Principles of Photovoltaics (PV)

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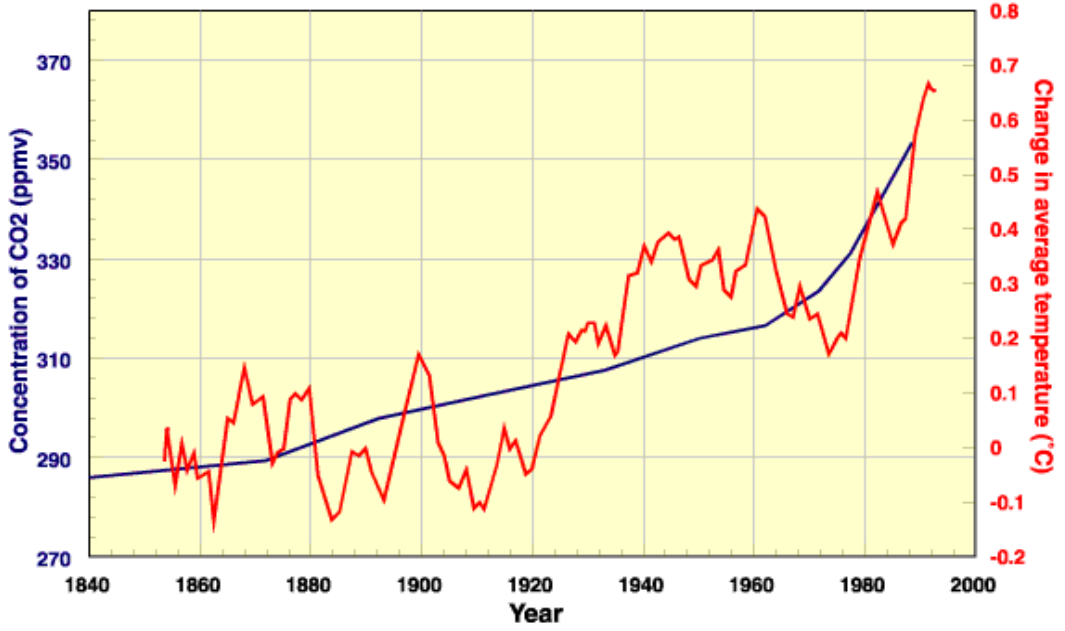
The Greenhouse Effect

- 270 ppm carbon dioxide (CO_2) in the atmosphere absorbs outgoing radiation, thereby keeping this energy in the atmosphere and warming the Earth



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Target Renewable Capacity by 2032

Maximizing Renewable Deployment Return

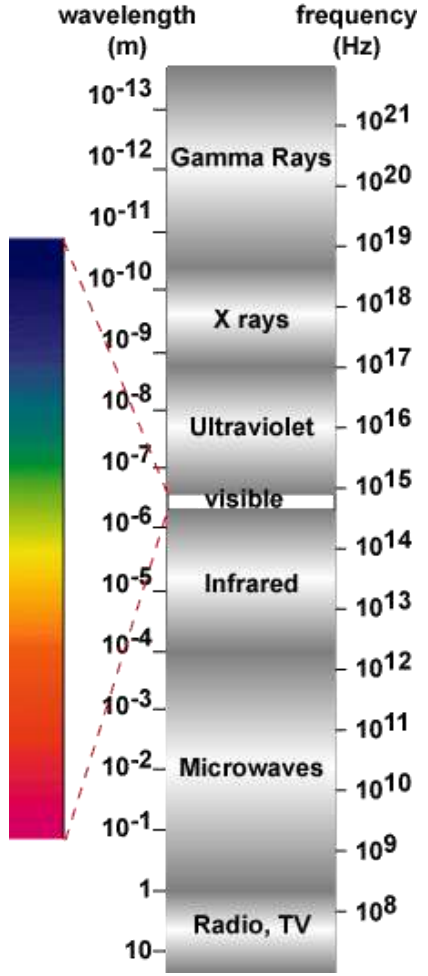
54 GW

Properties of Light

High energy photon for blue light.

Lower energy photon for red light.

Low energy photon for infrared light.
Should be invisible!



$E = hc/\lambda$

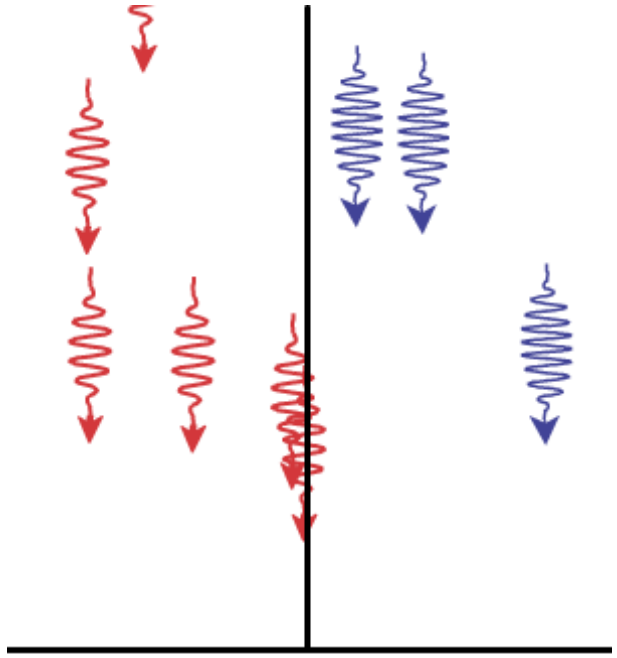
$h = 6.626 \times 10^{-34}$ joule·s
$c = 2.998 \times 10^{8}$ m/s

Photon Flux

- the photon flux gives the energy striking a surface per unit time, which is equivalent to a power density.

$$\Phi = \frac{\#\ of\ photons}{\sec m^2}$$

For determining the power density
the energy or wavelength of the photons in the light source must also be specified.



For the same light intensity, blue light requires fewer photons since the energy content of each photon is greater.

Solar Radiation at the Earth's Surface

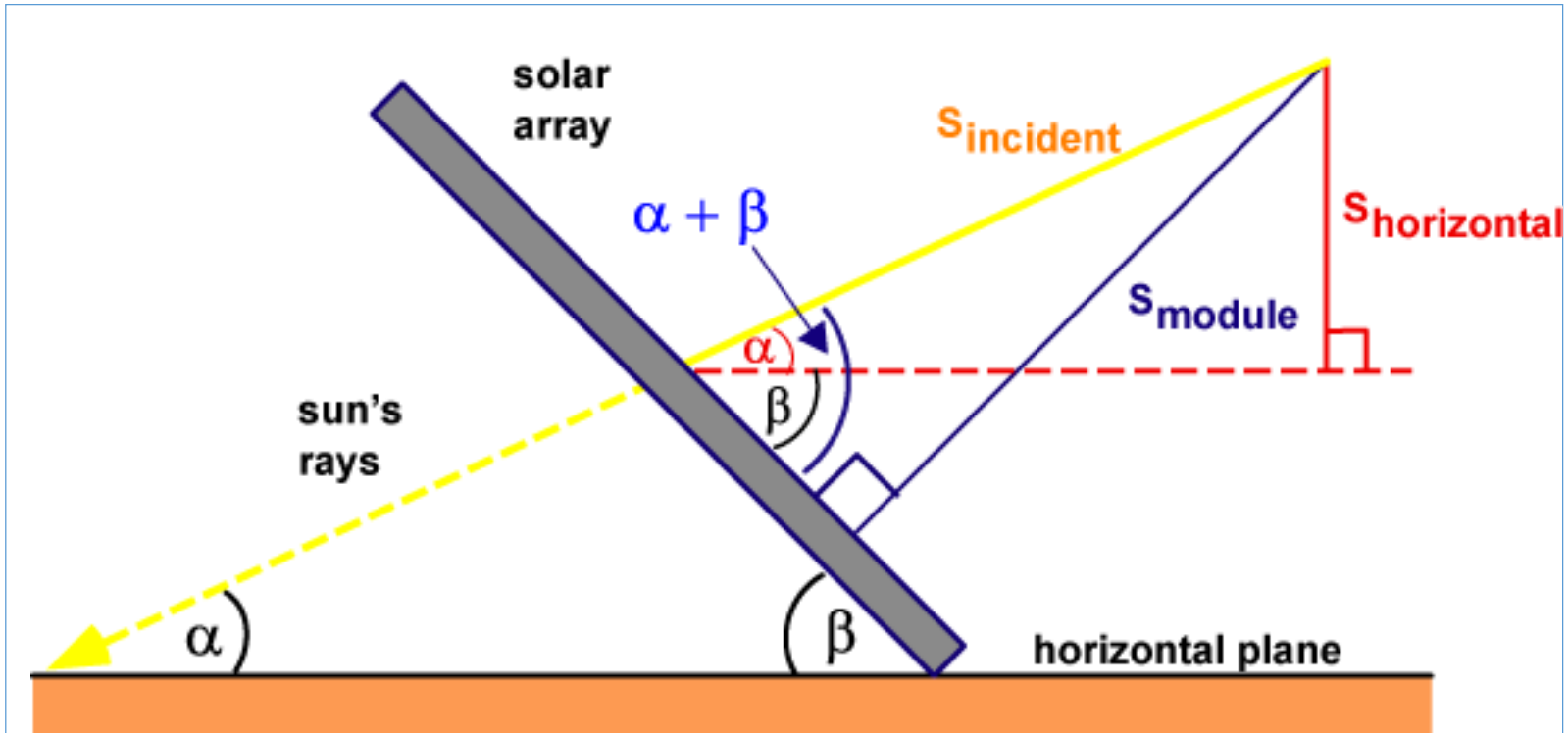
- atmospheric effects, including absorption and scattering
- local variations in the atmosphere, such as water vapour, clouds, and pollution
- latitude of the location
- the season of the year and the time of day.

Solar Radiation on a Tilted Surface

- α is the elevation angle; and β is the tilt angle of the module measured from the horizontal.

$$S_{horizontal} = S_{incident} \sin\alpha$$

$$S_{module} = \frac{S_{horizontal} \sin(\alpha+\beta)}{\sin\alpha}$$



Semiconductor Materials

		IIIA	IVA	VA	VIA	VIIA	
							4.003
		5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.183
IB	IIB	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.064	17 Cl 35.453	18 Ar 39.948
29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.922	34 Se 78.96	35 Br 79.909	36 Kr 83.80
47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.904	54 Xe 131.30

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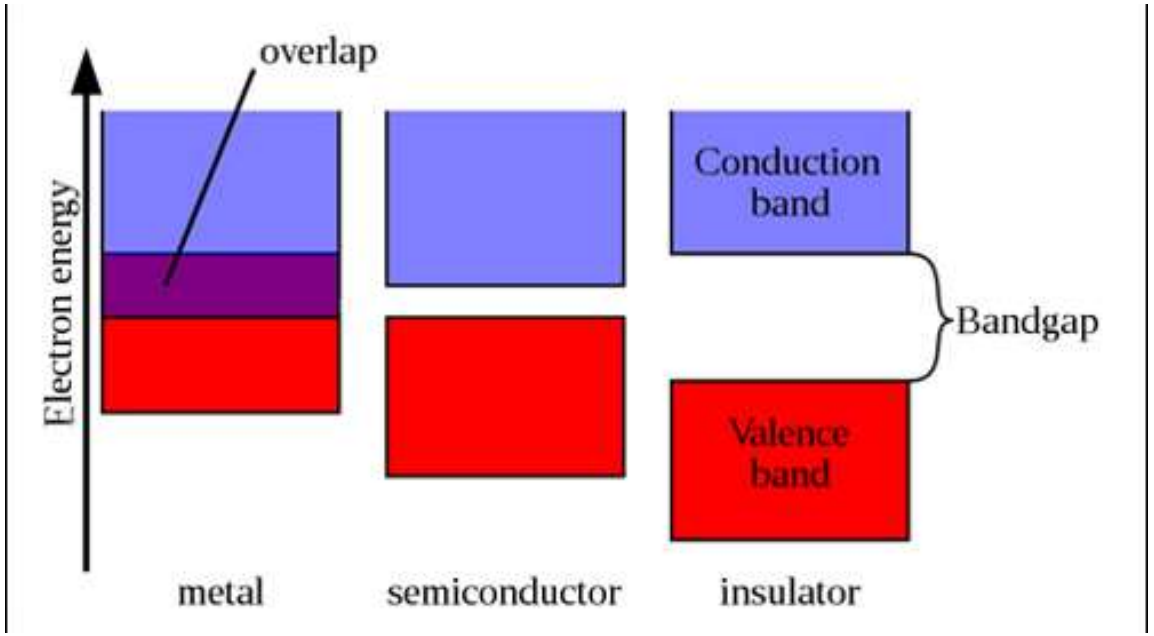
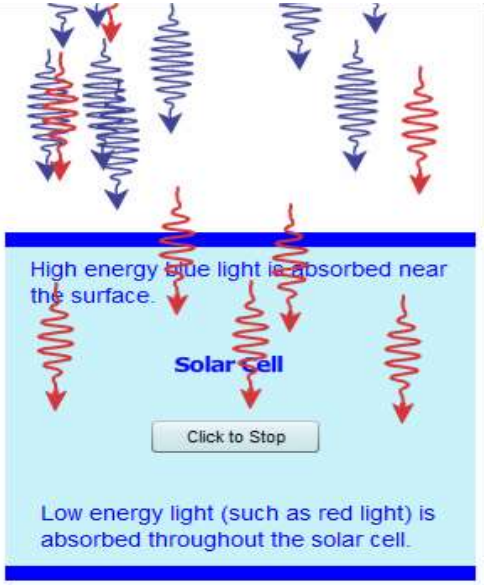
Band Gaps Of Different Materials

Material	Symbol	Band Gap (eV)
Silicon	Si	1.11
Cadmium telluride	CdTe	1.49
Cadmium selenide	CdSe	1.73
Copper oxide	CuO	1.20
Gallium arsenide	GaAs	1.43
Indium phosphide	InP	1.35
Selenium	Se	1.74
Visible light		1.59- 3.26



Absorption of Light

- $E_{ph} < E_G$ Photons with energy E_{ph} less than the band gap energy E_G interact only weakly with the semiconductor, passing through it as if it were transparent.
- $E_{ph} = E_G$ have just enough energy to create an electron hole pair and are efficiently absorbed.
- $E_{ph} > E_G$ Photons with energy much greater than the band gap are strongly absorbed. However, for photovoltaic applications, the photon energy greater than the band gap is wasted as electrons quickly thermalize back down to the conduction band edges



Absorption Depth

- The absorption depth is given by the inverse of the absorption coefficient, and describes how deeply light penetrates into a semiconductor before being absorbed.
- Higher energy light is of a shorter wavelength and has a shorter absorption depth than lower energy light, which is not as readily absorbed, and has a greater absorption depth.
- Absorption depth affects aspects of solar cell design, such as the thickness of the semiconductor material.

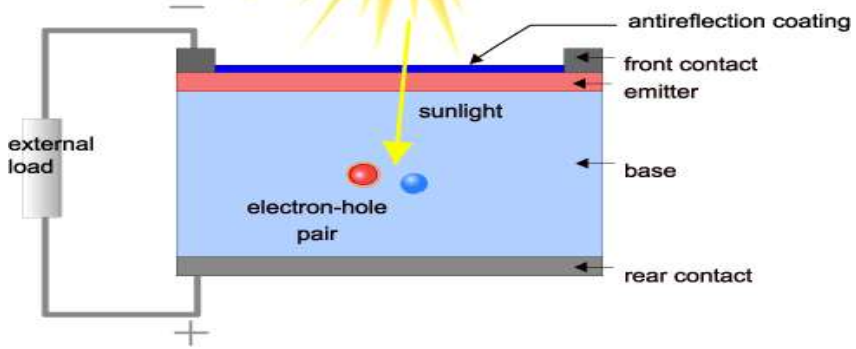
Generation Rate

- The generation of an electron-hole pair can be calculated at any location within the solar cell, at any wavelength of light, or for the entire standard solar spectrum.
- Generation is the greatest at the surface of the material, where the majority of the light is absorbed.
- Because the light used in PV applications contains many different wavelengths, many different generation rates must be taken into account when designing a solar cell.

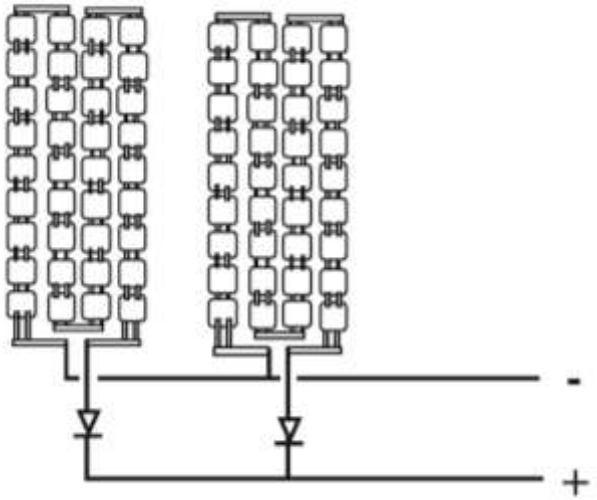
Types of Recombination&Lifetime

- The lifetime of a semiconductor is contingent upon the recombination rate, which is dependent upon the concentration of minority carriers.
- The lifetime of the material takes into account the different types of recombination.
- Lifetime is an indicator of the efficiency of a solar cell, and thus is a key consideration in choosing materials for solar cells.
- Eventually, electrons lose energy and stabilize back to the valence band, recombining with a hole.
- There are three types of recombination; Radiative, Shockley-Read-Hall, and Auger.
- Auger and Shockley-Read-Hall recombination dominate in silicon-based solar cells.
- Among other factors, recombination is associated with the lifetime of the material, and thus of the solar cell.

Solar Cell Structure



- A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p*-*n* junction.
- the collection of these carriers by the *p*-*n* junction, prevents this recombination by using a *p*-*n* junction to spatially separate the electron and the hole. The carriers are separated by the action of the electric field existing at the *p*-*n* junction. If the light-generated minority carrier reaches the *p*-*n* junction, it is swept across the junction by the electric field at the junction, where it is now a majority carrier. If the emitter and base of the solar cell are connected together (i.e., if the solar cell is short-circuited), the the light-generated carriers flow through the external circuit. The ideal flow at short circuit is shown in the animation below.



A photovoltaic (PV) cell, also known as “solar cell,”
is a semiconductor device that generates electricity when light falls on it with
(0.5–0.55 V) for the individual cells.

To increase power output, many PV cells are connected together to
form modules. A photovoltaic solar panel or module is made of similar cells
assembled in series or parallel in
order to achieve a given voltage or current output.

current depends on the size of the cells as the individual cells
and a voltage equal to the sum of their individual voltages.

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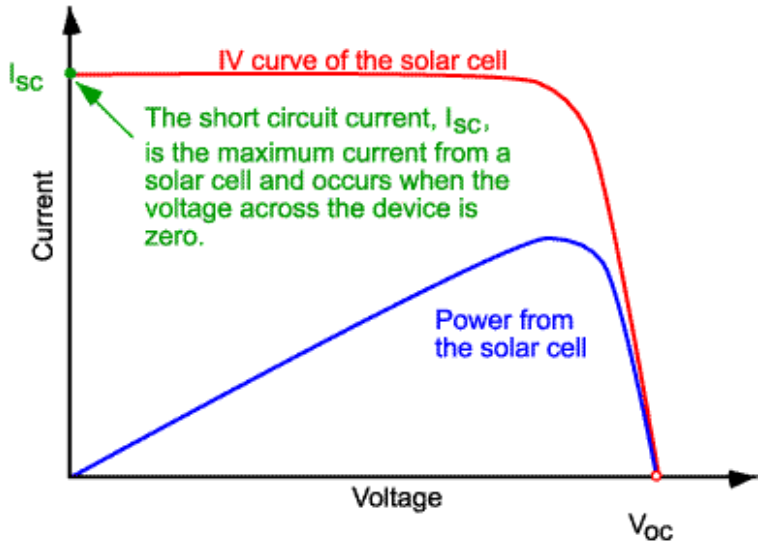
Factors affecting PV performance

Many factors affect solar PV performance such as orientation of the PV module, tracking the sun, temperature of PV module, incidence/tilt angle of the PV panel, shading of the panel, mounting rooftop material, mounting height, s olar irradiance, type of PV module, and dust on module.
The output power can be shown in the I-V Characteristics curve (relation between current and voltage)



I-V Characteristics curve for solar cell

The Fill Factor (FF) is a measure of the quality of the solar cell.

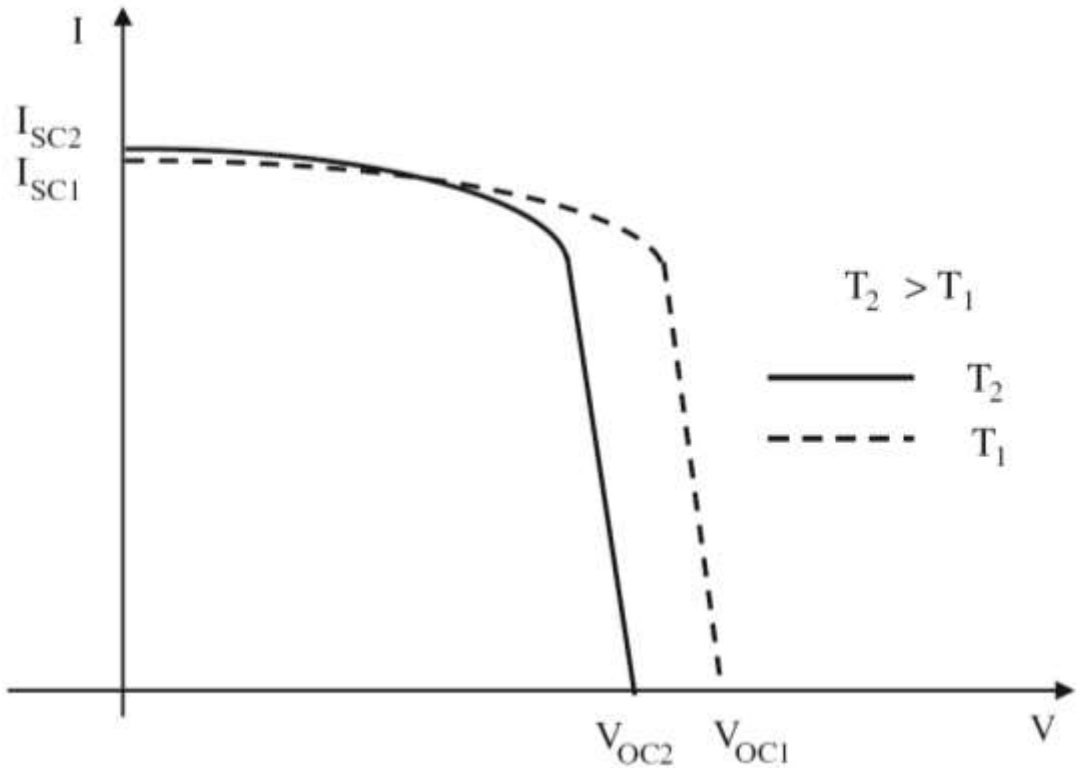
$$FF = P_{max} / P_{theoretical}$$

The efficiency of a photovoltaic solar cell is the ratio of the electrical power output P_{out}, compared to the solar optical power input P_{in}

$$\text{Efficiency} = P_{out} / P_{in} = P_{max} / P_{in} = (FF * V_{oc} * I_{sc}) / P_{in}$$

Temperature

As the temperature
increases the rate of photon generation increases, Hence this leads to marginal changes in current but major changes in voltage



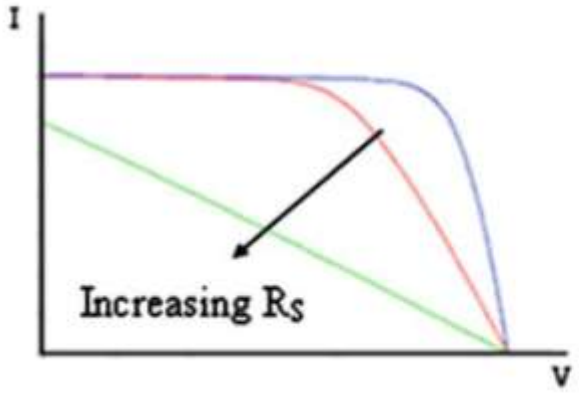
Temperature effect On I-V

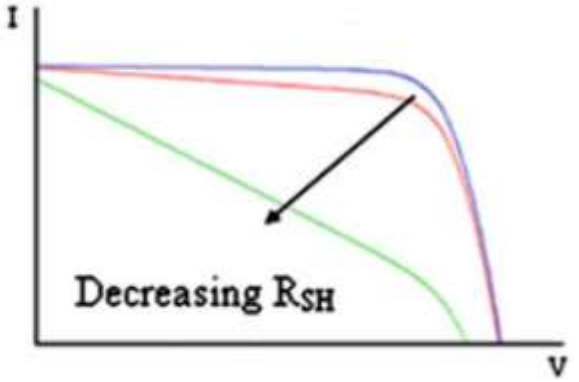
Shading

Shading mainly affects the series connected PV module. Since the current produced by shaded portion is less as compared to the illuminated portion. But current in series must be same illuminated cells current forced the shaded portion current to increase result in hotspot and may cause damage to the entire module. For this problem to overcome parallel configuration is used for arranging the PV module. In parallel the output is not so affected as in case of series configuration. Since the current in parallel is not same in the entire panel but voltage should be same. It is experimentally proved that parallel configuration is better than series.

Dusts

Dusts impact solar photovoltaic (PV) performance because they block the transmission of sunlight and affect the temperature of the module in addition to surface corrosion.





Shunt Resistance (R_{SH}) and Series Resistance (R_S)

The efficiency of solar cells is reduced by the dissipation of power through internal resistances. These parasitic resistances can be modeled as a shunt resistance (R_{SH}) and a series resistance (R_s),

The shunt resistance is due to fabrication defects, the photogenerated current will find alternative paths rather than flowing through the cell's junction. An estimated value of R_{SH} can be determined from the I–V curve as detailed below. The shunt resistance will lower the open circuit voltage without changing the short circuit current. The series resistance of a solar cell originates mostly from the contact between the metal connections, especially the front contact, and the semiconductor or the current in the emitter. The high-series resistance will reduce the short circuit current without affecting the open circuit voltage.

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Photovoltaic Cell Types

*Crystalline silicon is the traditional cell material for solar modules,

*thin film technology uses less material and the layers are much thinner
compared to mono- and polycrystalline solar cell
thus lowering the manufacturing cost.
*Three materials that have been given much attention under thin film technology are amorphous silicon,
CdS/CdTe and copper indium selenide CIS) copper indium diselenide (CIS), and copper indium gallium diselenide (CIGS).

*Polymer materials have many advantages like low cost, lightweight and environmental friendly.
The only problem is it has very low efficiency compared to other materials.

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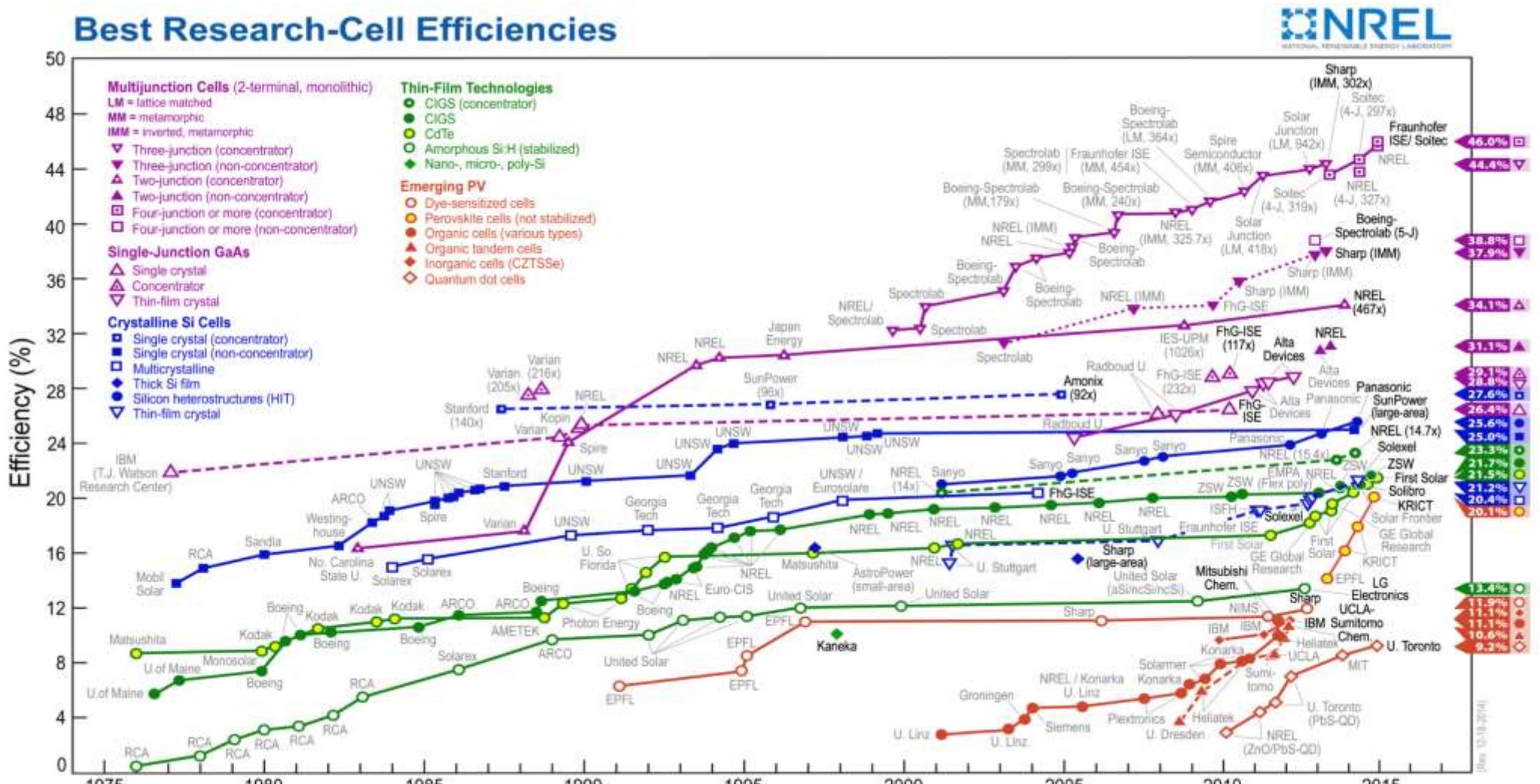

System Sizing

Sizing Process

- Determine the load to be served in Wh/day.
- Determine the available solar energy on at least a month by month basis.
- Determine the types of equipment that will be used in the system so losses can be estimated.
- Calculate the size of panel that will be needed to meet the required load under the worst month conditions.
- Calculate the size and type of battery that will be needed to provide needed reliability of power.

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Thank you