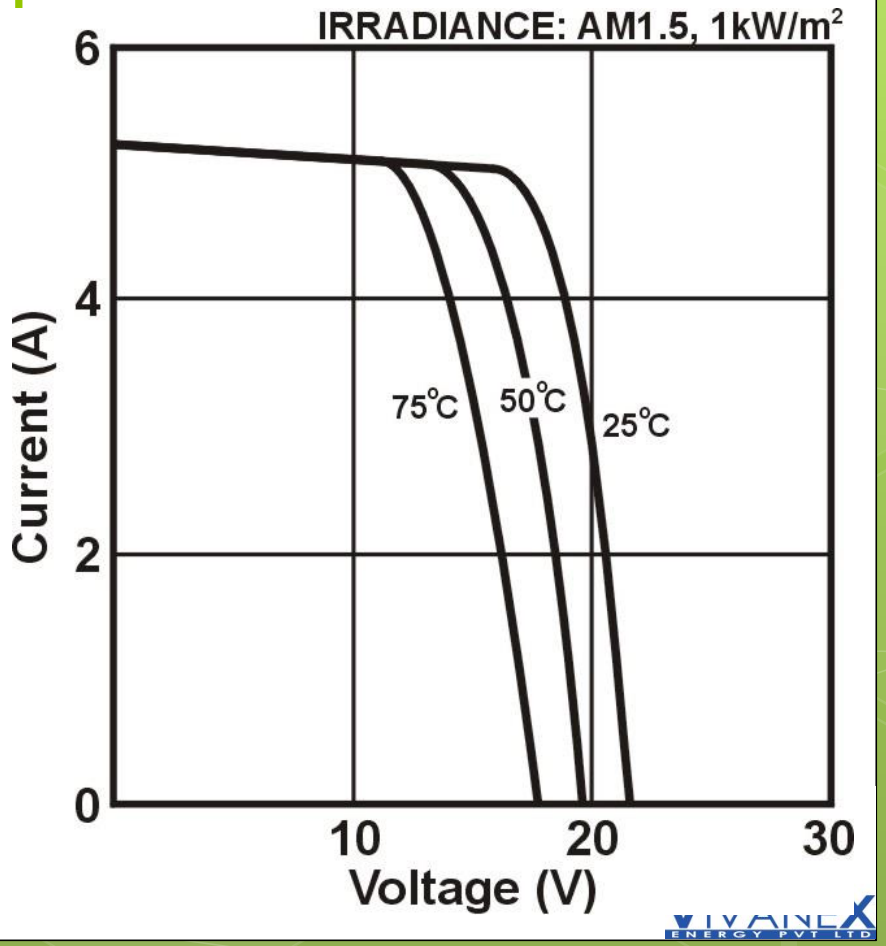
- Practical Criteria
  - Size
  - Voltage
  - Availability
  - Warranty
  - Mounting Characteristics
  - Cost (per watt)

Current-Voltage (I-V) Curve



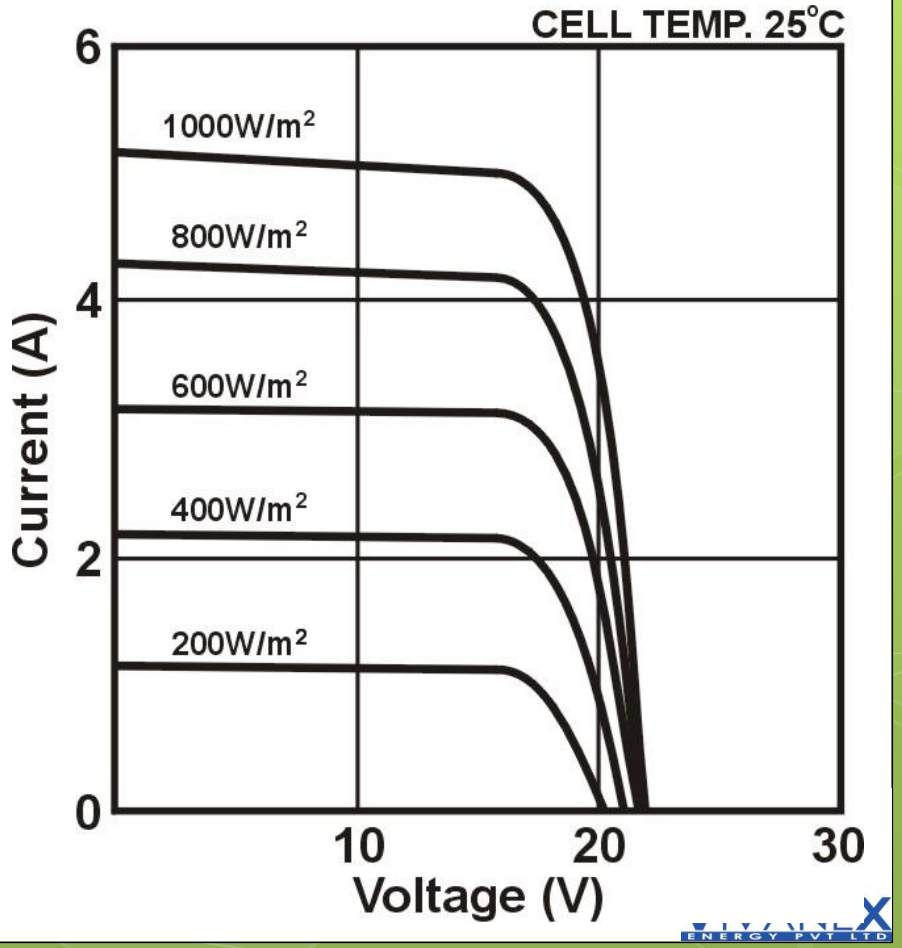
Effects of Temperature

- As the PV cell temperature increases above 25° C, the module V_{mp} decreases by approximately 0.5% per degree C



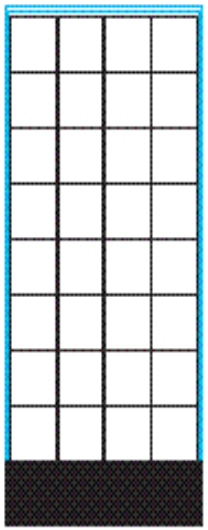
Effects of Shading/Low Insolation

- As insolation decreases amperage decreases while voltage remains roughly constant

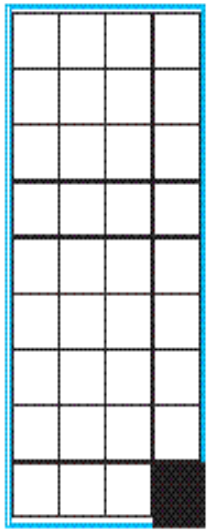


Shading on Modules

- Depends on orientation of internal module circuitry relative to the orientation of the shading.
- SHADING can half or even completely eliminate the output of a solar array!



Example of full-cell shading that can reduce PV module power to zero



Example of full-cell shading that can reduce PV module power by ½

Tools

Insolation

Pyranometer

Surface Temperature

Laser Thermometer

PV Wiring

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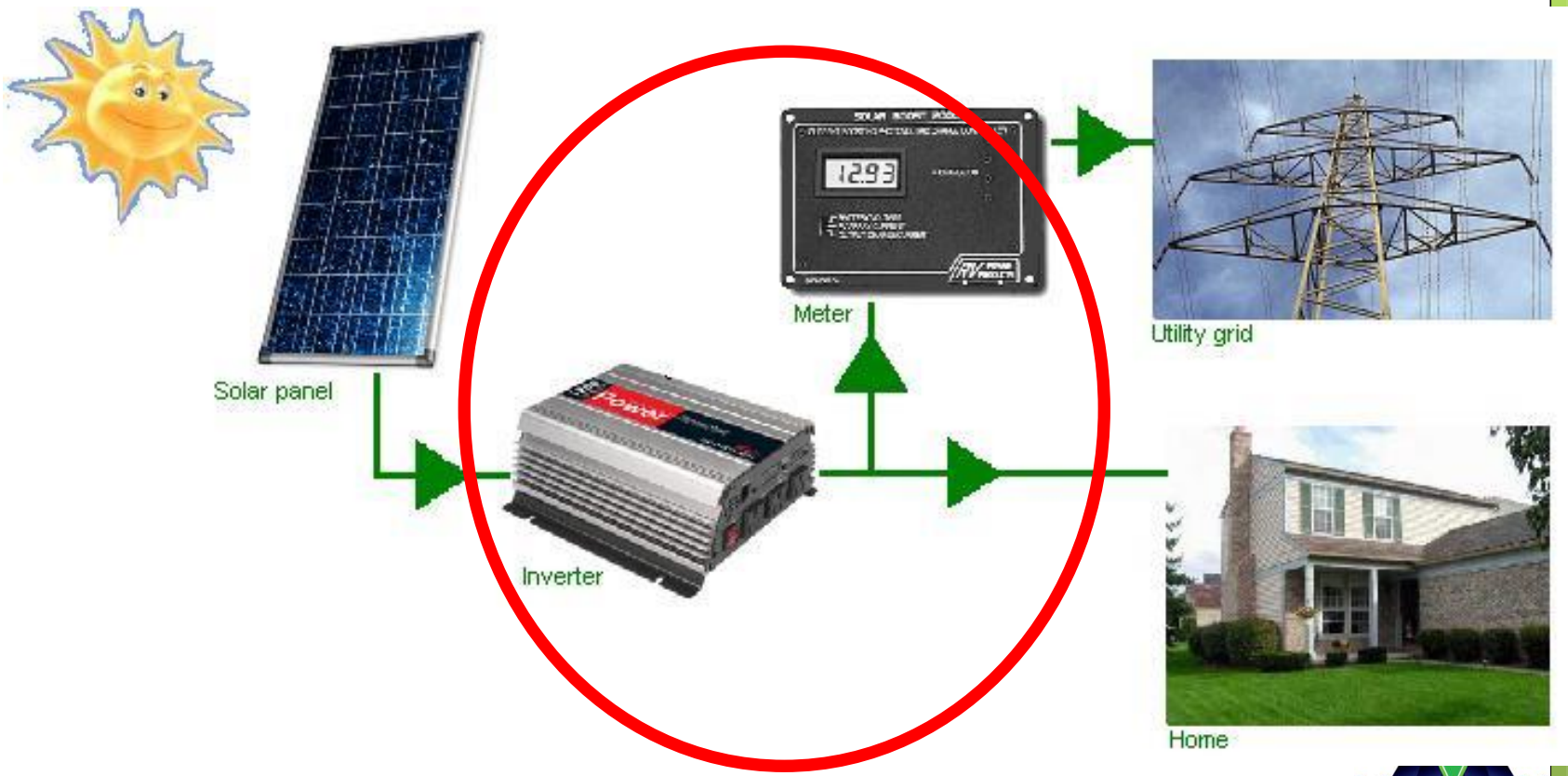
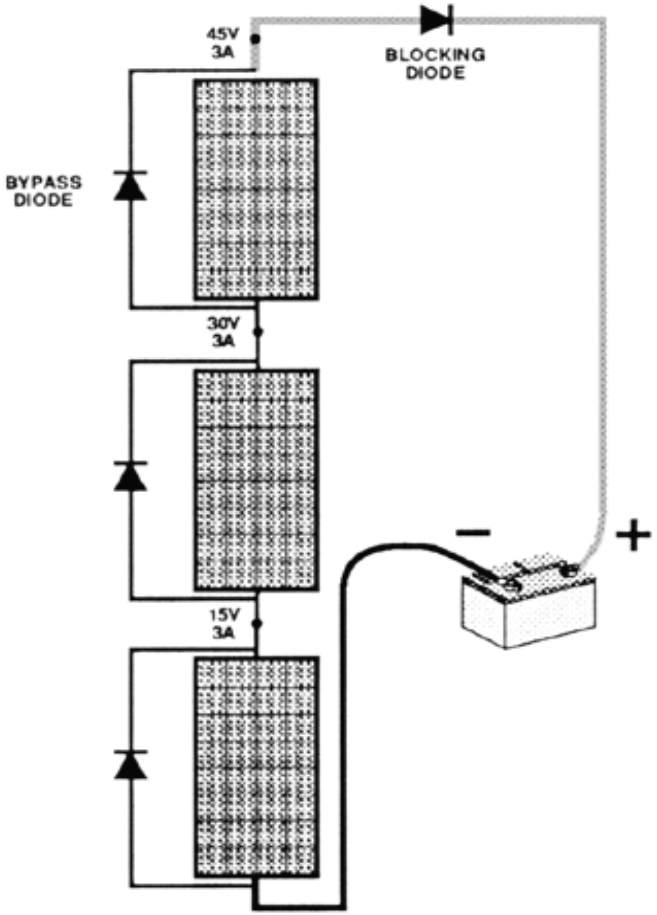
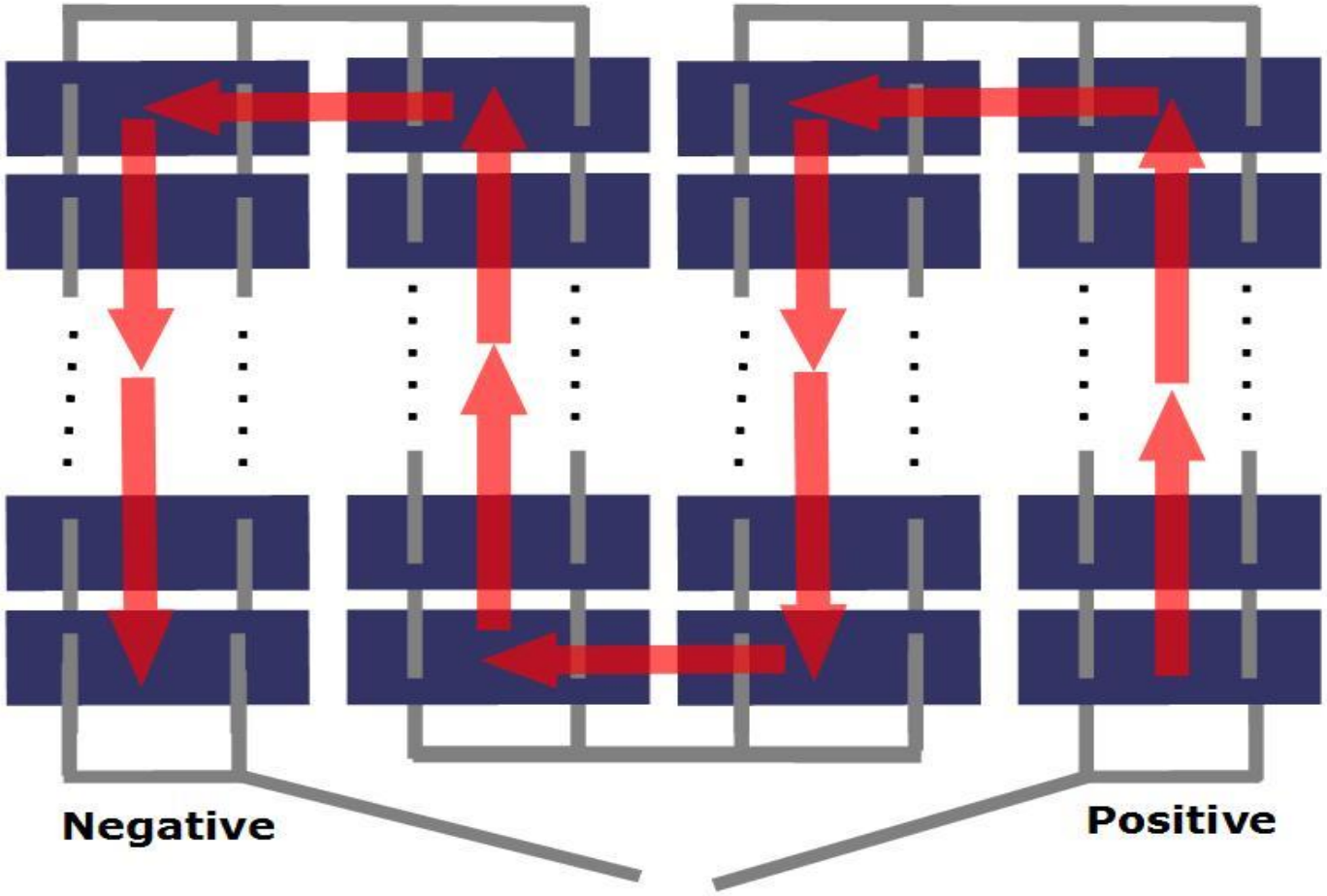

Solar panel
Meter
Utility grid
Inverter
Home

Series Connections

- Loads/sources wired in **series**
  - VOLTAGES ARE ADDITIVE
  - CURRENT IS EQUAL

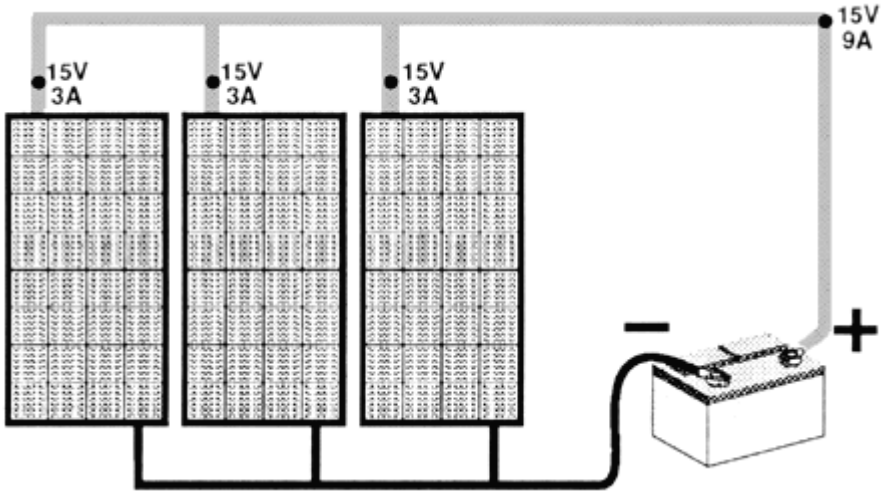


Panel Cell Connection



Parallel Connections

- Loads/sources wired in **parallel**:
  - VOLTAGE REMAINS CONSTANT
  - CURRENTS ARE ADDITIVE



Wiring Introduction

- Should wire in Parallel or Series?

Wire Components

- Conductor material = copper (most common)
- Insulation material = thermoplastic (most common)

- Wire exposed to sunlight must be classed as sunlight resistant

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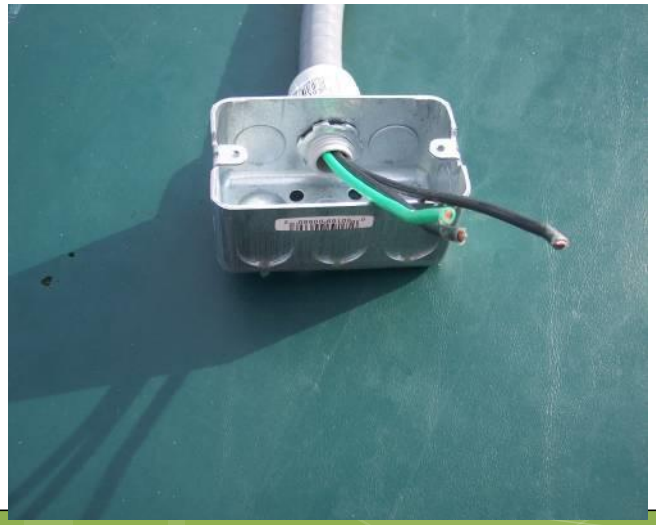
Color Coding of Wires

- Electrical wire insulation is color coded to designate its function and use

Alternating Current (AC) Wiring		Direct Current (DC) Wiring	
Color	***Application***	***Color***	***Application***
Black	Ungrounded Hot	Red (not NEC req.)	Positive
White	Grounded Conductor	White	Negative or Grounded Conductor
Green or Bare	Equipment Ground	Green or Bare	Equipment Ground
Red or any other color	Ungrounded Hot		

Cables and Conduit

- ***Cable:*** two or more insulated conductors having an overall covering
- ***Conduit:*** metal or plastic pipe that contains wires



Wire Size

- Wire size selection based on two criteria:
  - Ampacity
  - Voltage drop
- Ampacity - Current carrying ability of a wire
- Voltage drop: the loss of voltage due to a wire's resistance and length

Safety Considerations

- Unsafe Wiring
  - Splices outside the box
  - Currents in grounding conductors
  - Indoor rated cable used outdoors
  - Single conductor cable exposed
  - “Hot” fuses

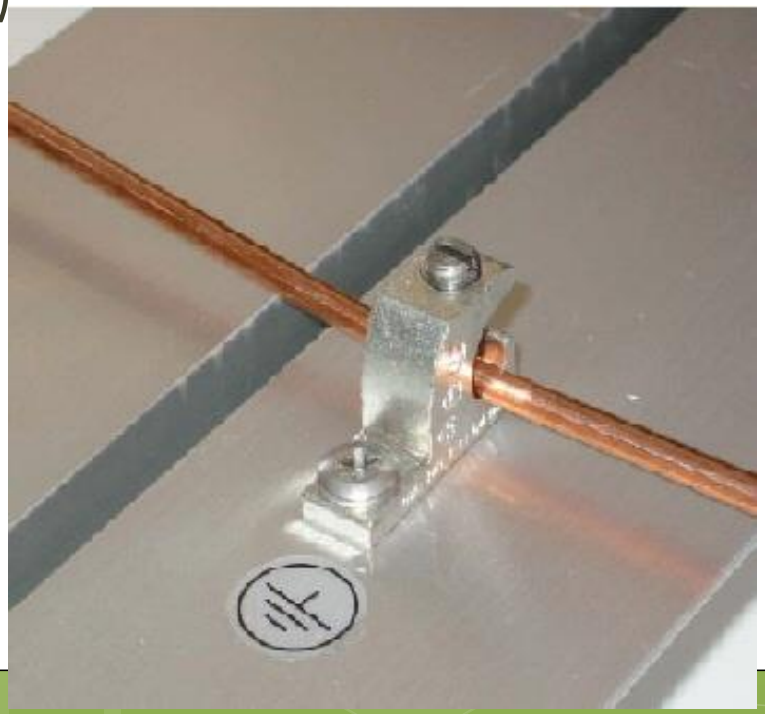
Safety Equipment

- Disconnects

- Overcurrent Protection

Grounding

- Provides a current path for surplus electricity to travel too (earth)



Solar Site & Mounting

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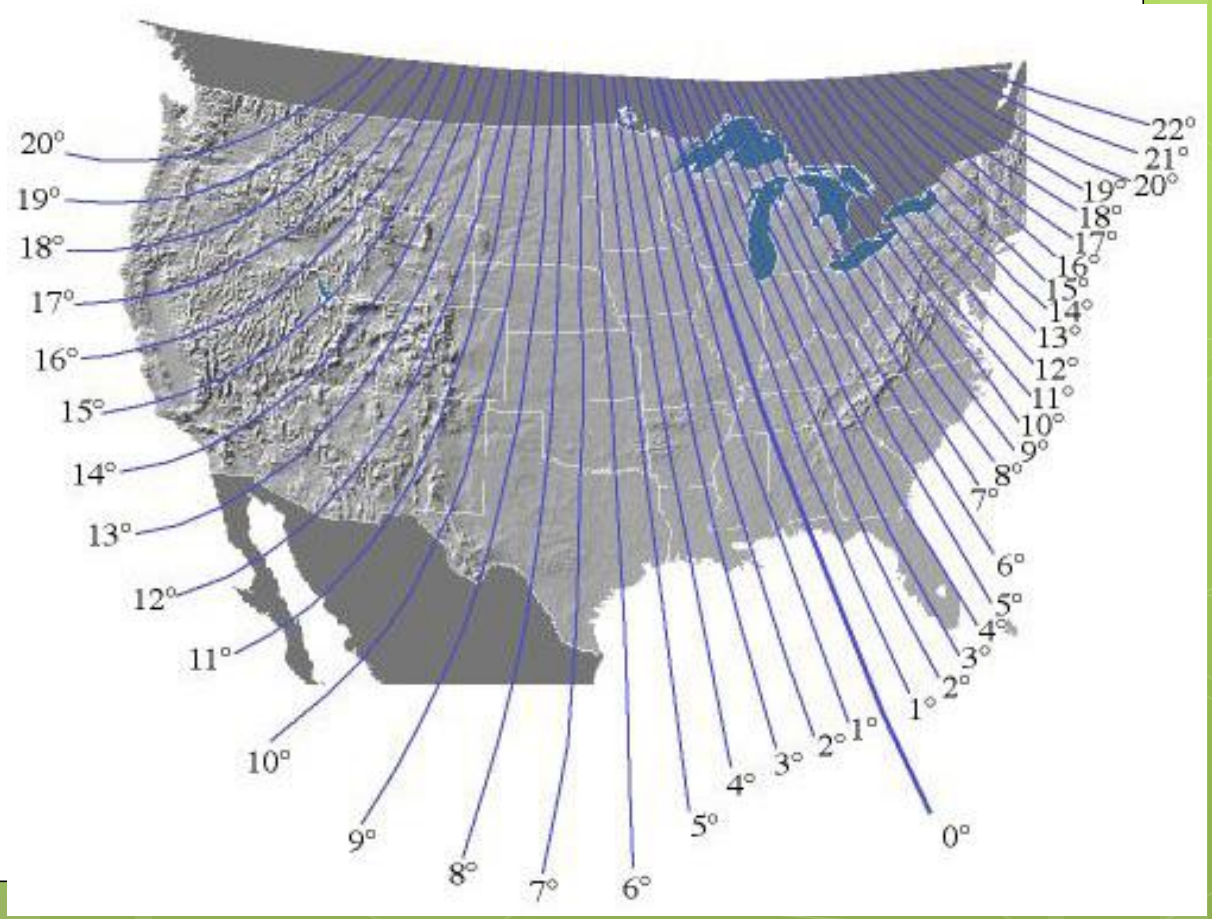
Part 6: Learning Objectives

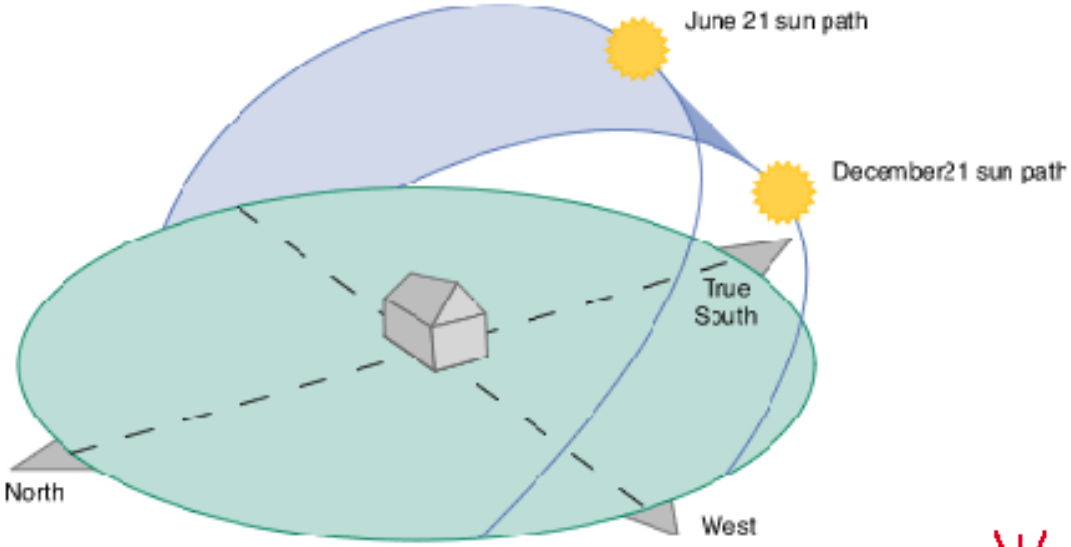
- Understand azimuth and altitude
- Describe proper orientation and tilt angle for solar collection
- Describe the concept of “solar window”
- Evaluate structural considerations
- Pros and cons of different mounting techniques

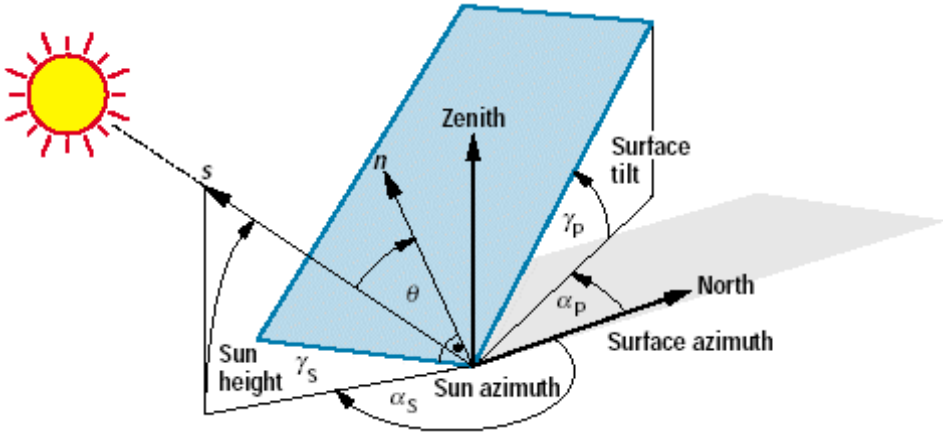
Site Selection – Panel Direction

- Face true south
- Correct for magnetic declination

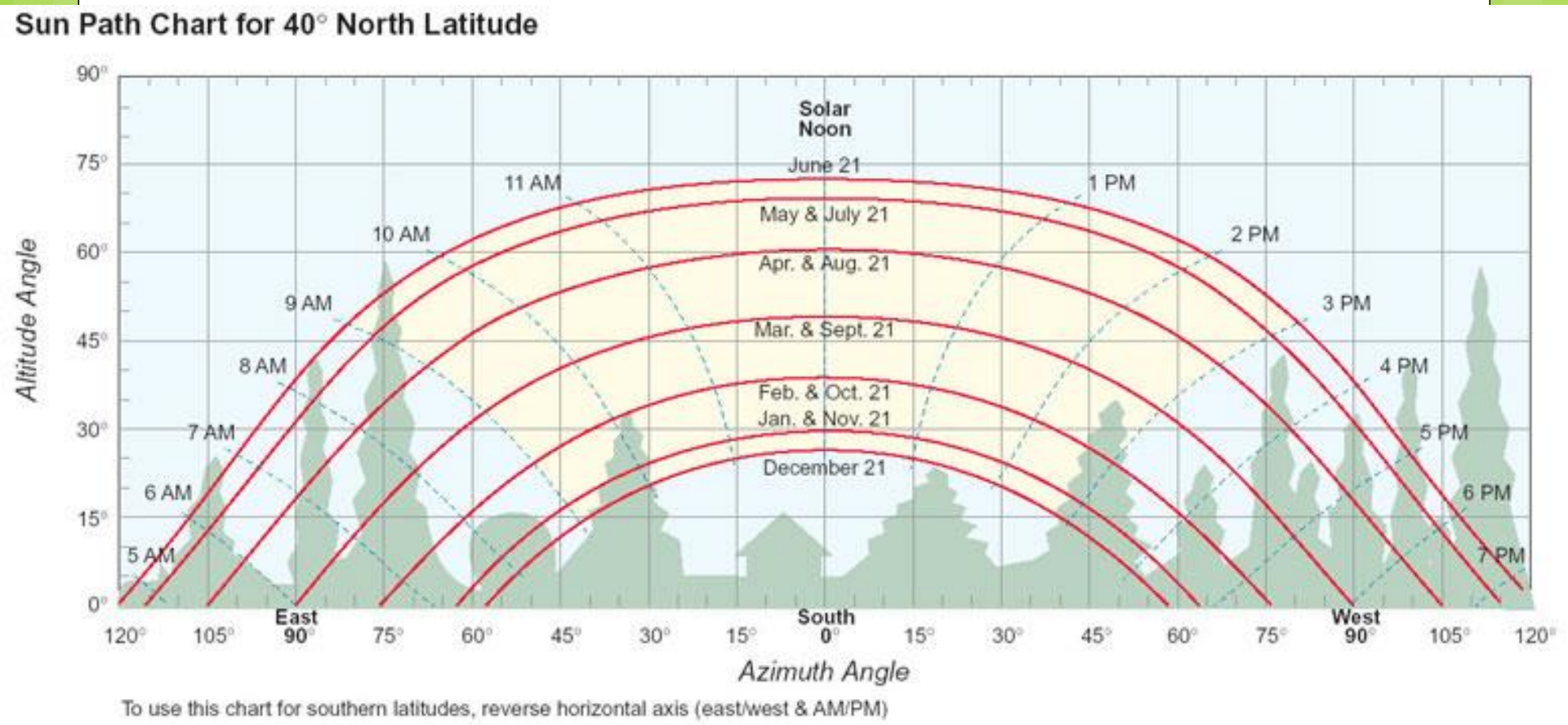


Altitude and Azimuth





Sun Chart for 40 degrees N Latitude

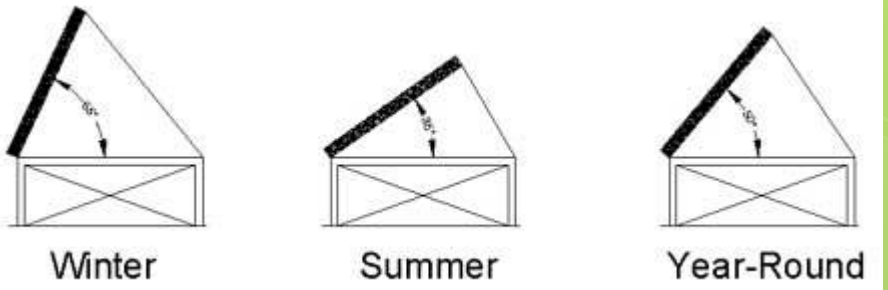


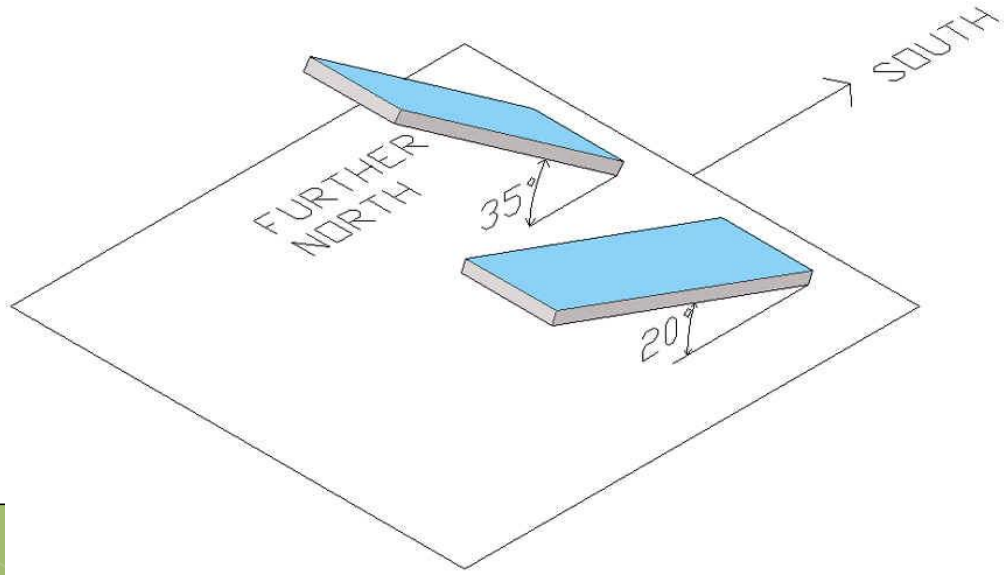
Solar Pathfinder

- An essential tool in finding a good site for solar energy is the Solar Pathfinder
- Provides daily, monthly, and yearly solar hours estimates

Site Selection – Tilt Angle

Max performance is achieved when panels are perpendicular to the sun's rays





Year round tilt = latitude
Winter + 15 lat.
Summer – 15 lat.

Solar Access

- Optimum Solar Window 9 am – 3 pm
- Array should have NO SHADING in this window (or longer if possible)

General Considerations

- Weather characteristics
  - Wind intensity
  - Estimated snowfall
- Site characteristics
  - Corrosive salt water
  - Animal interference
- Human factors
  - Vandalism
  - Theft protection
  - Aesthetics

General Considerations Continued

- Loads and time of use
- Distance from power conditioning equipment
- Accessibility for maintenance
- Zoning codes

Basic Mounting Op

- Fixed
  - Roof, ground, pole
- Integrated
- Tracking
  - Pole (active & passive)

Pole Mount Considerations

- Ask manufacturer for wind loading specification for your array
  - Pole size
  - Amount of concrete
  - Etc.
- Array can be in close proximity to the house, but doesn't require roof penetrations

Tracking Considerations

- Can increase system performance by:
  - 15% in winter months
  - 30% in summer months
- Adds additional costs to the array

Passive Vs. Active

Active:

- Linear actuator motors controlled by sensors follow the sun throughout the day

Passive Vs. Active

Passive:

- Have no motors, controls, or gears
- Use the changing weight of a gaseous refrigerant within a sealed frame member to track the sun

Roof Mount Considerations

- simple and cheap to install
- offer no flexibility in the orientation of your solar panel
- can only support small photovoltaic units.

Roof Mount Considerations

- Penetrate the roof as little as possible
- Weather proof all holes to prevent leaks
  - May require the aid of a professional roofer
- Re-roof before putting modules up
- Leave 4-6" airspace between roof and modules
- On sloped roofs, fasten mounts to rafters not decking

Building Integrated PV

Energy Efficiency

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Part 7: Learning Objectives

- Identify cost effective electrical load reduction strategies
- List problematic loads for PV systems
- Describe penalties of PV system components
- Explain phantom loads
- Evaluate types of lighting; efficiency comparison

1. Conservation

2. Efficiency

3. Renewable Energy

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Practical Efficiency Recommendations

- For every Rs1 spent on energy efficiency, you save Rs3-Rs5 on system cost
- Start with your load use:
  - Do it efficiently
  - Do with less
  - Do without
  - Do it while the sun shines

Improving Energy Efficiency in the Home

- Space Heating:
  - Insulation
  - Passive solar design
  - Wood stoves
  - Propane
  - Solar hot water
  - Radiant Floor/ baseboard
  - Efficient windows
- Domestic hot water heating
  - Solar thermal
  - Propane/natural gas
  - On demand hot water

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Improving Energy Efficiency in the Home

- Washing machines
  - Energy efficient front loading machine
- Cooling
  - Ceiling fans
  - Window shades
  - Insulation
  - Trees
  - Reflective attic cover
  - Attic fan

Lighting Efficiency

- Factors effecting light efficiency
  - Type of light
  - Positioning of lights
  - Fixture design
  - Color of ceilings and walls

Incandescent Lamps

- Advantages
  - Most common
  - Least expensive
  - Pleasing light
- Disadvantages
  - Low efficiency
  - Short life ~ 750 hours

Electricity is conducted through a filament which resists the flow of electricity, heats up, and glows

Efficiency increases as lamp wattage increases

FROM THE POWER PLANT TO YOUR HOME INCANDESCENT BULBS ARE LESS THAN 2% EFFICIENT

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Fluorescent Bulbs

- Less wattage, same amount of lumens
- Longer life (~10,000 hours)
- May have difficulty starting in cold environments
- Not good for lights that are repeatedly turned on and off
- Contain a small amount of mercury

Pushing a Bright Idea

Wal-Mart is promoting consumer use of compact fluorescent light bulbs over incandescents. Here's how the bulbs compare.

	INCANDESCENT	FLUORESCENT
Energy used (watts)	60	13
Light output (lumens)	850	800
Average cost (dollars)	$0.25 to 0.60	$2 to 4
Annual savings (dollars)	$0	$8
Annual carbon savings (pounds)	0	roughly 100
Life (hours)	1,000	5,000 to 10,000
Mercury in the bulb (miligrams)	none	4
Mercury emissions (miligrams)	10	2.4
Number of bulbs sold annually*	1.5 to 2 billion	130 to 150 million

*Includes all wattages

Sources: Environmental Protection Agency; Environmental Defense; itron; Philips — The New York Times

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Light Emitting Diode (LED) Lights

- Advantages
  - Extremely efficient
  - Long life (100,000 hours)
  - Rugged
  - No radio frequency interference
- Disadvantages
  - Expensive (although prices are decreasing steadily)
  - A relatively new technology

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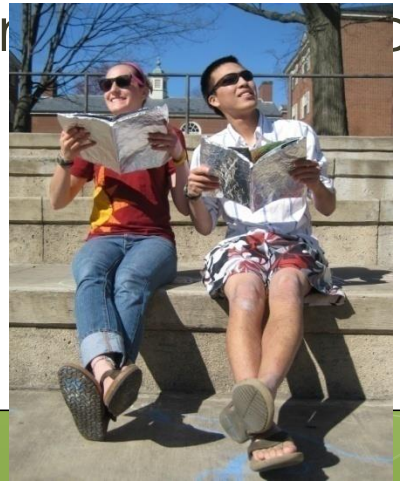
Ready for a field tour?

- Questions?

  If you are interested in anything you have seen today and would like to get involved, please contact any member of the Solar Scholars team:

  Barbara Summers or Brian Chiu
  (bls030@buckn[illegible]c021@bucknell.edu)



Solar Scholars Website

http://www.bucknell.edu/x20303.xml

The END

- Thank you for participating in this lecture series
- Now lets go out into the field and take a look at the systems that we have already installed.

Batteries

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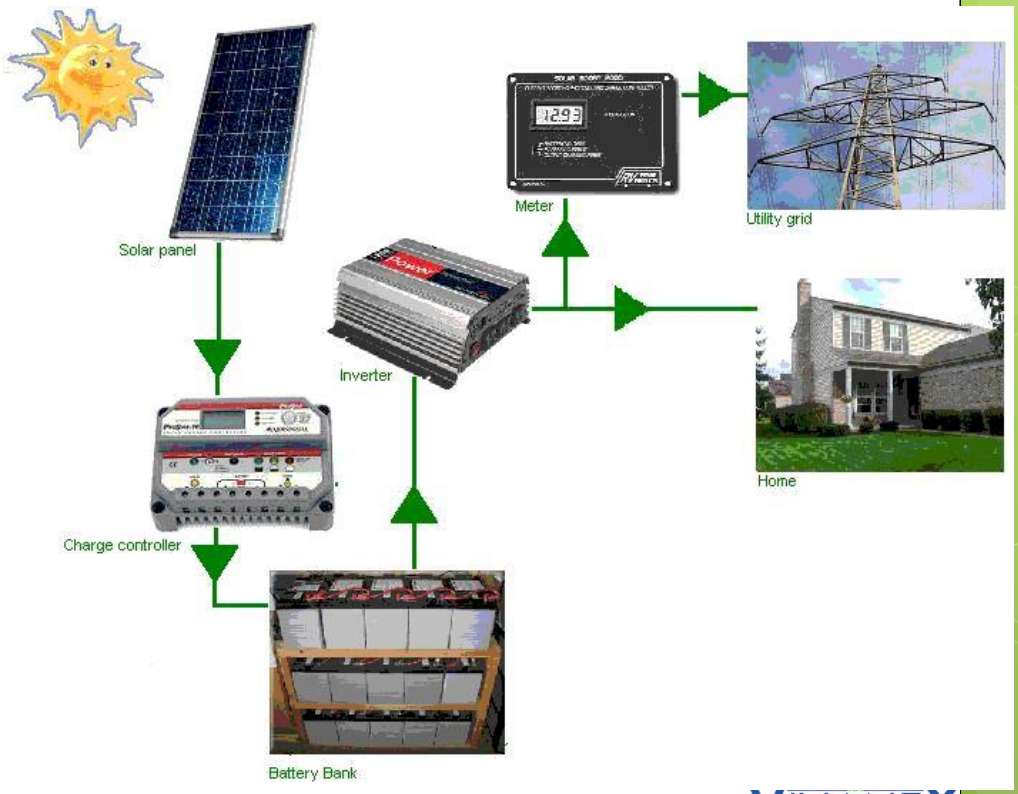
Grid-Tied System

- Advantages
  - Low: Easy to install (less components)
  - Grid can supply power
- Disadvantages
  - No power when grid goes down



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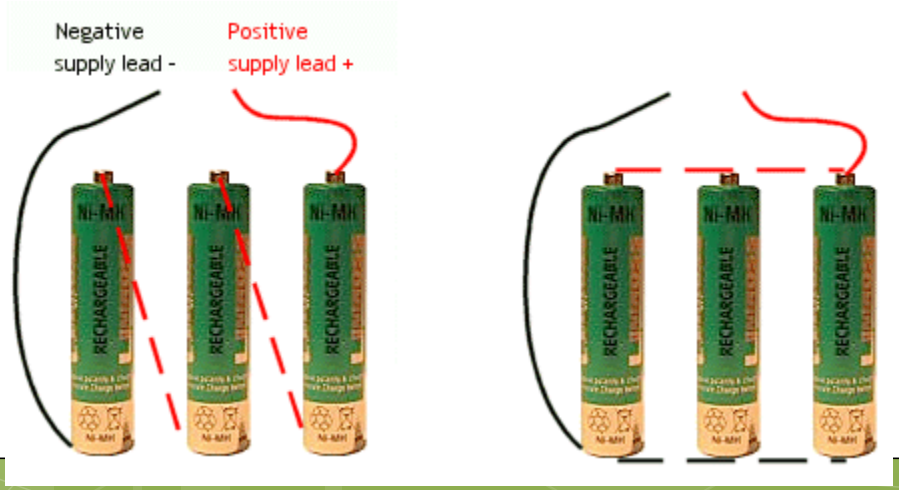
Part 4: Learning Objectives

- Battery basics
- Battery functions
- Types of batteries
- Charging/discharging
- Depth of discharge
- Battery safety

Batteries in Series and Parallel

- Series connections
  - Builds voltage
- Parallel connections
  - Builds amp-hour capacity



Battery Basics

The Terms:

- **Battery**
  - A device that stores electrical energy (chemical energy to electrical energy and vice-versa)
- **Capacity**
  - Amount of electrical energy the battery will contain
- **State of Charge (SOC)**
  - Available battery capacity
- **Depth of Discharge (DOD)**
  - Energy taken out of the battery
- **Efficiency**
  - Energy out/Energy in (typically 80-85%)

Functions of a Battery

- Storage for the night
- Storage during cloudy weather
- Portable power
- Surge for starting motors

****Due to the expense and inherit inefficiencies of batteries it is recommended that they only be used when absolutely necessary (i.e. in remote locations or as battery backup for grid-tied applications if power failures are common/lengthy)**

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Batteries: The Details

Types:

- Primary (single use)
- Secondary (recharged)
- Shallow Cycle (20% DOD)
- Deep Cycle (50-80% DOD)

Charging/Discharging:

- Unless lead-acid batteries are charged up to 100%, they will loose capacity over time
- Batteries should be equalized on a regular basis

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Battery Capacity

Capacity:

- Amps x Hours = Amp-hours (Ah)

100 Amp-hours	=	100 amps for 1 hour 1 amp for 100 hours 20 amps for 5 hours

- Capacity changes with Discharge Rate
- The higher the discharge rate the lower the capacity and vice versa
- The higher the temperature the higher the percent of rated capacity

Rate of Charge or Discharge

Rate = C/T

C = Battery's rated capacity (Amp-hours)
T = The cycle time period (hours)

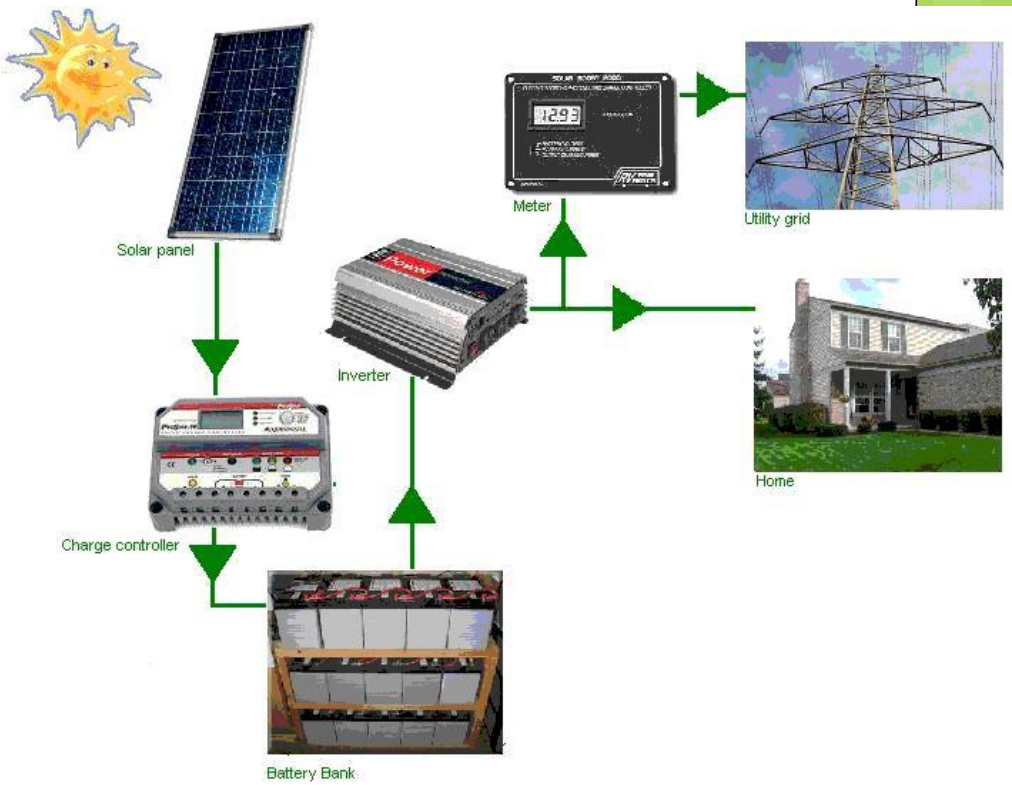
Maximum recommend charge/discharge rate = C/3 to C/5

Battery Safety

- Batteries are EXTREMELY DANGEROUS; handle with care!
  - Keep batteries out of living space, and vent battery box to the outside
  - Use a spill containment vessel
  - Don't mix batteries (different types or old with new)
  - Always disconnect batteries, and make sure tools have insulated handles to prevent short circuiting

Grid-Tied System
(With Batteries)

- Complexity
  - High: Due to the addition of batteries
- Grid Interaction
  - Grid still supplements power
  - When grid goes down batteries supply power to loads (aka battery backup)



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Controllers & Inverters

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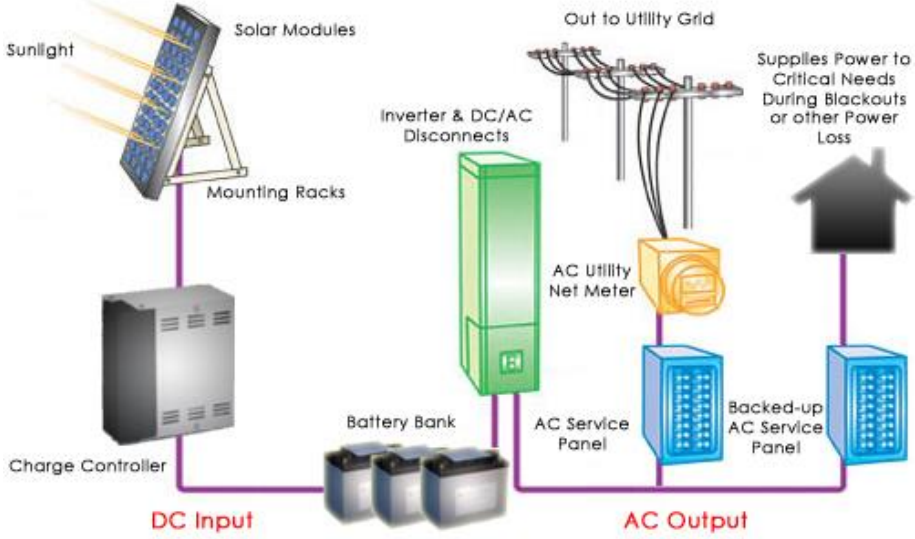
Grid-Tied System

- Advantages
  - Low: Easy to install (less components)
  - Grid can supply power
- Disadvantages
  - No power when grid goes down



Part 5: Learning Objectives

- Controller basics
- Controller features
- Inverter basics
- Specifying an inverter

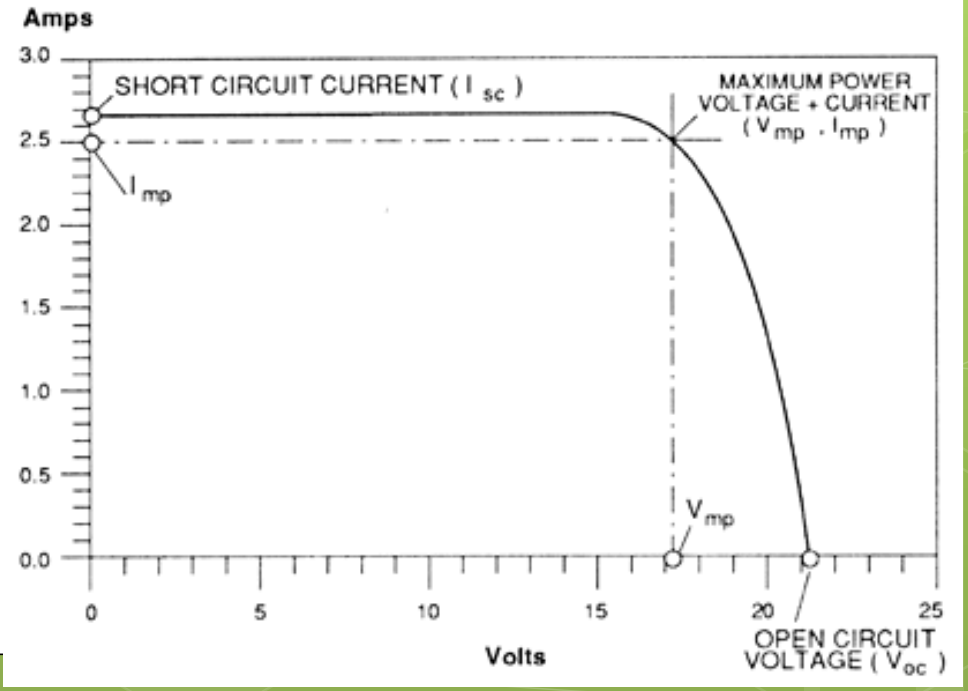
Controller Basics

Function:

- To protect batteries from being overcharged

Features:

- Maximum Power Point Tracking
  - Tracks the peak power point of the array (can improve power production by 20%)!!



Additional Controller Features

- Voltage Stepdown Controller: compensates for differing voltages between array and batteries (ex. 48V array charging 12V battery)
  - By using a higher voltage array, smaller wire can be used from the array to the batteries
- Temperature Compensation: adjusts the charging of batteries according to ambient temperature

Other Controller Considerations

- When specifying a controller you must consider:
  - DC input and output voltage
  - Input and output current
  - Any optional features you need
- Controller redundancy: On a stand-alone system it might be desirable to have more then one controller pe t of a failure

Inverter Basics

Function:

- An electronic device used to convert direct current (DC) electricity into alternating current (AC) electricity

Drawbacks:

- Efficiency penalty
- Complexity (read: a component which can fail)
- Cost!!

Specifying an Inverter

- What type of system are you designing?
  - Stand-alone
  - Stand-alone with back-up source (generator)
  - Grid-Tied (without batteries)
  - Grid-Tied (with battery back-up)
- Specifics:
  - AC Output (watts)
  - Input voltage (based on modules and wiring
  - Output voltage (120V/240V residential)
  - Input current (based on modules and wiring
  - Surge Capacity
  - Efficiency
  - Weather protection
  - Metering/programming