Solar Power

- Single cell
- Photovoltaic (PV) Cell
- Single panel
- Solar panel field
Nellis Airforce Base, in southern Nevada
● Built in April 2007 by SunPower Corporation in San Jose
● Cost $100 million

Capacity: 14 MW or 30 GWh/yr
● 72,000 solar panels on 140 acres land
● Supplies 30% of power requirement by the Base with 12,000 workers and 7,215 residents.
Agua Caliente in Yuma county in Arizona, produces 250 MW enough to provide power for 100,000 houses. Expected to be completed in 2014 producing 400 MW on 2400 acres of land, 5.2 million PV modules.
Solar Energy

• Every hour, enough sunlight energy reaches Earth to meet the world’s energy demand for a whole year.

• The amount of energy from the Sun that reaches Earth annually is $4 \times 10^{18}$ Joules.

• The amount of energy consumed annually by the world's population is about $3 \times 10^{14}$ J.
A major drawback of most renewable energy sources is the high cost. To spur a huge rise in use, prices must come down and efficiencies must go up (better technology).
Factors Affecting Efficiency

• Sunlight consists of a spectrum of wavelengths – semiconductor materials cannot respond to the full spectrum

• As much as 30% of light is reflected from the surface of the cell (only absorbed light can produce electricity)

• Impurities can cause the charge to “recombine” and therefore not generate electricity
Other Factors Affecting Efficiency

- Angle of incidence of the sun
- Cloud cover
- Shading (even a small amount of shading reduces output dramatically)
- Dirt, snow, or other impurities on cell surface
- Efficiency goes down as the cell gets hotter
Atoms

An atom is composed of 3 particles:

- **Protons** - carrying positive charge
- **Neutrons** - charge neutral
- **Electrons** - carrying negative charge

- Nucleus consists of Protons and neutrons and electrons orbit around the nucleus
- The number of protons and electrons are the same, therefore an atom, as a whole, is electrical charge neutral.
- Different materials have different number of particles in their atoms.
Atoms

Each atom has a specific number of electrons, protons and neutrons. But no matter how many particles an atom has, the number of electrons usually needs to be the same as the number of protons. If the numbers are the same, the atom is called balanced, and it is very stable.

So, if an atom had six protons, it should also have six electrons. The element with six protons and six electrons is called carbon. Carbon is found in abundance in the sun, stars, comets, atmospheres of most planets, and the food we eat. Coal is made of carbon; so are diamonds.
Atoms

• In some materials, atoms have loosely attached electrons. An atom that loses electrons has more protons than electrons and is positively charged. An atom that gains electrons has more negative particles and is negatively charged. A "charged" atom is called an "ion."

• Electrons can be made to move from one atom to another. When those electrons move between the atoms, a current of electricity is created. The electrons move from one atom to another in a "flow." One electron is attached and another electron is lost.
Insulators

Insulators are materials that hold their electrons very tightly (high bonding force). Electrons do not move through them very well.

Rubber, plastic, cloth and glass are good insulators and have very high resistance.
Conductors & Insulators

Conductors

Other materials have some *loosely held electrons*, which move through them very easily. These are called *conductors*.

Most metals – like copper, aluminum or steel – are good conductors.
**Electric Current**

- Electric current is the flow of **positive charge**. 1 Amp = 1 Coulomb per second.
- Electric current is an effect of the flow of free electrons which carries **negative charge**. (6.28 x $10^{18}$ electrons = -1 Coulomb).
- Positive charge flow (current) and negative charge flow (electron flow) are the same in magnitude but in the opposite direction.
- By convention, **current flow** is used in analyzing circuits. **Electron flow** is used ONLY for describing the physical behavior of electric conduction of materials.
Clicker Question

Q1. What type of electric charge does an atom carry?

(a) Positive charge
(b) Negative charge
(c) Neutral
(d) Radiation charge
(e) Magnetic charge
Q2. What type of electric charge does the nucleus of an atom carry?

(a) Positive charge
(b) Negative charge
(c) Neutral
(d) Radiation
(e) Magnetic
**Silicon atom** has 14 electrons and 14 protons.

The outer 4 electrons, together with the 4 from their adjacent atoms, form “**octets**” which is a stable structure. Electrons don’t “wandering off” (i.e., free) from this structure.
Octet structure
(Only outer orbit electrons are shown)
When sunlight strikes a piece of Silicon, however, the solar energy knocks and frees electrons from their atom structure (the octets structure)
For simplicity, we only show the charge of free electrons (-1) and the corresponding positive charges (14-13= +1) at the nucleus.

The freed electrons randomly move within the material. This random motion of charge cannot be utilized for power generation. In order to utilize the energy from the sun, this flow of charges must be directed in one direction.
**N-type (Negative Type) Semiconductor**

A small amount of impurity (doping) such as Phosphorus, arsenic, or antimony is mixed into a Silicon base and this forms an N-type material. Phosphorus has 5 outer orbit electrons. Therefore, when bonded with Silicon, there is one electron extra to form the stable octet configuration. This extra electron is loosely bonded. These loosely bonded electron helps with conducting current. The conductivity is not nearly as good as a true conductor. That’s why it is called a “semiconductor”.

![Diagram of N-Type Semiconductor](image)
**P-type (Positive Type) Semiconductor**

A small amount of impurity such as boron, aluminum or gallium is mixed into a Silicon base. Boron has 3 outer orbit electrons. Therefore, when bonded with Silicon, it is **one electron short** to form the stable octet configuration. This type materials can, on the other hand, easily accept one electron. For simplicity, this characteristic of ‘easily accepting electron’ is represented by a “**hole**” with a **positive charge** and a corresponding negative charge at the nucleus.
Silicon has 4 valence electrons: [Ne]3s^23p^2

- Silicon
- Electron
- Phosphorus
- Boron

Loosely bonded electron

Hole

Array of Si atoms  n-type semiconductor  p-type semiconductor
• Although there are free electrons and holes in N-type and P-type materials, they are charge neutral.

• **N-type materials** conduct electric current (supports movement of charge) by the free electrons — just like metal but with fewer free electrons than that in metal.

• **P-type materials** conduct electric current (supports movement of charge) by electric “holes”. When electrons jump from hole to hole in one direction, the holes appear moving in the opposition direction. Similar to the situation when you turn a filled water bottle upside down; as the water moves downward (electrons), the bubbles (holes) moves up.
Interesting things happen when you put an N-type material in contact with a P-type material.

Before making the contact:

- **P-type (neutral)**

- **N-type (neutral)**
In the boundary layer, the free electrons in the N-type materials combine with the holes in the P-type. Consequently, the P-type side of the boundary layer is negatively charged and N-type side is positively charged.

Negative charge in P-type material prevents the free electrons in the rest of the N-type material to continue to migrate into the P-type. (Negative charge repels negative charged free electrons.)

The boundary layer is called PN-junction or depletion region.
n-type and p-type materials brought together.

Diffusion establishes “built-in” electric field.
When sunlight strikes atoms in the P-N Junction and knocks out more electrons (and creates corresponding holes), the free electrons are expelled by the negative charge on the P-type side and hence move towards the N-type side.
If a load is connected across the cell, electric current is formed and the energy is transmitted to the load.

![Diagram showing P-type and N-type junctions](http://www.youtube.com/watch?v=xLGOagKiXqg)
Summary

Sunlight irradiation causes electrons to separate from their atoms.

Electron holes and electrons begin to move toward the P-N junction.

When the electron holes and electrons come together at the P-N junction, voltage is generated. When lead wires are connected, electricity is generated.
Clicker Question

Q3. The purpose of the PN junction in a solar cell is

(a) to generate free electrons
(b) to generate holes
(c) to isolate P and N materials
(d) to accelerate the electrons flow
(e) to direct the direction of electron flow
Q4. P-type material conducts current by

(a) Metallic element
(b) Free electron
(c) Electric ‘holes’
(d) Conductor
(e) Insulator
Solar panels capture sunlight and convert it to electricity using photovoltaic (PV) cells like the one illustrated above. The name implies photo meaning "light" and voltaic meaning "electricity"
Major Components in a typical PV installation

- **PV Panels** – solar cells
- **Charge Controller**
  1. Match the panel voltage and battery voltage
  2. Extract maximum power from the panel
  3. Prevent over-charge
- **Battery** - hold energy
- **Inverter** - convert DC to 60Hz AC for compatibility with the power line voltage.