

Photovoltaic

1839 - French physicist A. E. Becquerel first recognized the photovoltaic effect.

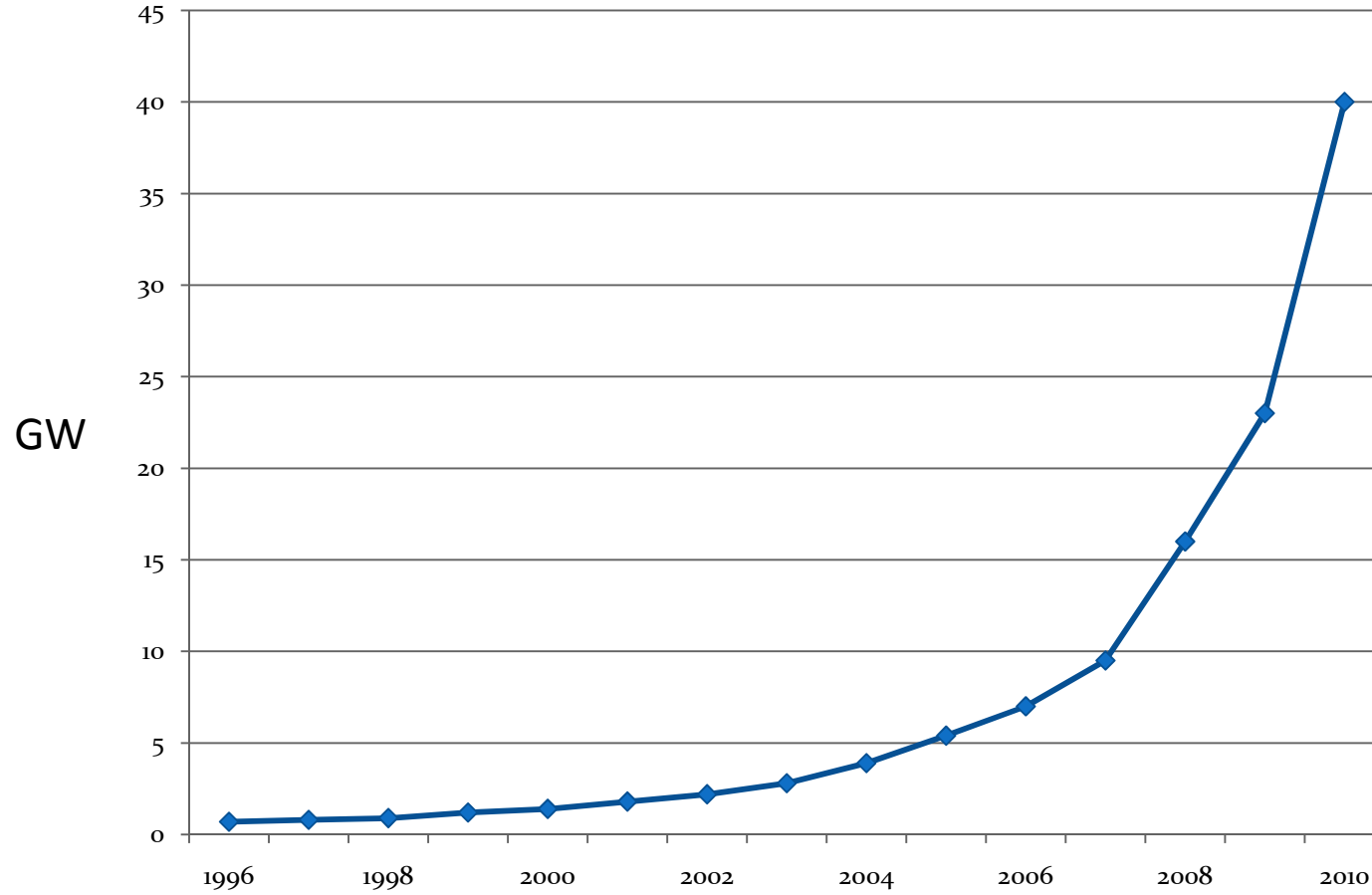
**Photo+voltaic = convert light to electricity**

1883 - first solar cell built, by Charles Fritts, coated semiconductor selenium with an extremely thin layer of gold to form the junctions.

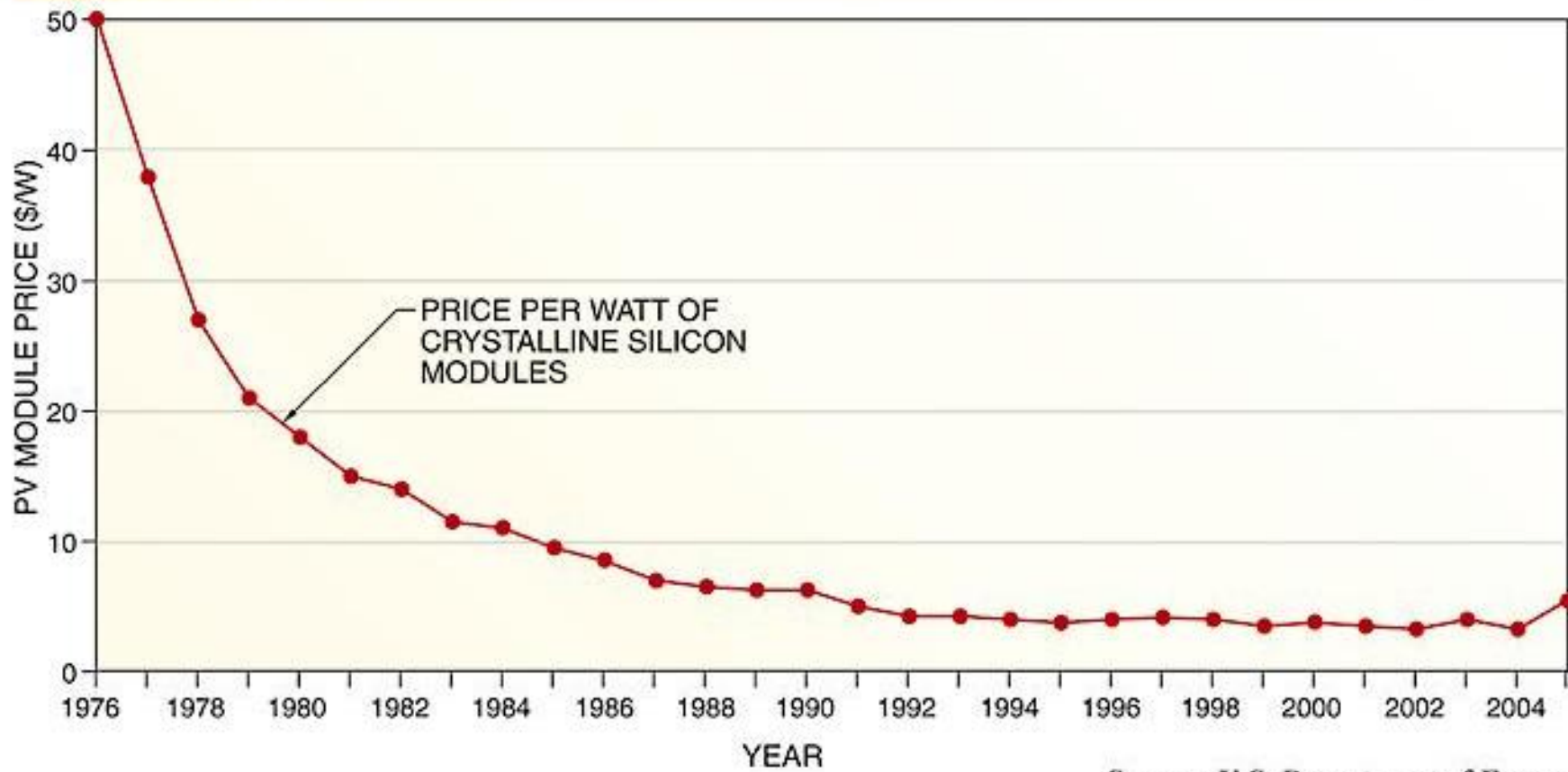
**1954** - Bell Laboratories, experimenting with semiconductors, accidentally found that silicon doped with certain impurities was very sensitive to light. Daryl Chapin, Calvin Fuller and Gerald Pearson, invented the first practical device for converting sunlight into useful electrical power. Resulted in the production of the first practical solar cells with a **sunlight energy conversion efficiency of around 6%.**

1958 - First spacecraft to use solar panels was US satellite Vanguard 1

# World PV Production Growth

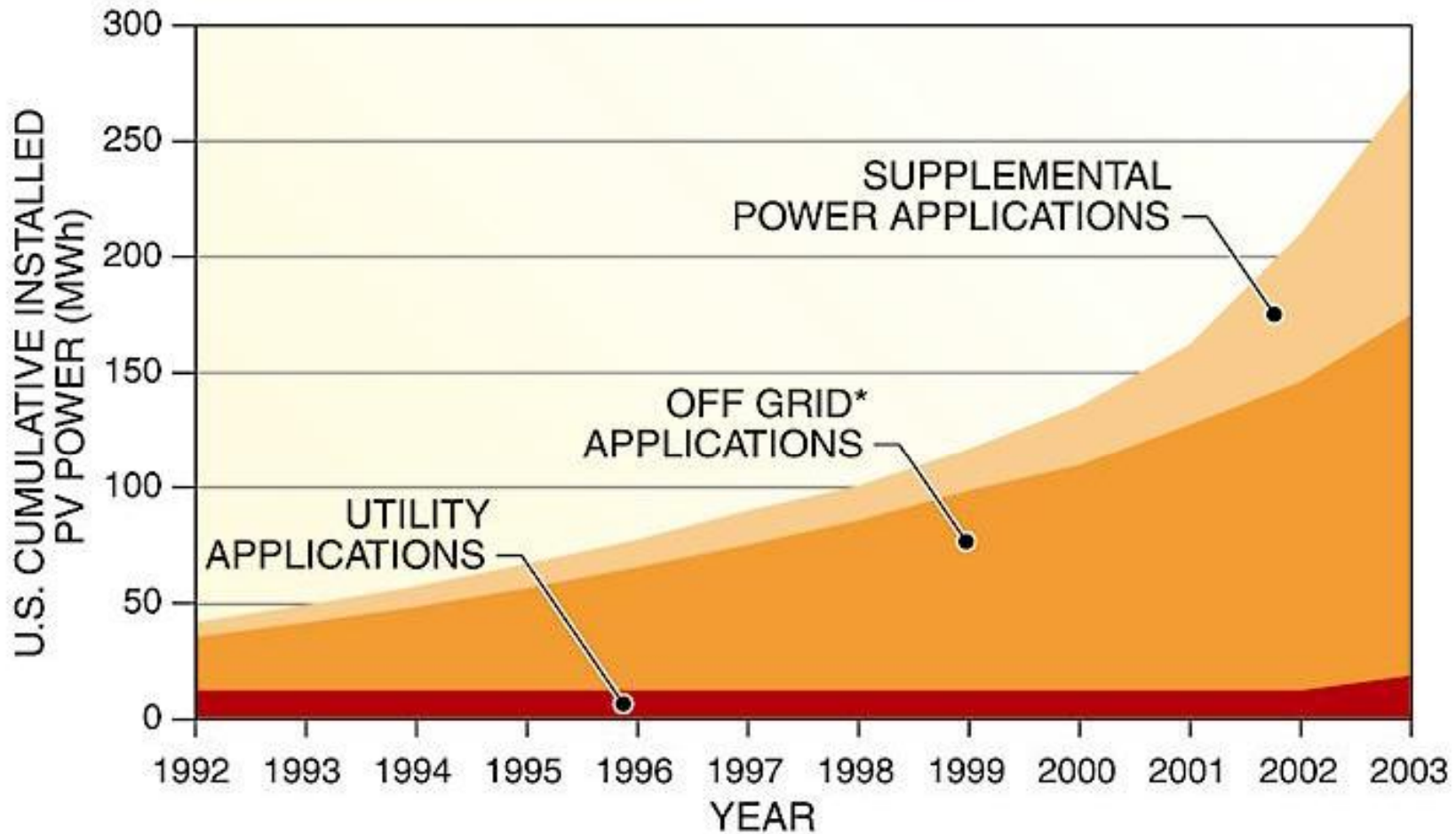


## Module Prices



Source: U.S. Department of Energy

## PV System Applications



*Source: International Energy Agency*

\* includes portable and remote applications

# Roof top PV potential in INDIA

According 2011 Census

India is having – 330 million houses.

– 166 million electrified houses.

– 76 million houses uses kerosene for lighting.

– 1.08 million houses are using solar for lighting.

– 140 million houses with proper roof (Concrete or Asbestos / metal sheet).

– 130 million houses are having > 2 rooms.

- Average house can accommodate 1-3 kWp of solar PV system.

- The large commercial roofs can accommodate larger capacities.

- As a conservative estimate, about 25000 MW capacity can be accommodated on roofs of buildings having > 2 rooms alone if we consider 20% roofs.

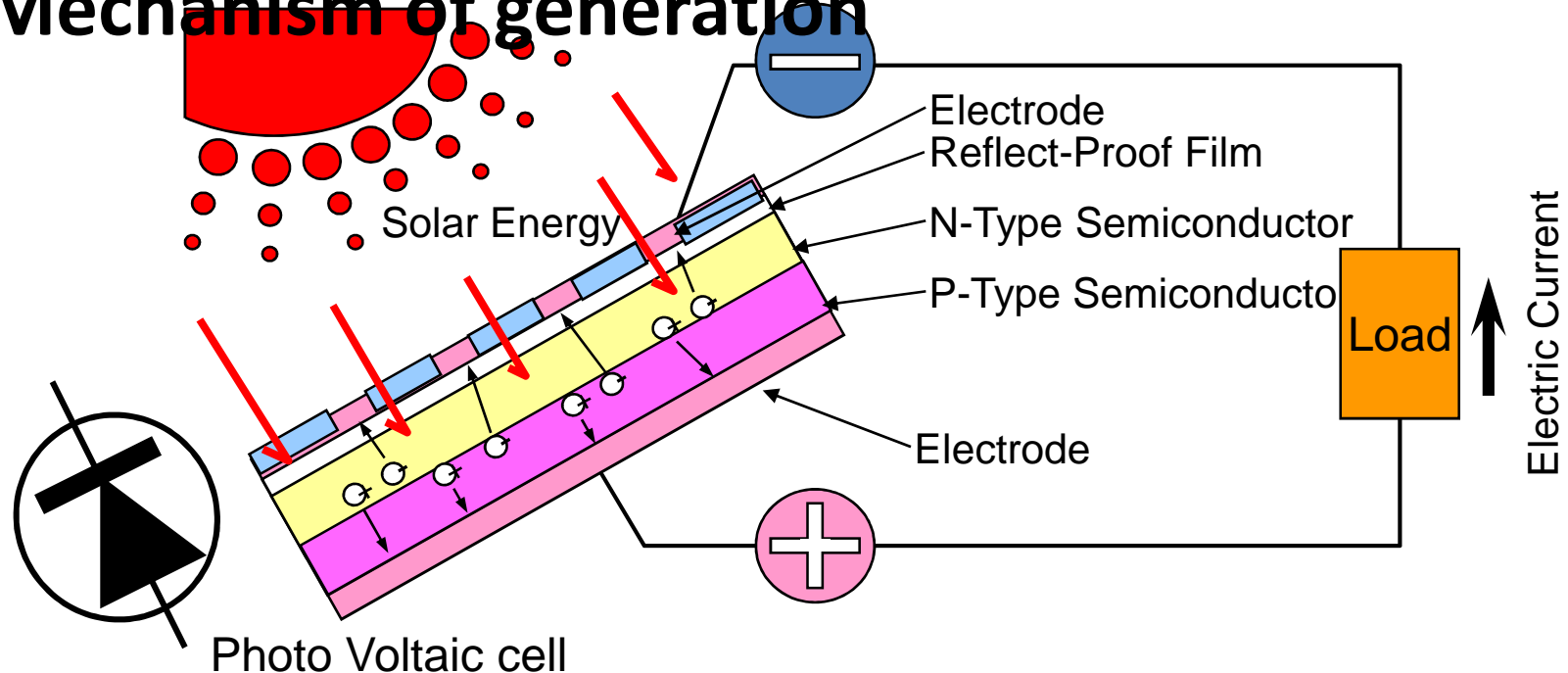
- Photovoltaics (PV) or solar cells as they are often referred to, are semiconductor devices that convert sunlight into direct current (DC) electricity.
- Groups of PV cells are electrically configured into modules and arrays, which can be used to charge batteries, operate motors, and to power any number of electrical loads.
- With the appropriate power conversion equipment, PV systems can produce alternating current (AC) compatible with any conventional appliances, and operate in parallel with and interconnected to the utility grid.

# Mechanism of generation

The solar cell is composed of a P-type semiconductor and an N-type semiconductor. Solar light hitting the cell produces two types of electrons, negatively and positively charged electrons in the semiconductors.

Negatively charged (-) electrons gather around the N-type semiconductor while positively charged (+) electrons gather around the P-type semiconductor. When you connect loads such as a light bulb, electric current flows between the two electrodes.

- **Mechanism of generation**

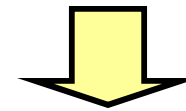
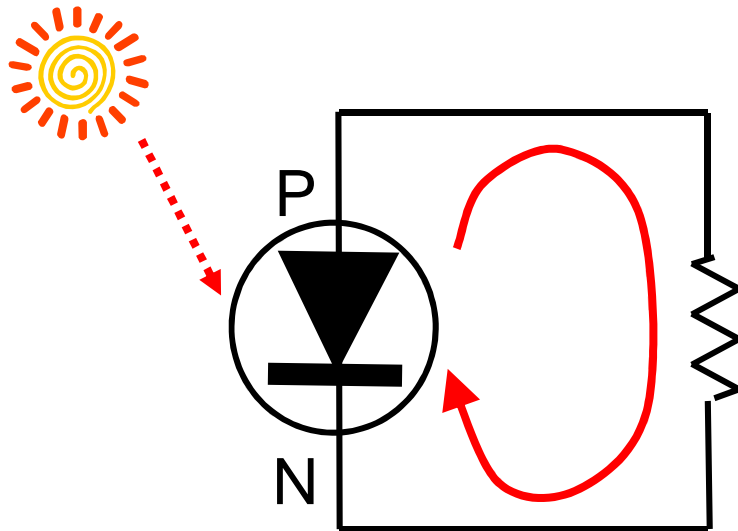




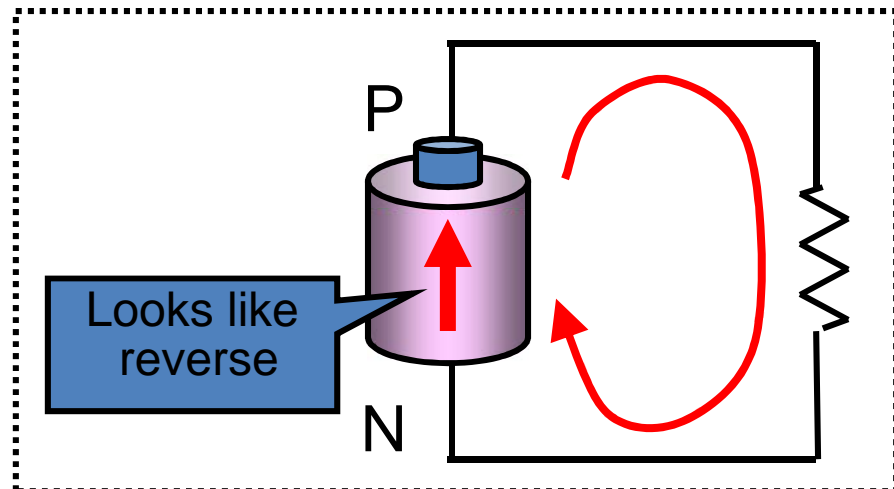
# Mechanism of generation

- **Direction of current inside PV cell**

- Inside current of PV cell looks like “Reverse direction.” Why?

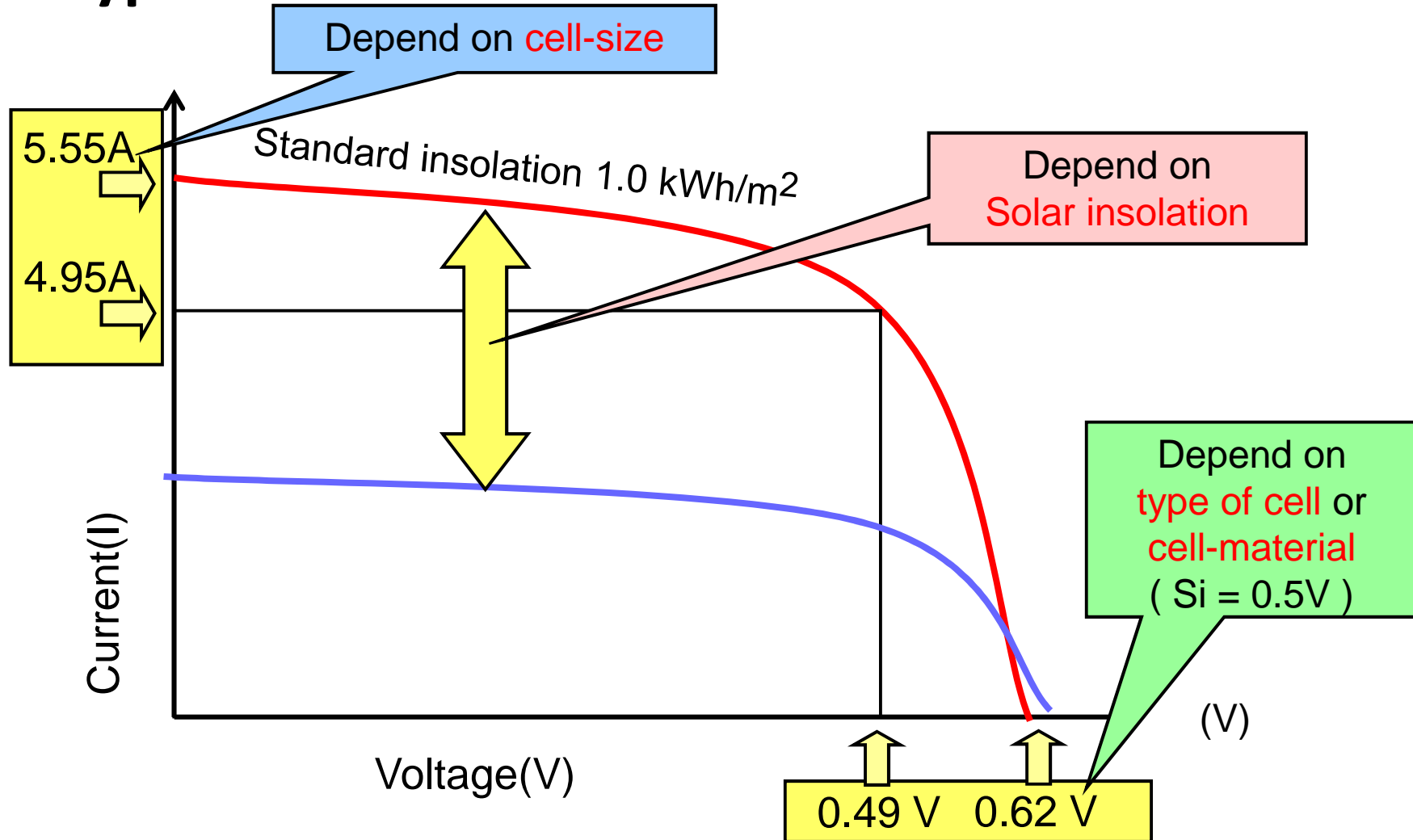


- By Solar Energy, current is pumped up from N-pole to P-pole.
- In generation, current appears reverse. It is the same as for battery.



# Mechanism of generation

- **Typical I-V Curve**



# Photovoltaic power

## Photovoltaic cells: Specifications:

### Efficiency

$$\eta = \frac{P_{out}}{P_{in}} = \frac{VI}{G_t A}$$

$\eta$  = efficiency

$P_{out}$  = Power out (W)

$P_{in}$  = Power in (W)

$V$  = Voltage (V)

$I$  = Current (A)

$G_t$  = Irradiance on the surface (W)

$A$  = Cell area (m<sup>2</sup>)

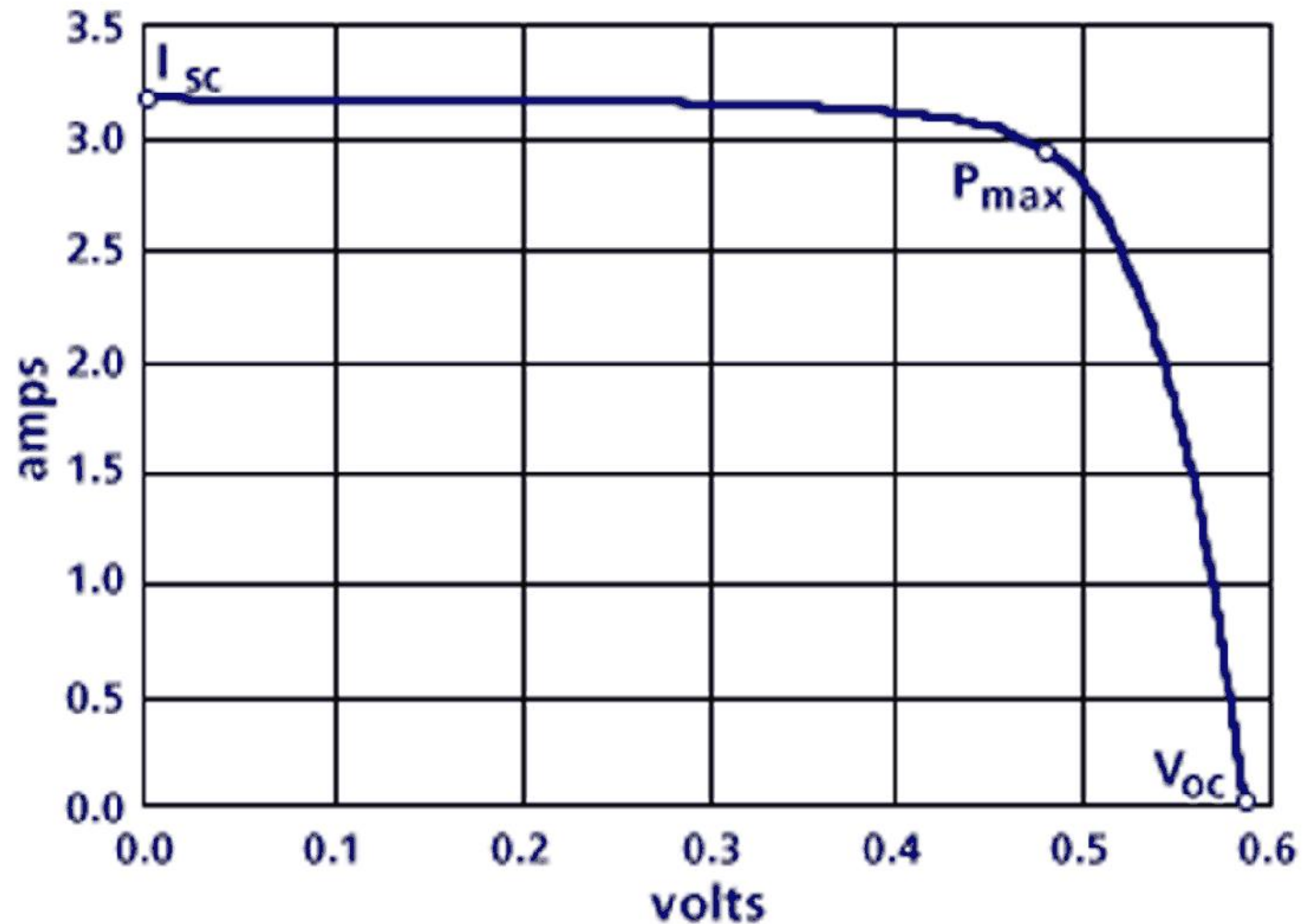
# Photovoltaic power

## Photovoltaic cells: Specifications: measures

- Peak power ( $P_{max}$ )
- Open circuit voltage ( $V_{oc}$ )
- Max power voltage ( $V_{mp}$ )
- Short circuit current ( $I_{sc}$ )
- Max power current ( $I_{mp}$ )

# Photovoltaic power

## Photovoltaic cells: Specifications:



# Photovoltaic power

## Photovoltaic cells: Specifications:

### IV curve: Fill factor

$$FF = \frac{P_{\max}}{V_{oc} I_{sc}}$$

$FF$  = Fill factor

$P_{\max}$  = Maximum power out (W)

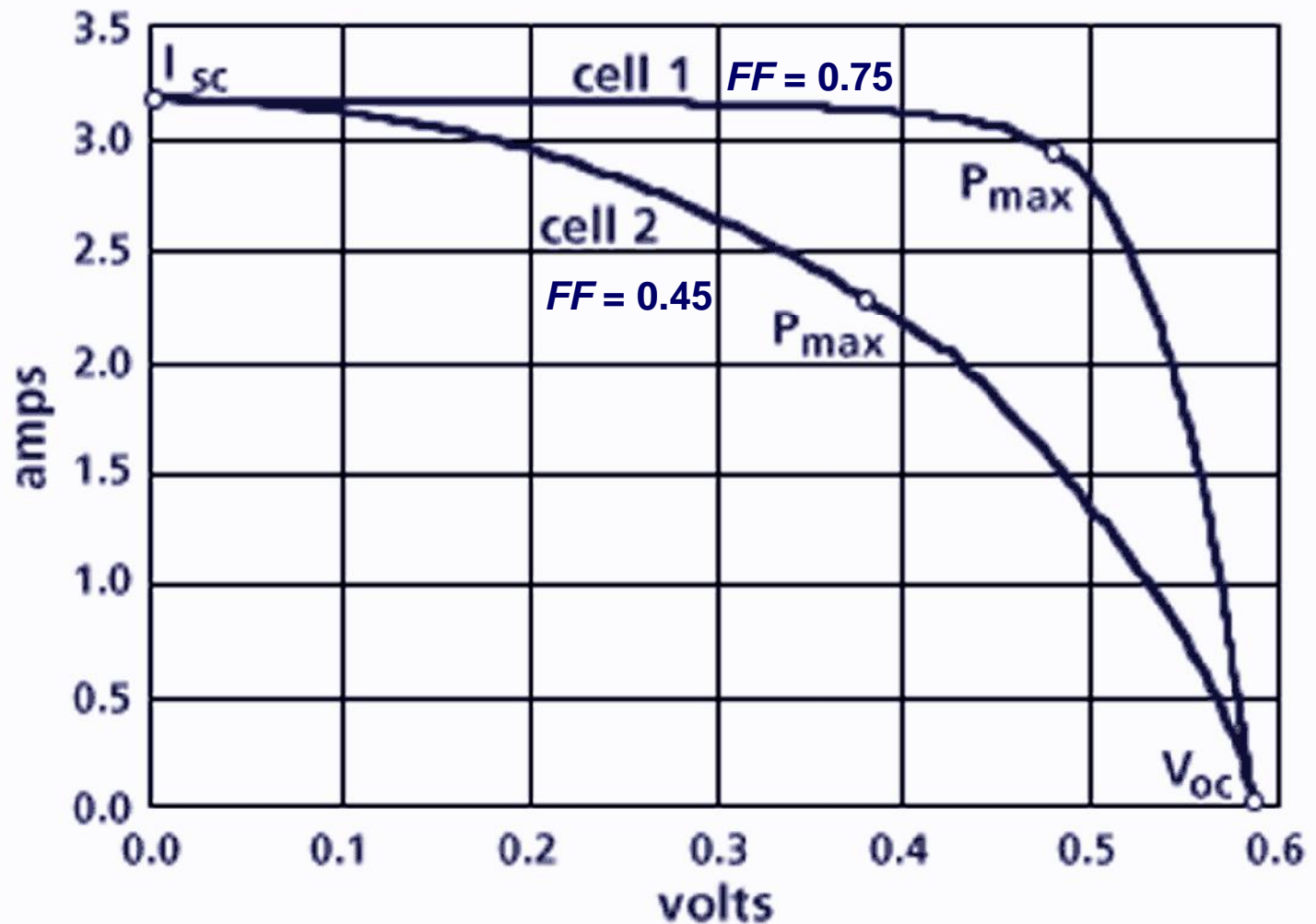
$V_{oc}$  = Open circuit Voltage(V)

$I_{cs}$  = Short circuit current (A)

# B8.3 Photovoltaic power

## Photovoltaic cells: Specifications:

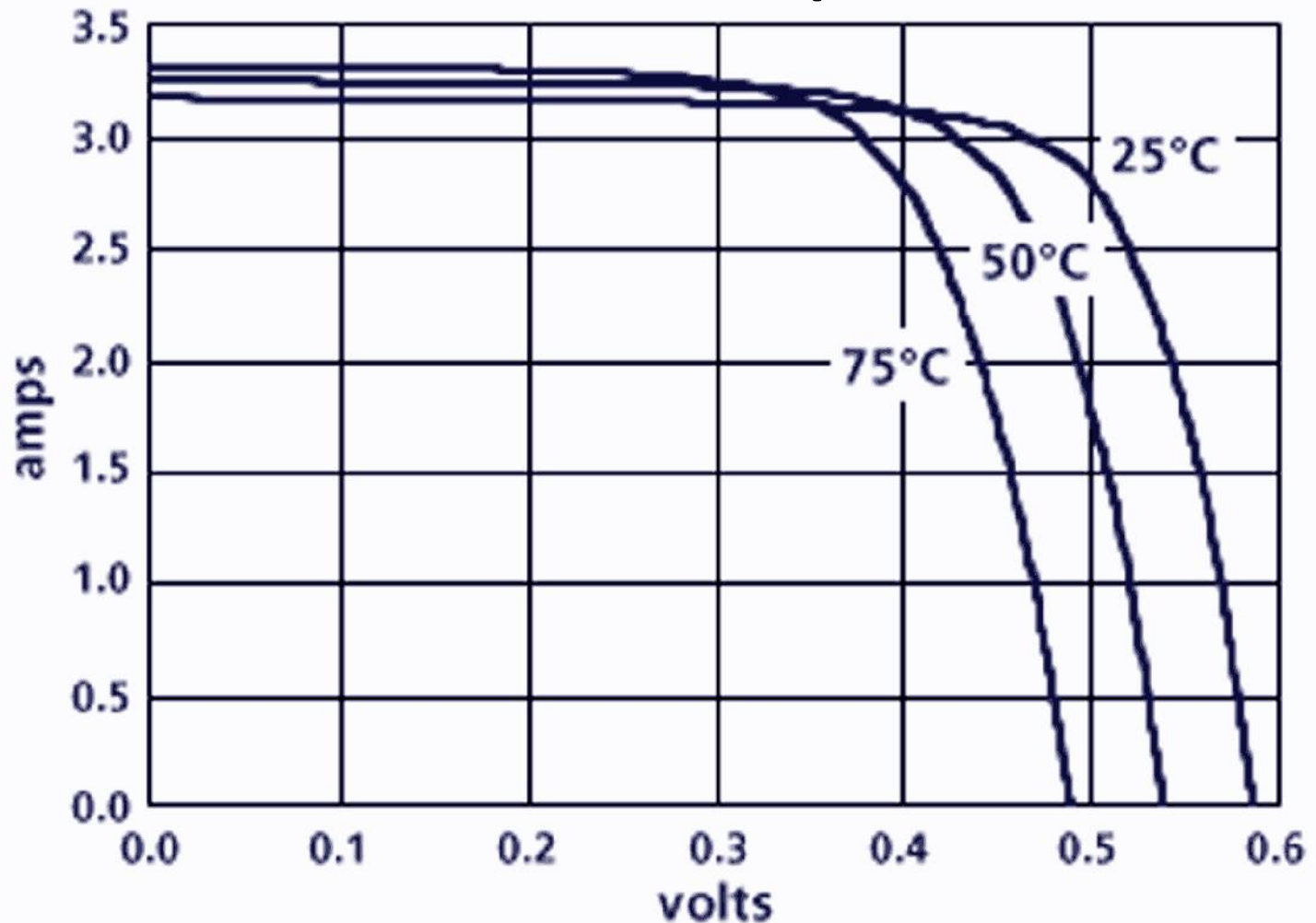
### IV curve: Fill factor



# Photovoltaic power

## Photovoltaic cells: Specifications:

### IV curve: Effect of temperature





# Photovoltaic power

## Photovoltaic cells: Specifications:

### IV curve: Effect of temperature

- Power output falls as temperature increases
- Voltage falls  $\sim 0.0023\text{V}$  per  $^{\circ}\text{C}$
- Current rises (but only a bit – you can really ignore it)

# Photovoltaic power

## Photovoltaic cells: Specifications:

### IV curve: Effect of insolation



## B8.3 Photovoltaic power

### Photovoltaic cells: Specifications: IV curve: Effect of insolation

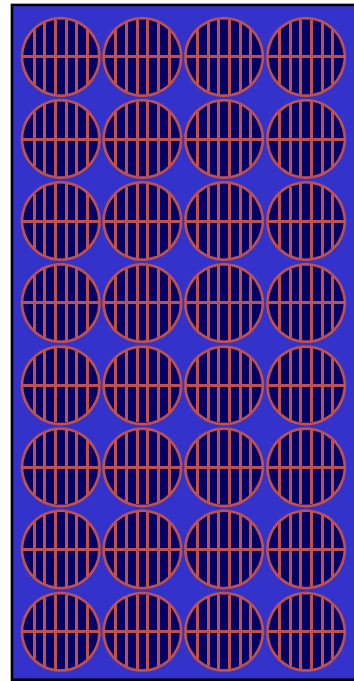
- Power output increases as insolation increases
- Voltage has a slight increase and can be ignored
- Current rises significantly in direct proportion to insolation

# Photovoltaic power

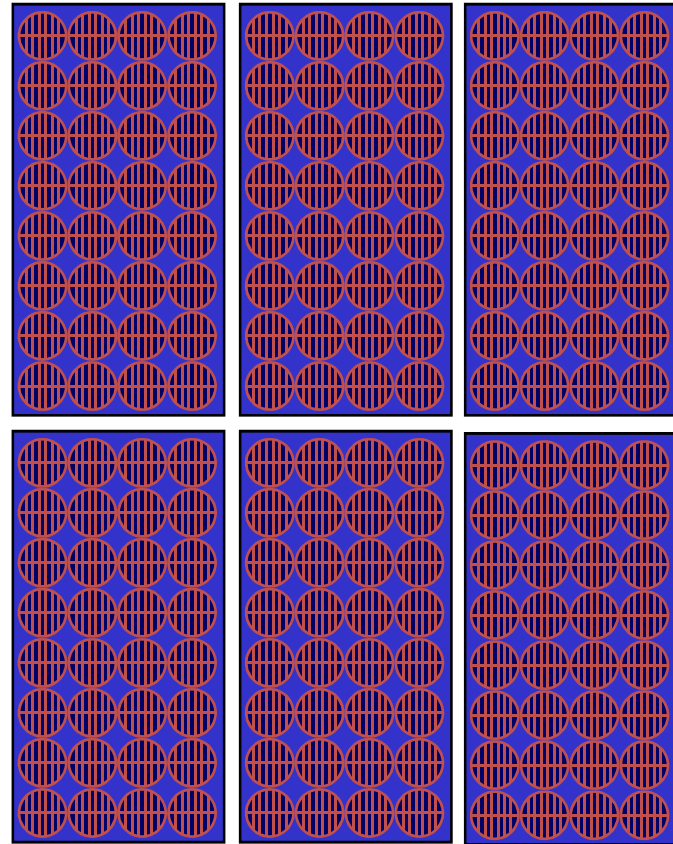
## Photovoltaic cells: Arrays



Cell



Module



Array

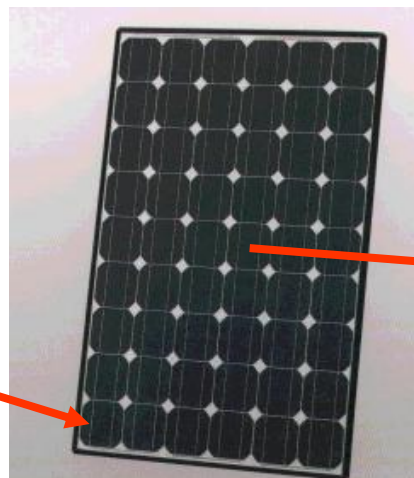
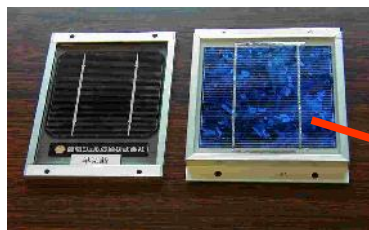
	Volt	Ampere	Watt	Size
Cell	0.5V	5-6A	2-3W	about 10cm
Module	20-30V	5-6A	100-200W	about 1m
Array	200-300V	50A-200A	10-50kW	about 30m

- **Hierarchy of PV**

**Module, Panel**  
100 - 200 W

**Array**  
10 - 50 kW

**Cell**  
2 - 3 W



6x9=54 (cells)



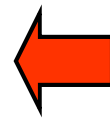
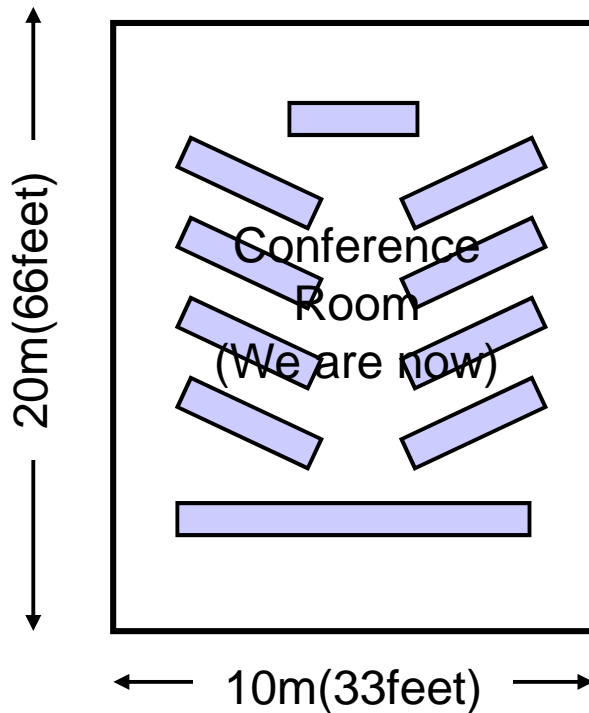
100-300 (modules)

## Size of PV

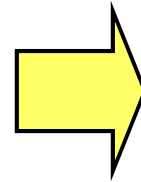
### • Roughly size of PV Power Station.

1 kw PV need 10 m<sup>2</sup>

(108 feet<sup>2</sup>)



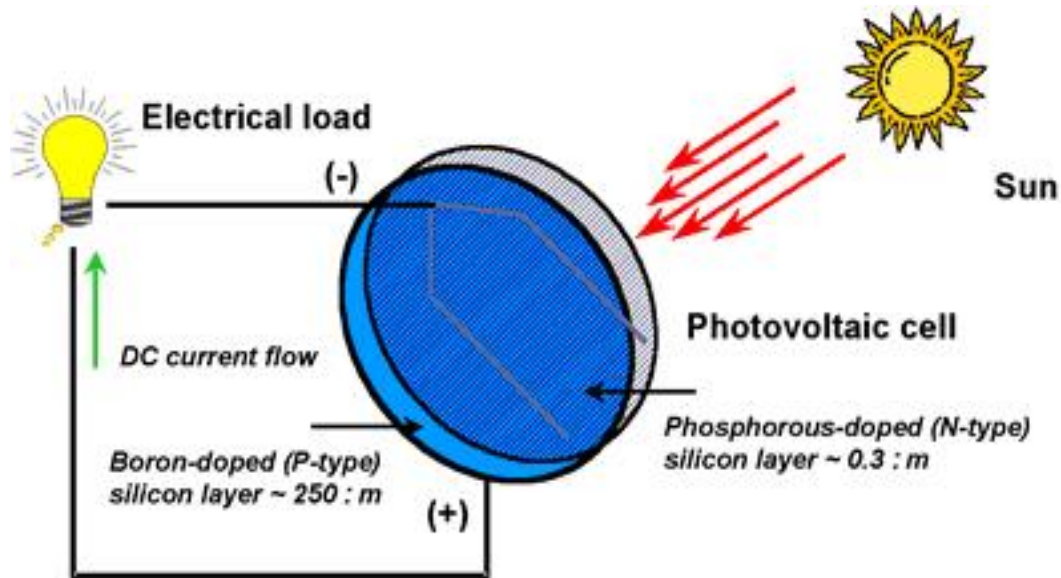
Please remember



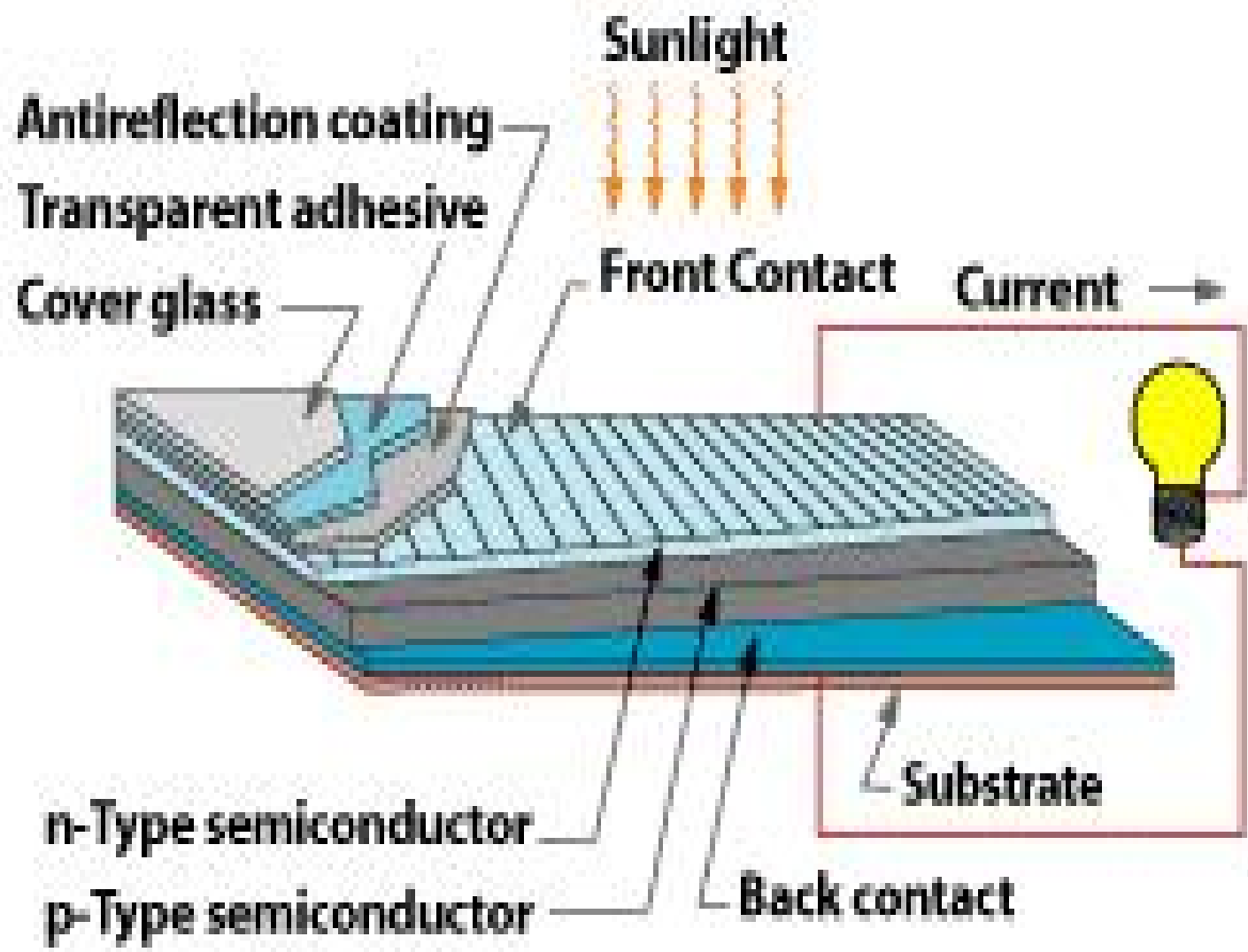
Our room has about 200 m<sup>2</sup>  
(2,178 feet<sup>2</sup>)

We can install about  
**20 kW PV** in this room

# How PV Cells Work



A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load.



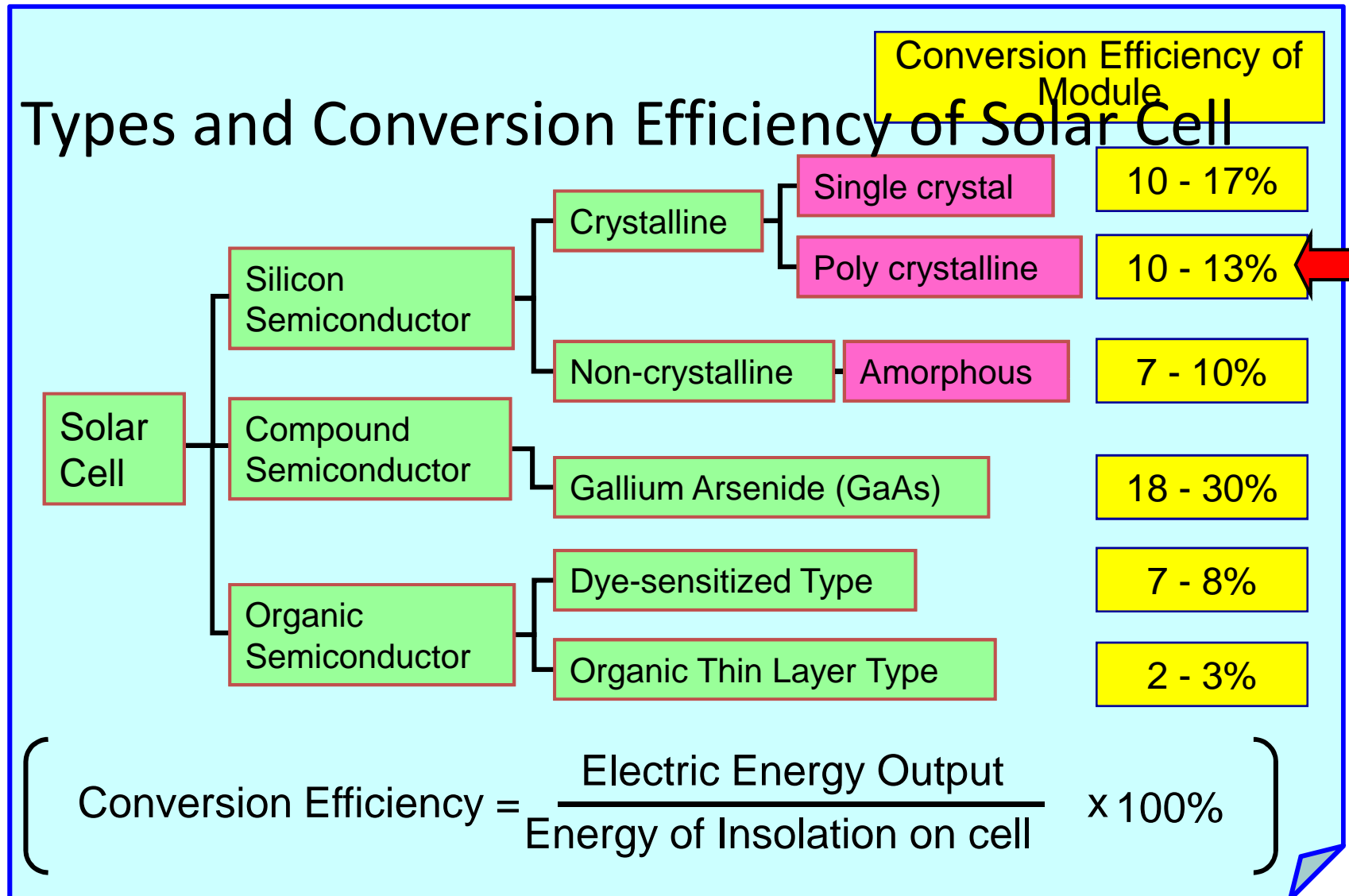


# Solar Cells : Technology Options

- **Crystalline Silicon solar cells**
  - Single, Multi, Ribbon
- **Thin Film solar cells**
  - Silicon, a-Si(Amorphous silicon), m-Si, CdTe (Cadmium Telluride), CIGS
- **Concentrating solar cells**
  - Si, GaAs
- Dye, Organic, nano materials & other emerging solar cells

# Various type of PV cell

- Types and Conversion Efficiency of Solar Cell



$$\left[ \text{Conversion Efficiency} = \frac{\text{Electric Energy Output}}{\text{Energy of Insolation on cell}} \times 100\% \right]$$

# Solar Cell Best Efficiencies: India

<b>TECHNOLOGY</b>	<b>AREA SQ. CM.</b>	<b>EFF. %</b>	<b>Group</b>
SINGLE CRYSTAL	64.00	19.7	CEL
MULTI CRYSTAL	100.00	16.8	Tata BP
a-Si SINGLE JUNCTION	1.00	12.0	IACS
a-Si MULTI JUNCTION	1.00	11.5	IACS
a-Si/ $\mu$ c-Si(nc-Si)	1.00	9.0	IACS
CdTe	1.00	12.0	NPL
CIGS	0.41	13.0	IISC
Si FILMS	0.98	8.7	Jadavpur
Dye Sensitized	1.00	9.5	Amrita
Organic cells	1.00	6.2	NPL

# Crystalline Silicon Solar Module Efficiency

## TYPICAL IN PRODUCTION

	<u>INTERNATIONAL</u>	<u>INDIAN</u>
• SINGLE CRYSTAL	15 – 20.4 %	14 – 17 %
• MULTI CRYSTAL	13 – 16%	13 – 16%

- A typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit, no-load conditions.
- The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is proportional the intensity of sunlight striking the surface of the cell.

For example, under peak sunlight conditions a typical commercial PV cell with a surface area of 160 cm<sup>2</sup> ( $\approx 25$  in<sup>2</sup>) will produce about 2 watts peak power. If the sunlight intensity were 40 percent of peak, this cell would produce about 0.8 watts.

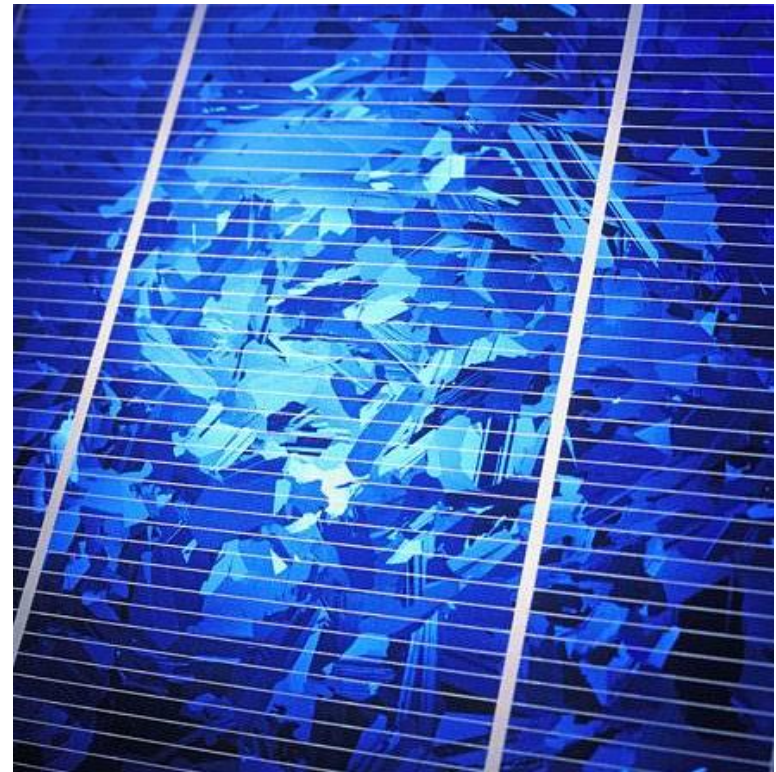
# Monocrystalline Silicon Modules

- Most efficient commercially available module (11% - 14%)
- Most expensive to produce
- Circular (square-round) cell creates wasted space on module



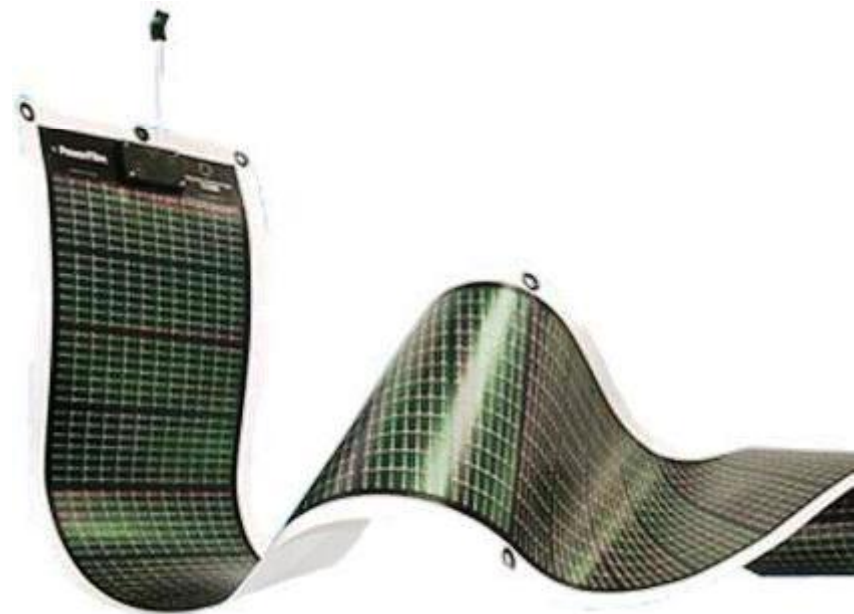
# Polycrystalline Silicon Modules

- Less expensive to make than single crystalline modules
- Cells slightly less efficient than a single crystalline (10% - 12%)
- 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 than with crystalline modules





# How PV system(BOS) works?

## **BALANCE-OF-SYSTEM**

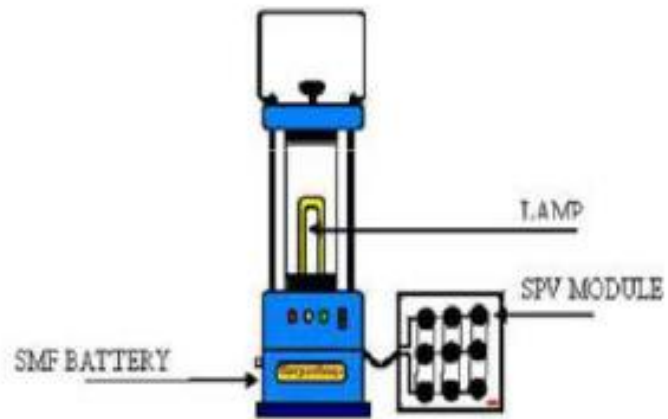
- PV array produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array.
- A DC-AC power inverter,
- Battery bank, system and battery controller,
- Auxiliary energy sources
- specified electrical load (appliances).

- PV unit : Price per peak watt (Wp) ( Peak watt is the amount of power output a PV module produces at Standard Test Conditions (STC) of a module operating temperature of 25°C in full noontime sunshine (irradiance) of 1,000 Watts per square meter )
- A typical 1kWp System produces approximately 1600-2000 kWh energy in India.

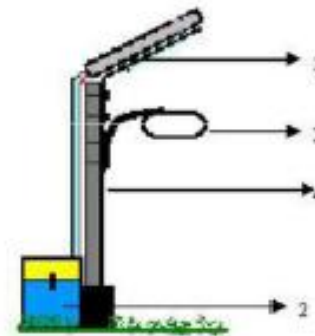
# Applications

- **Water Pumping: PV powered pumping systems are excellent**, simple, reliable – life 20 yrs
- **Commercial Lighting: PV powered lighting systems are reliable** and low cost alternative. Security, billboard sign, area, and outdoor lighting are all viable applications for PV
- **Consumer electronics: Solar powered watches, calculators, and cameras** are all everyday applications for PV technologies.
- **Telecommunications**
- **Residential Power: A residence located more than a mile from the electric grid can install a PV system more inexpensively than extending the electric grid(Over 500,000 homes worldwide use PV power as their only source of electricity)**
- **Vaccine refrigeration in remote villages**

## Solar lantern



## solar street light



1. SPV Module
2. Battery Box
3. Lamp with charge controller
4. Lamp Post

## Solar fencing system

