Solar Energy Principles & Fundamentals

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Why go Green Energy ?

الطـاقة عالميـا

أهـم عشــرة مشــاكل تواجه العــالم حتى عام ٢٠٥٠

- الطـاقة
- المياه
- الغـذاء
- البيئـــة
- الفقــر
- الإرهاب والحروب
- الأمــراض
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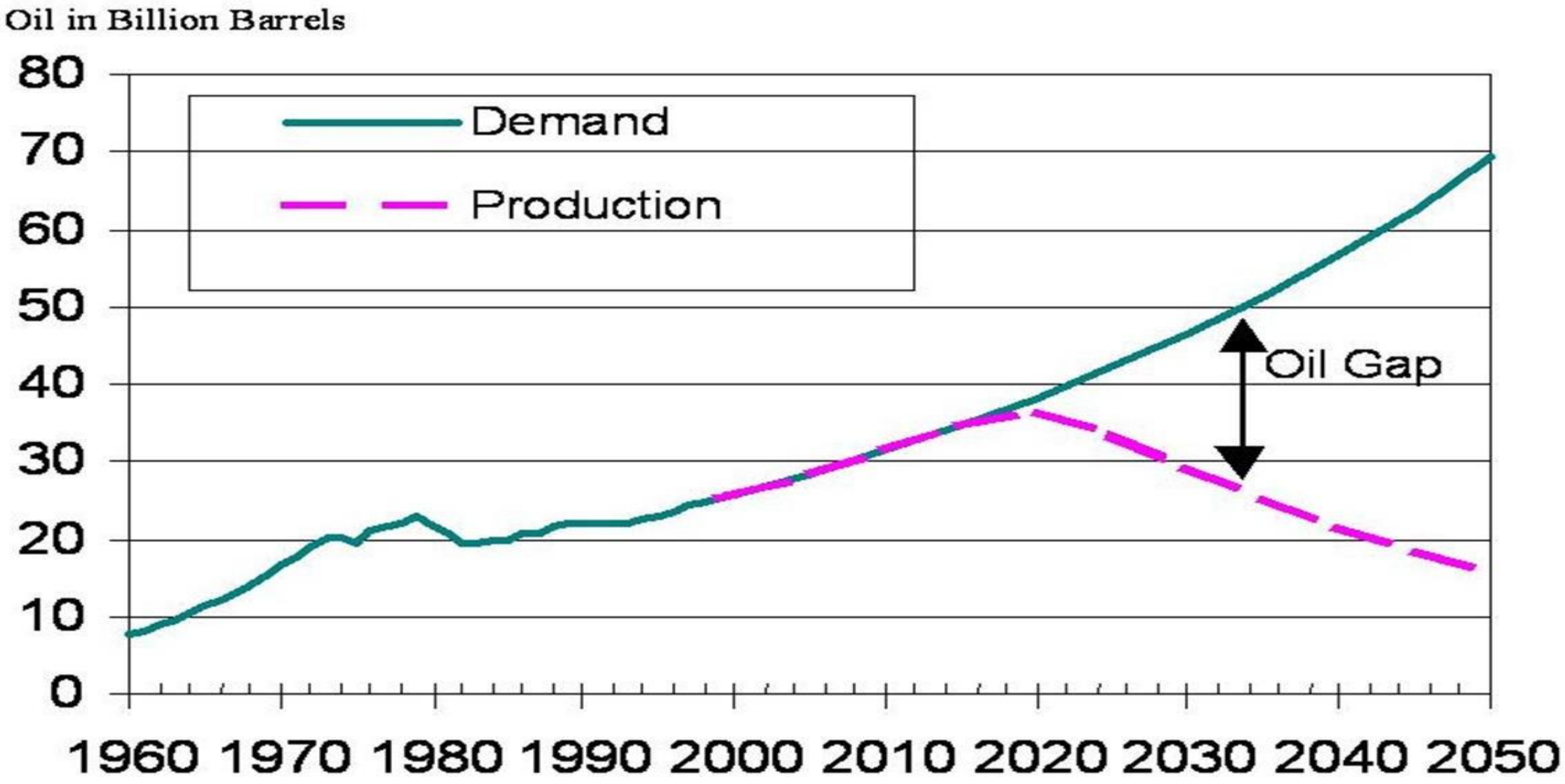
- الديمقراطية
- كثافة الســكان

٢٠٠٣ : ٦,٥ مليار نسمة

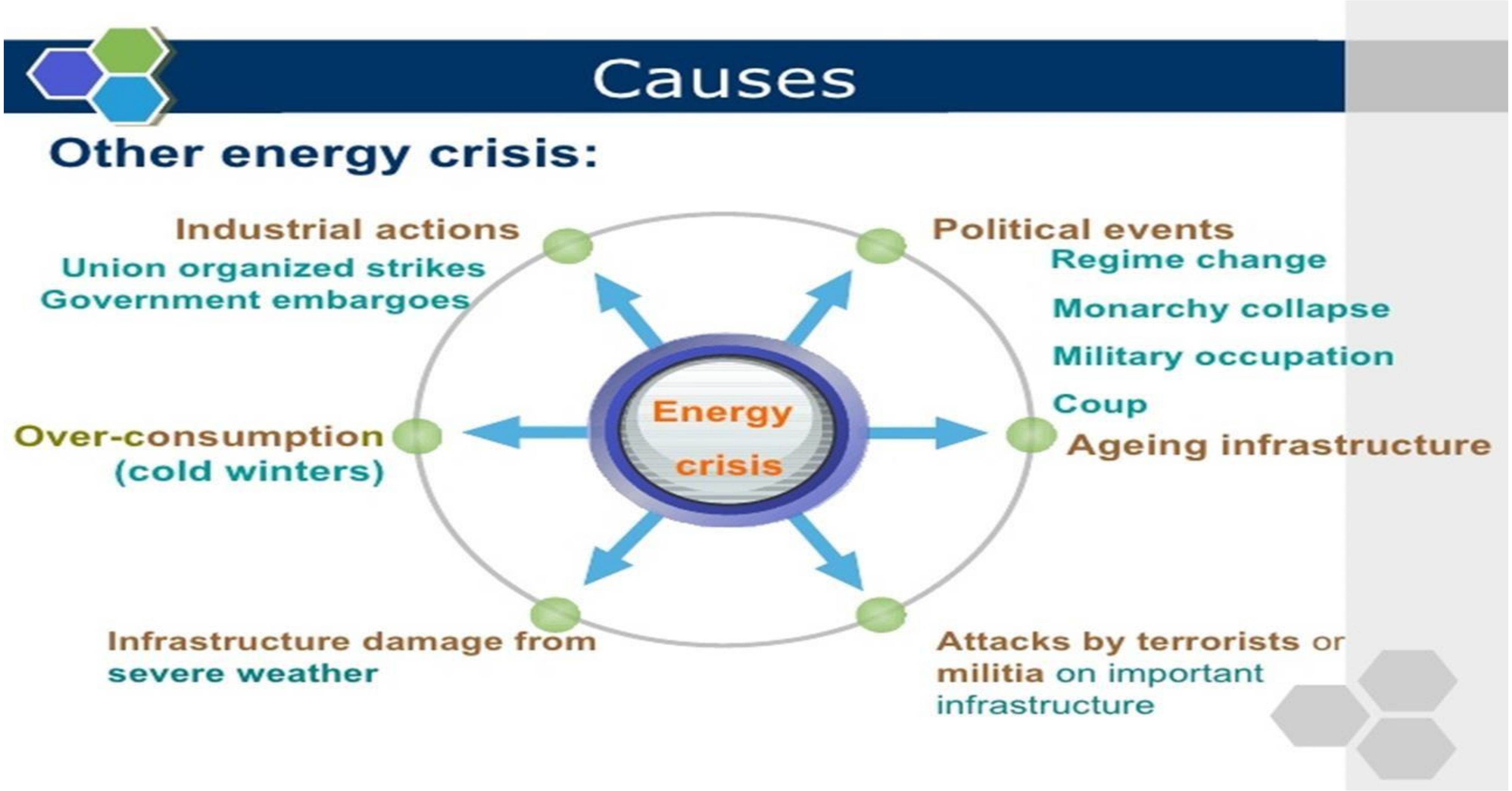
٢٠٥٠ : ٨-١٠ مليار نسمة

Energy Crisis



Gap between Energy Production & Demand

Energy Crisis



Causes of Energy Crisis

الطاقة عالميا


استكشافات


توترات سياسية


نوع الخام

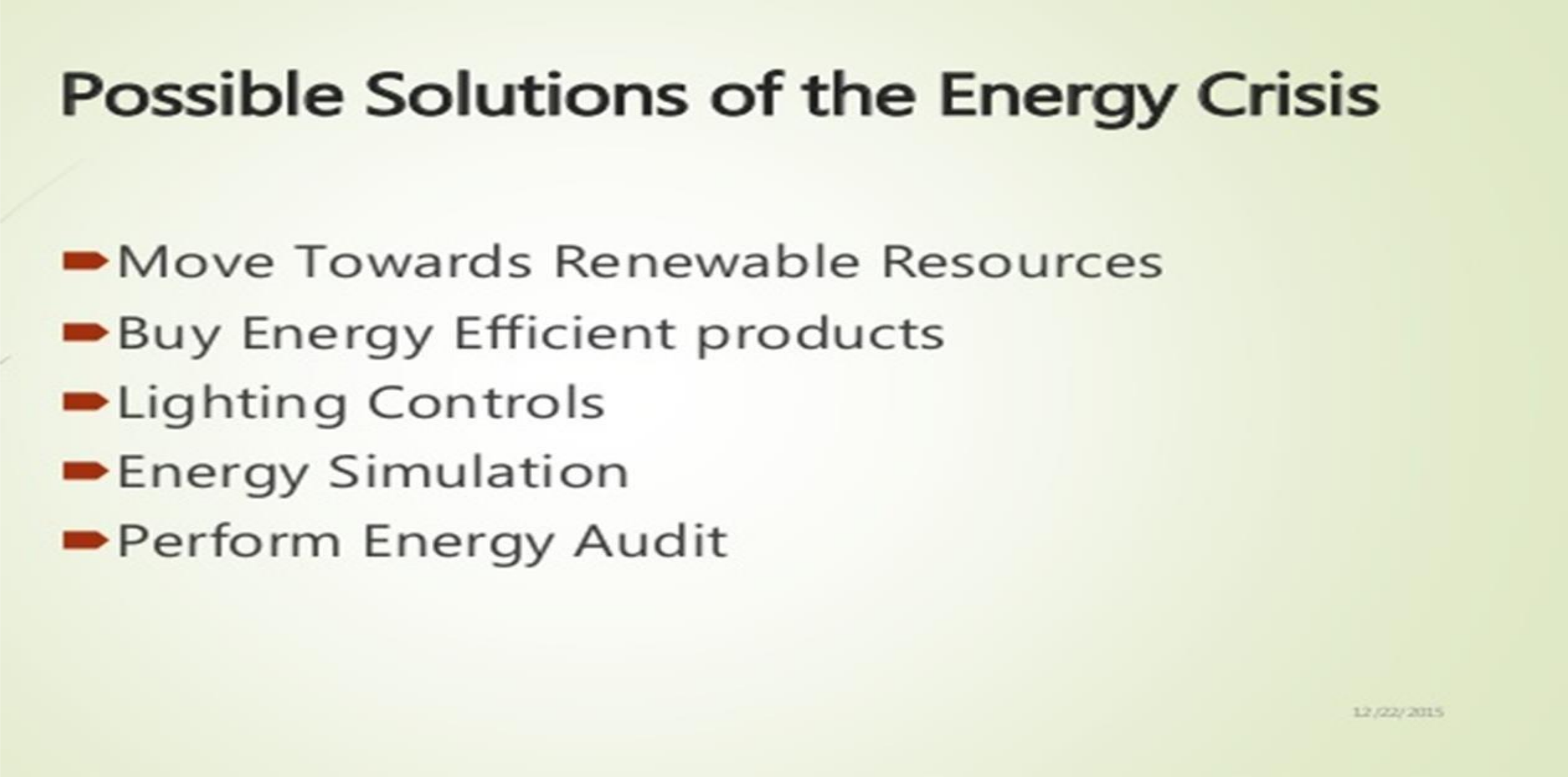
البترول


كوارث طبيعية

نمو الطلب


أسعار الصرف

Energy Crisis

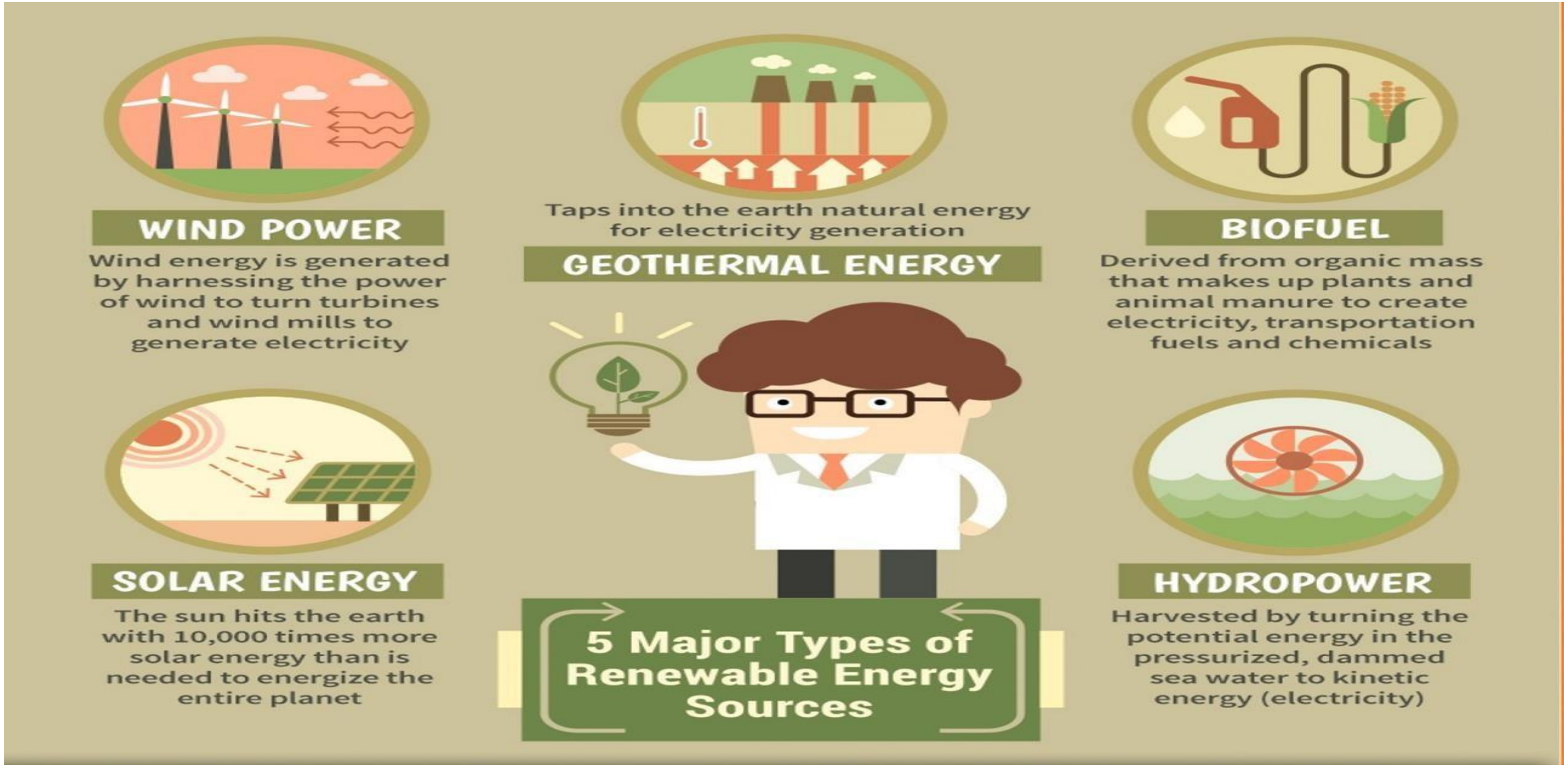


Possible Solutions of Energy Crisis

Energy Crisis

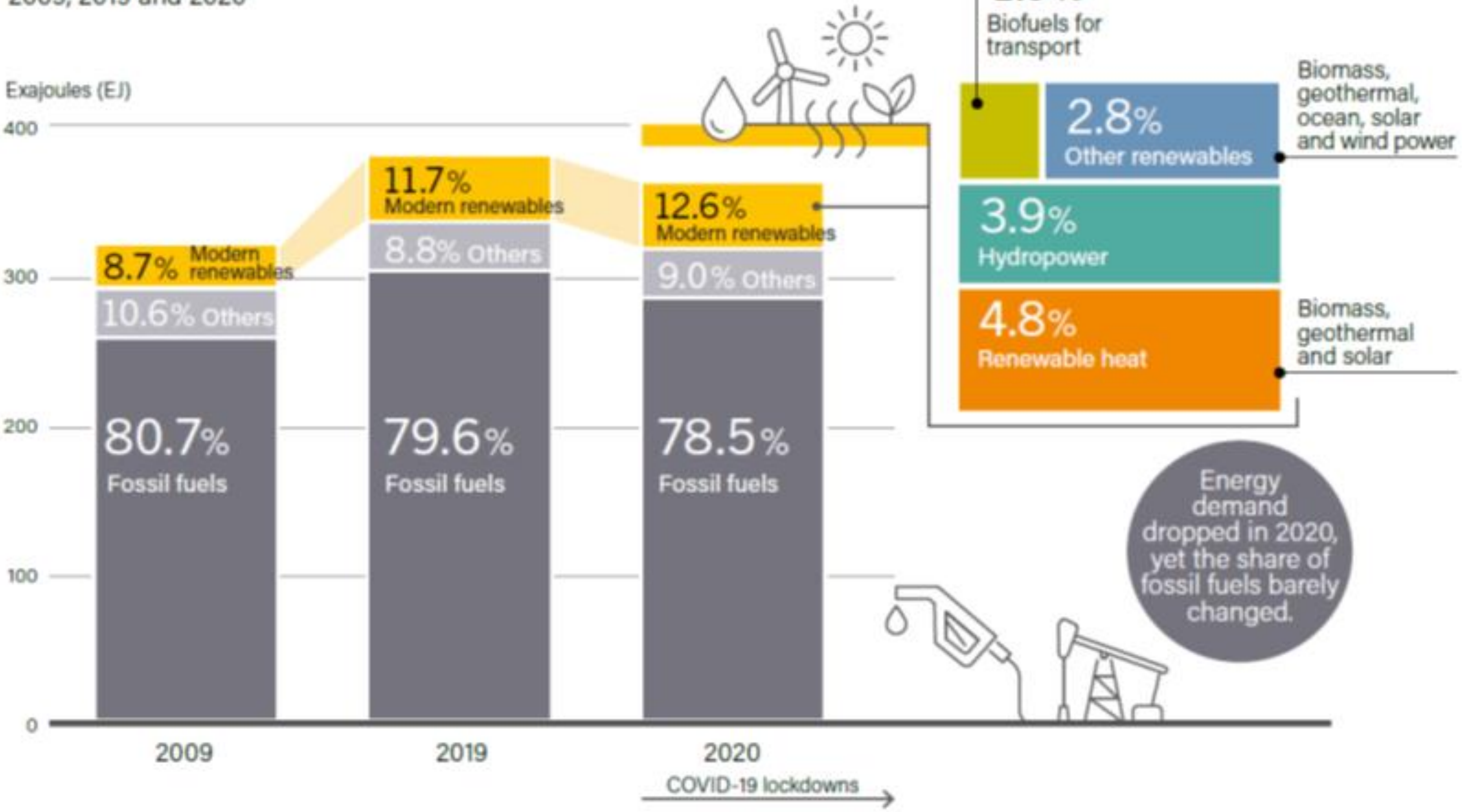
Renewable Energy Vs. Non-renewable Energy

Renewable Energy



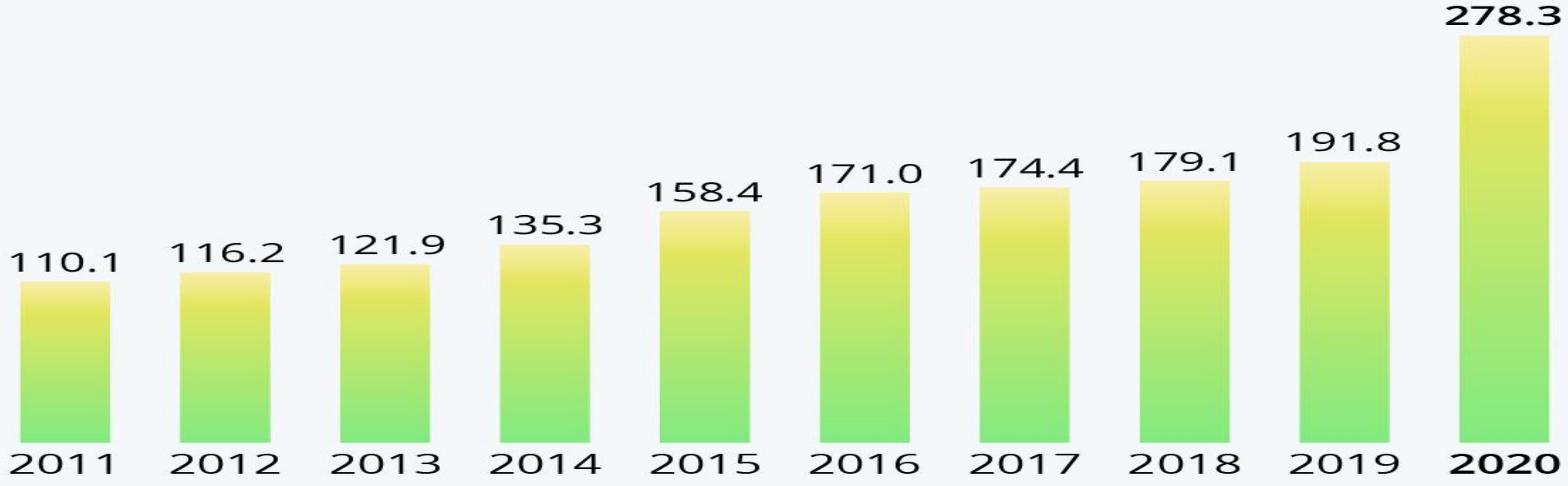
Renewable Energy Sources

Share of Modern Renewable Energy,
2009, 2019 and 2020



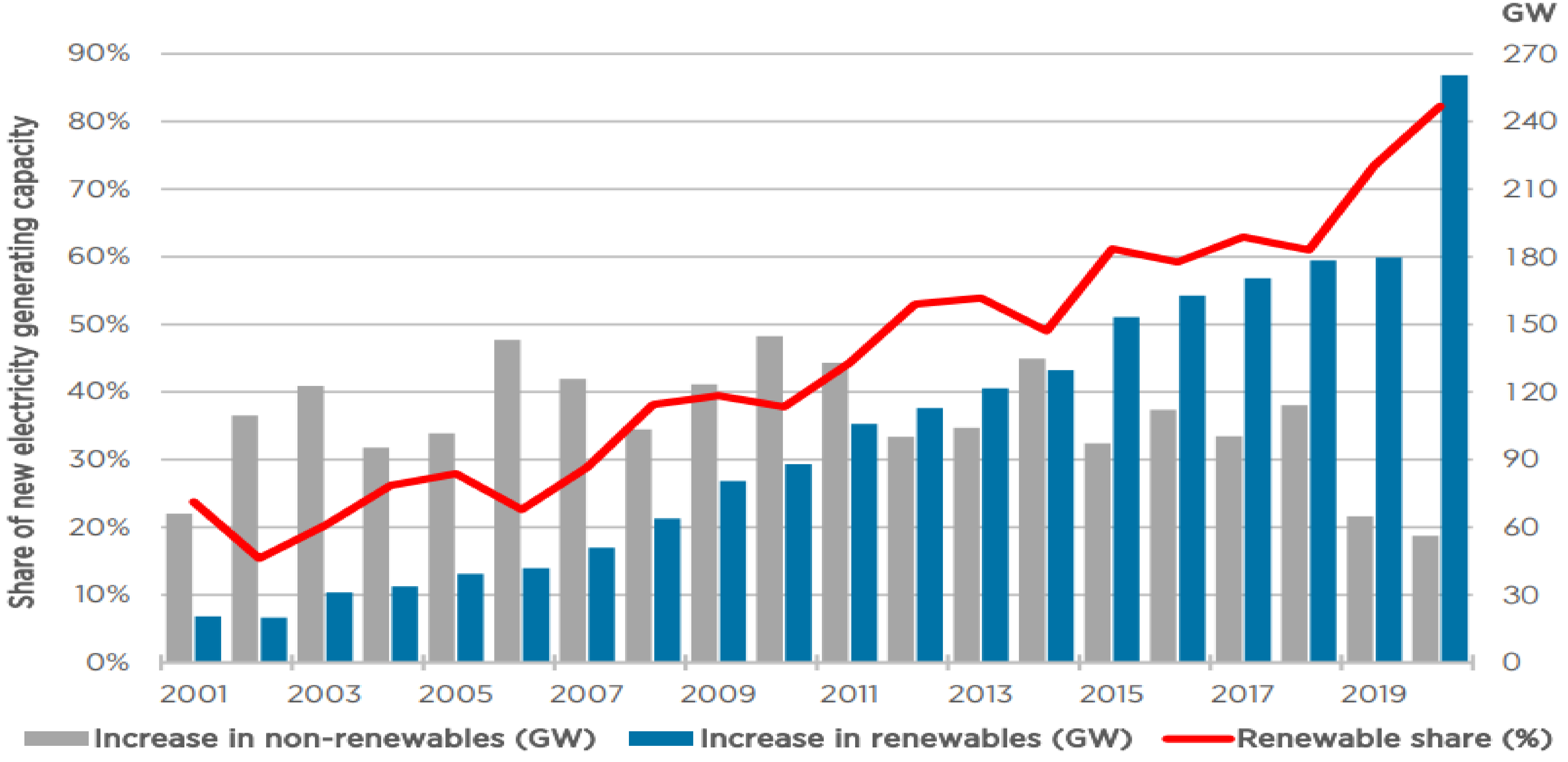
Renewable Energy Boomed In 2020

Net global renewable energy capacity additions by year (in gigawatts)

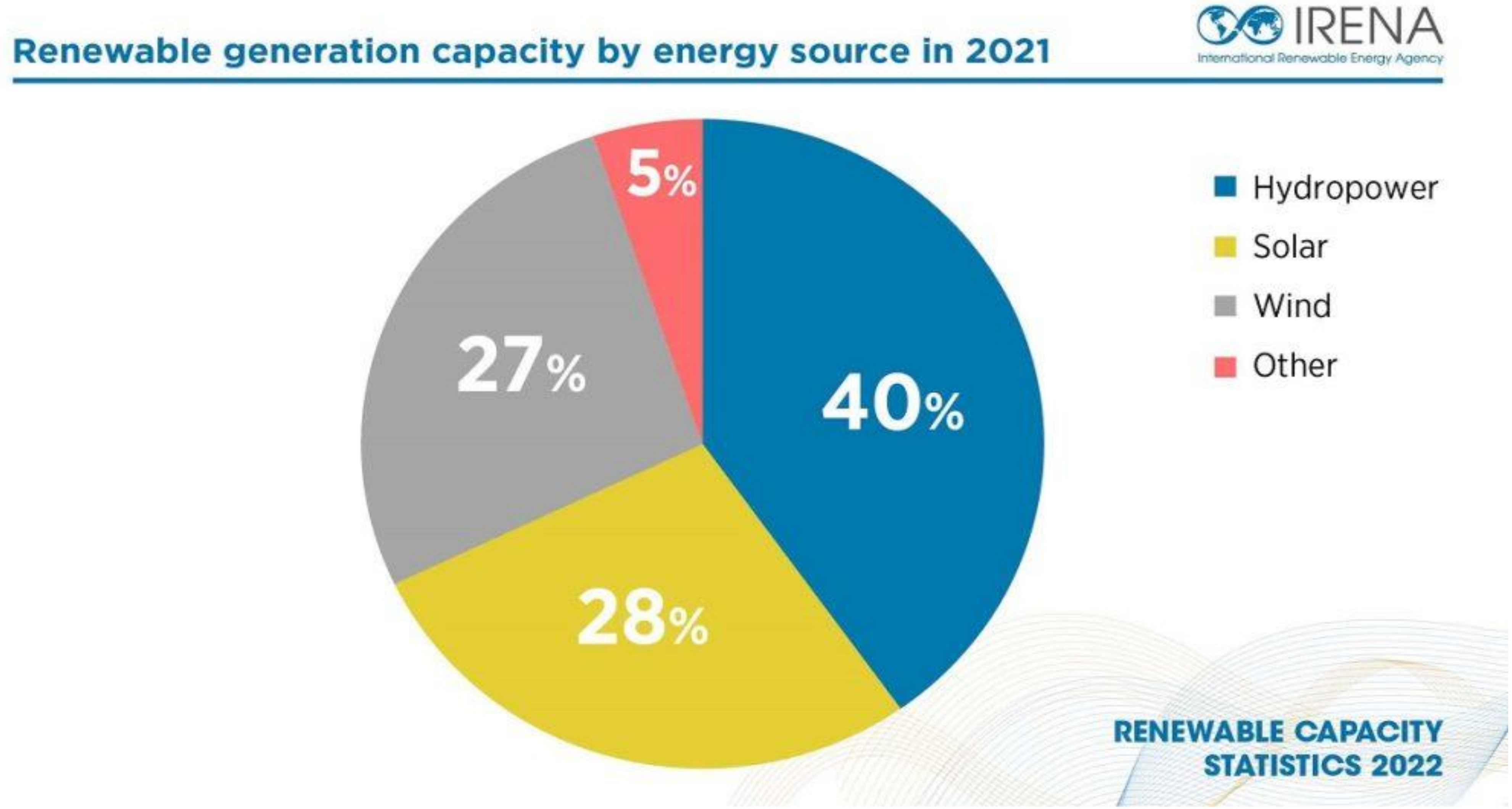


Source: International Energy Agency

Renewable share of annual power capacity expansion



Renewable Energy



Globle Renewable Energy Share

Solar Energy

الطــاقة الشمسية

نجم الشمس

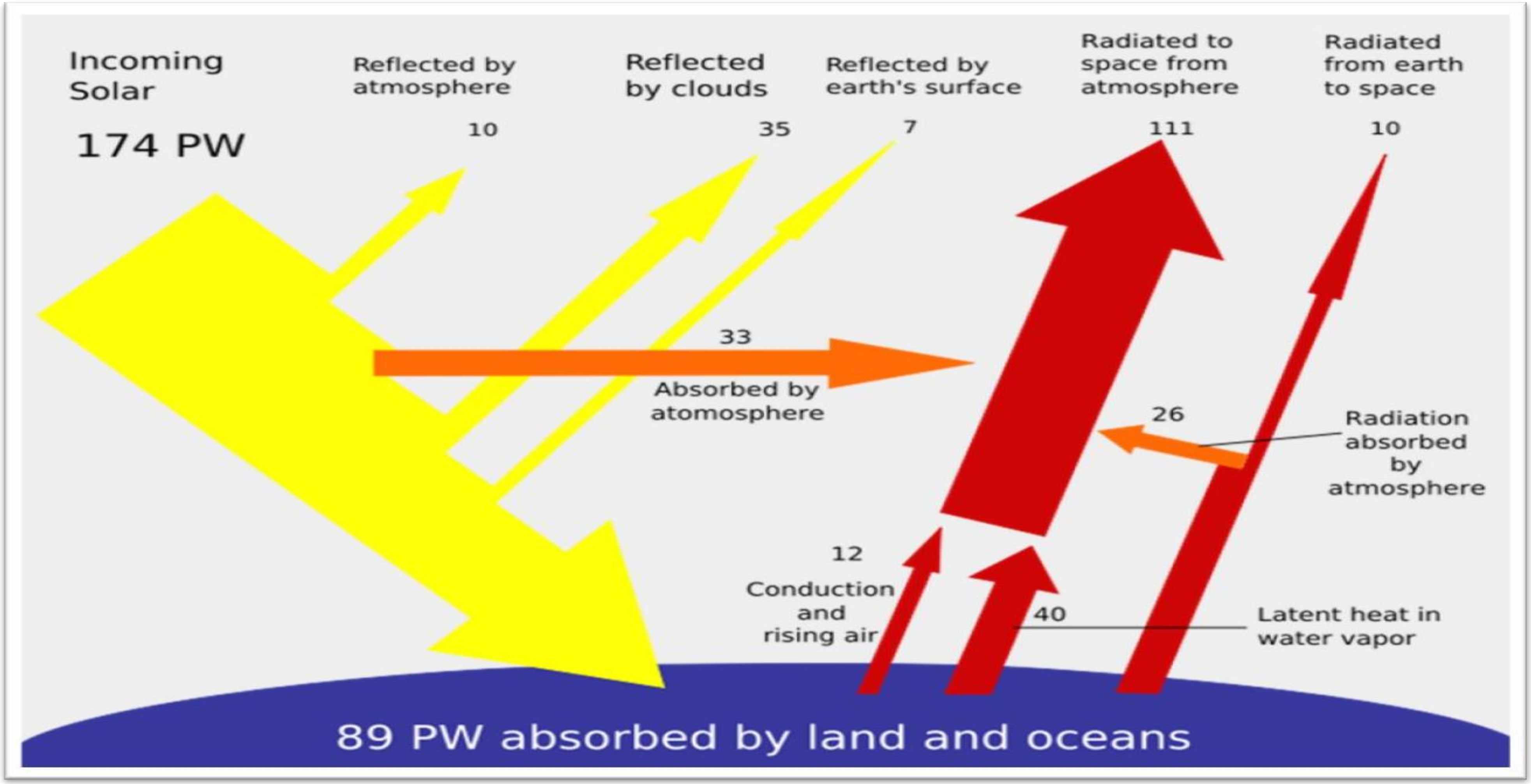
درجة الحرارة علي السطح حوالي ٥٠٠٠ درجة مئوية

درجة الحرارة في اللب حوالي ١٥٠٠٠ درجة مئوية

يبلغ قطر الشمس ١,٤ مليون كيلو متر

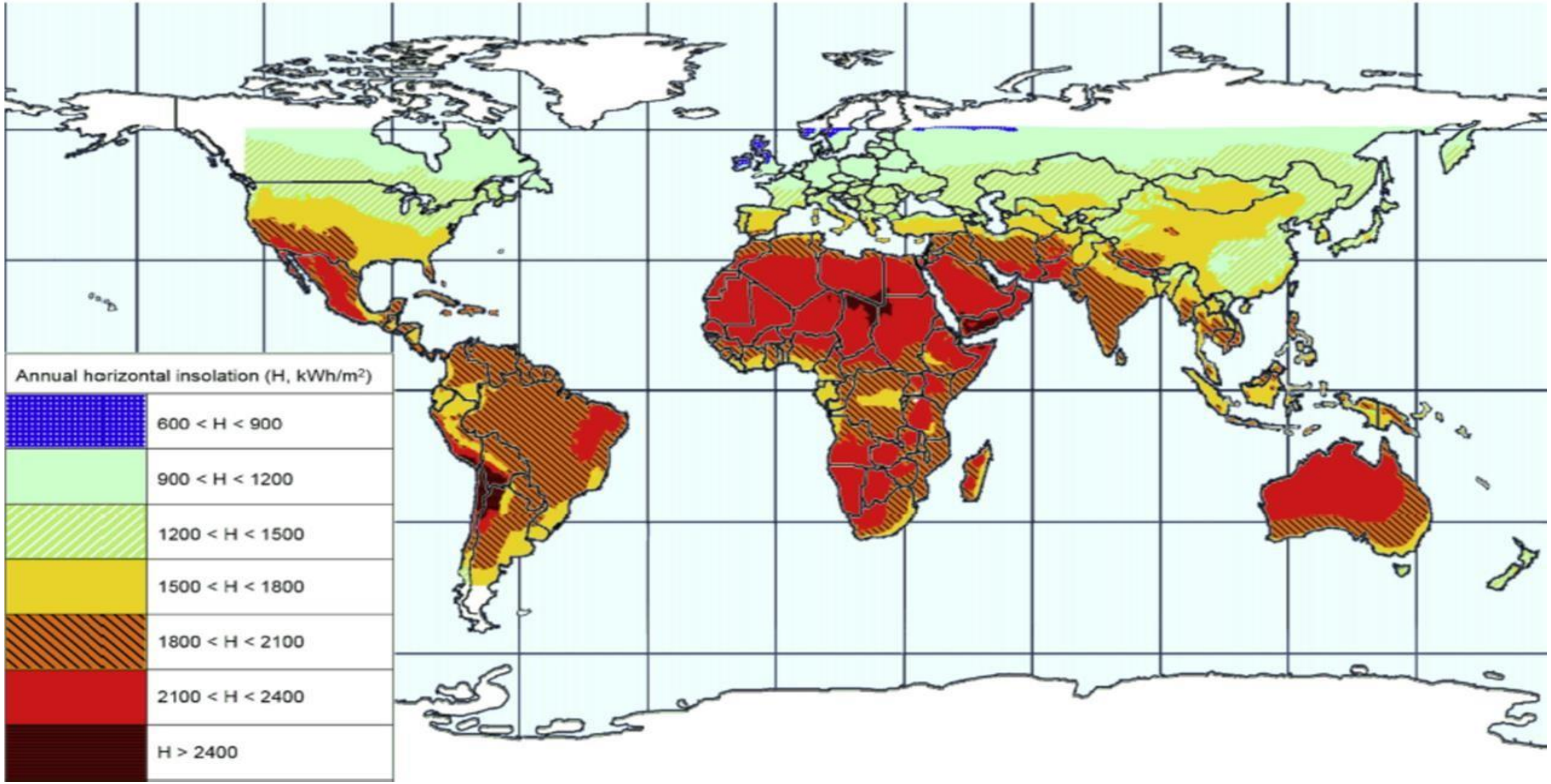
والشمس أكبر من كوكب الأرض ١٠٩ مرة

Solar Energy & Application



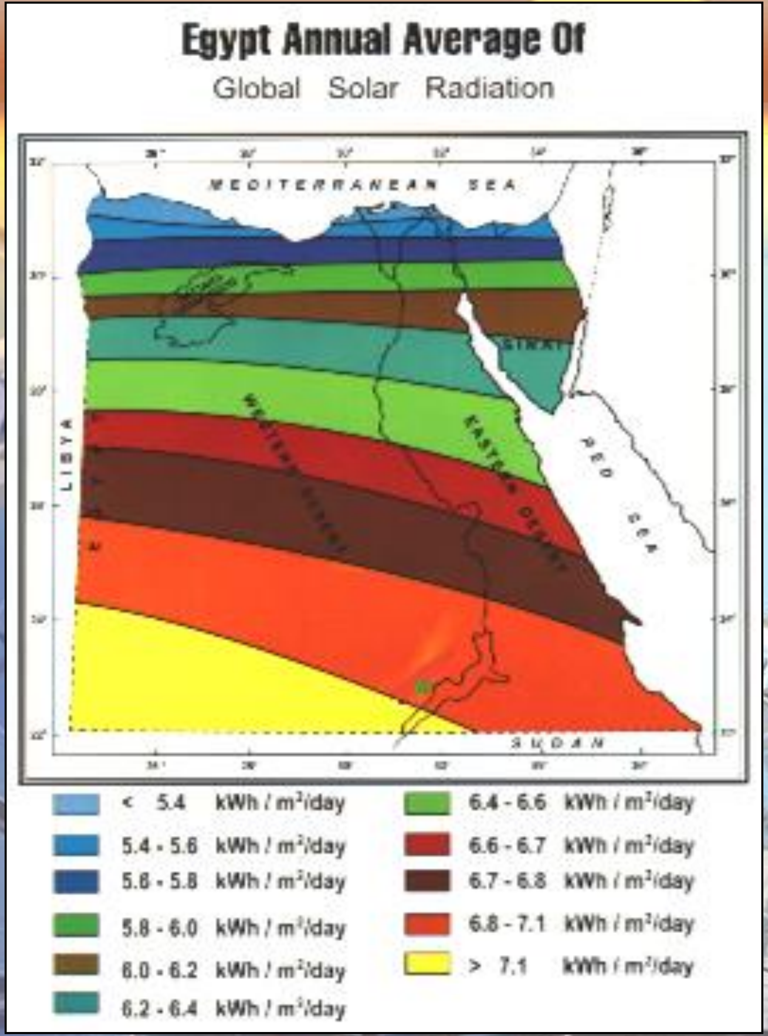
Solar Energy Radiation

Solar Energy



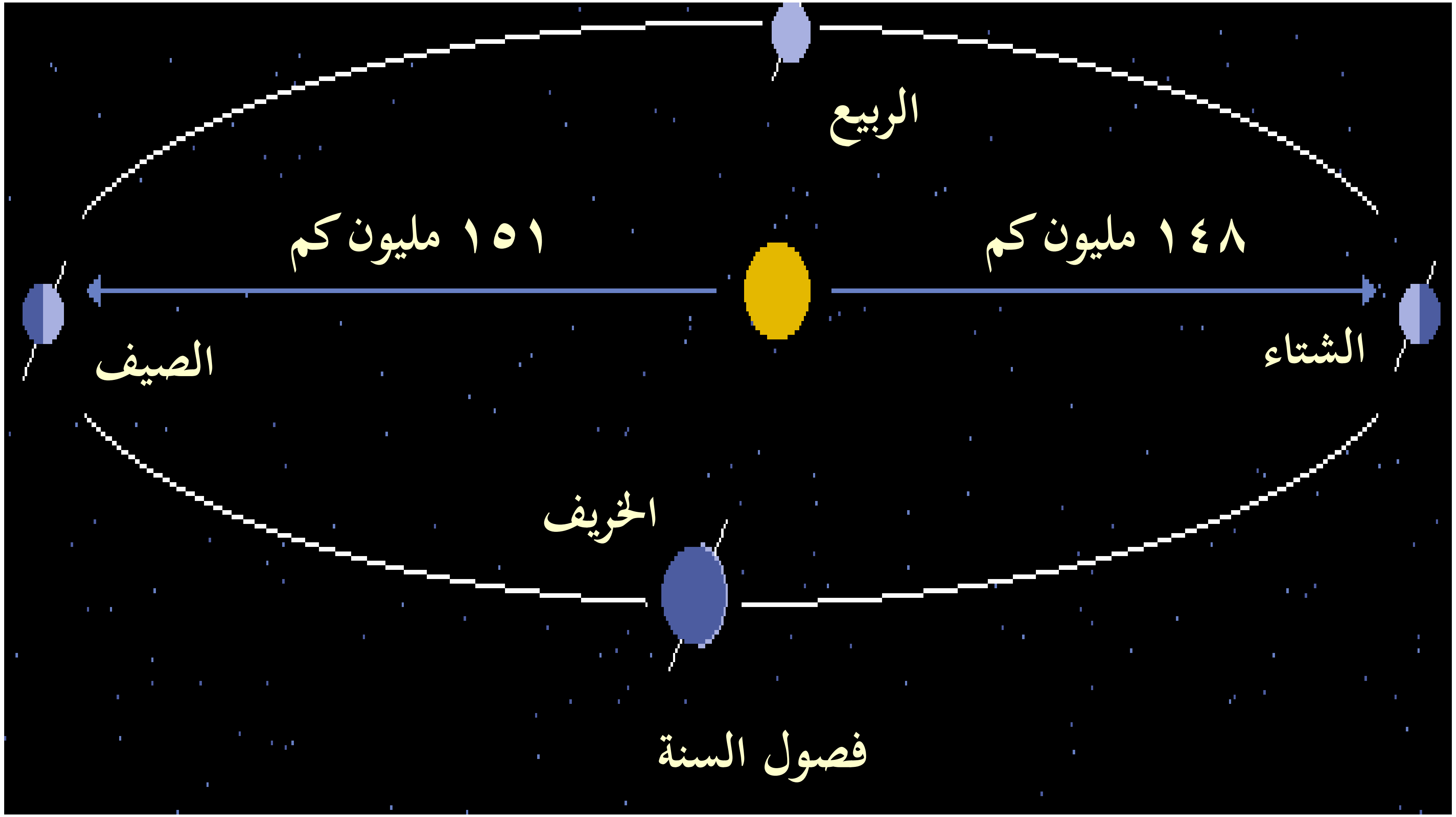
Annual cumulative global horizontal plane solar insolation

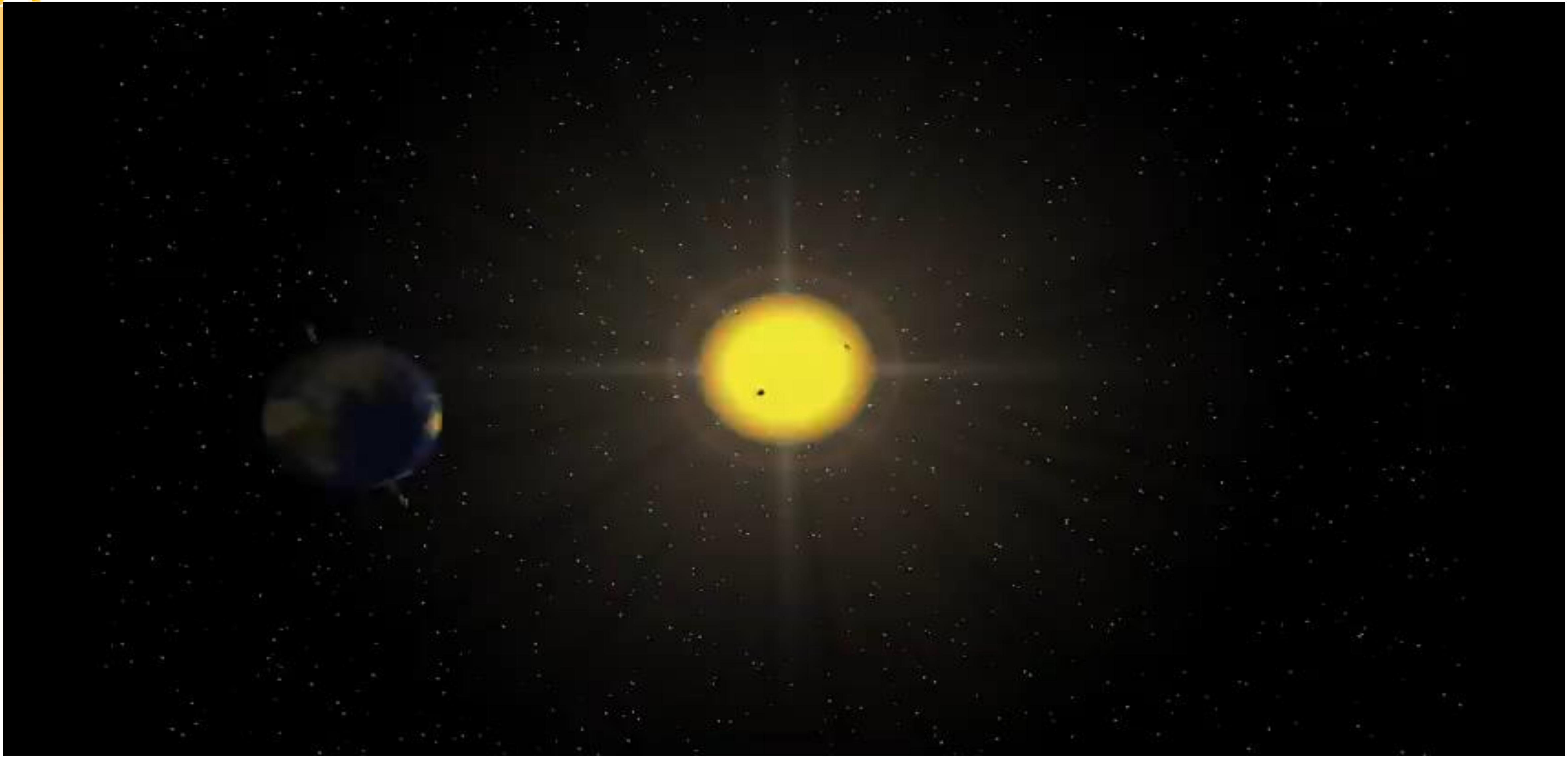
الأطلس الشمسى

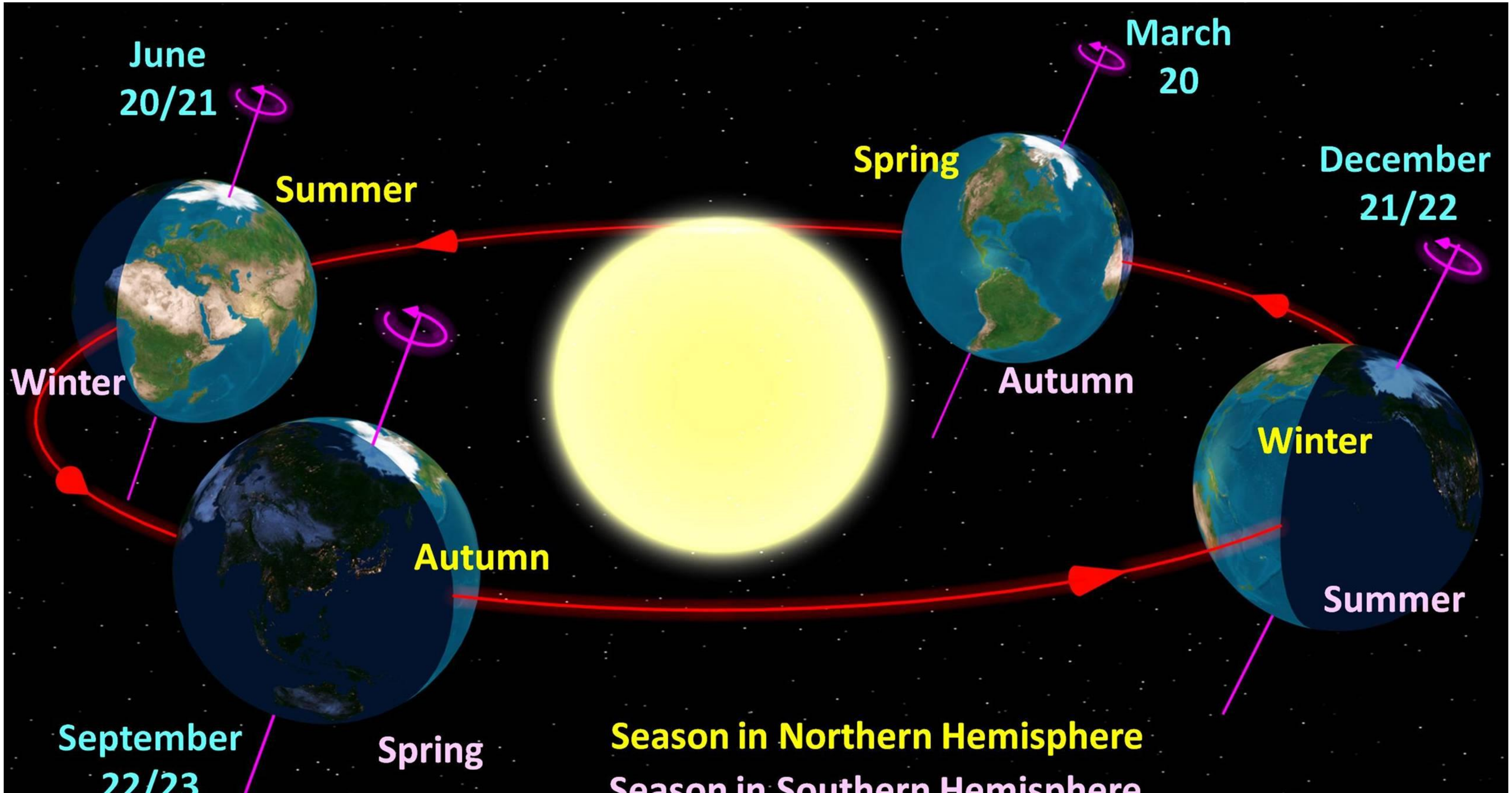


- تم اصدار اطلس شمسى شاملا تسجيلات على مدى سنوات لجميع مناطق الجمهورية ، متضمنا أيضا عام نمطي يتم فيه تمثيل البيانات المتوقعة لكل أيام العام مثل الاشعاع الشمسي وساعات سطوع الشمس.
- يتراوح متوسط الاشعاع الشمسي الكلي بين ١٩٠٠– ٢٦٠٠ ك.و.س/م٢/السنة.
- كثافة الاشعاع الشمسي المباشر بين ٢٠٠٠ – ٣٢٠٠ ك.و.س/م٢/السنة.
- يتراوح معدل سطوع الشمس بين ٩ – ١١ ساعة/ يوم.

حركة الشمس


الربيع
١٥١ مليون كم
١٤٨ مليون كم
الصيف
الشتاء
الخريف
فصول السنة

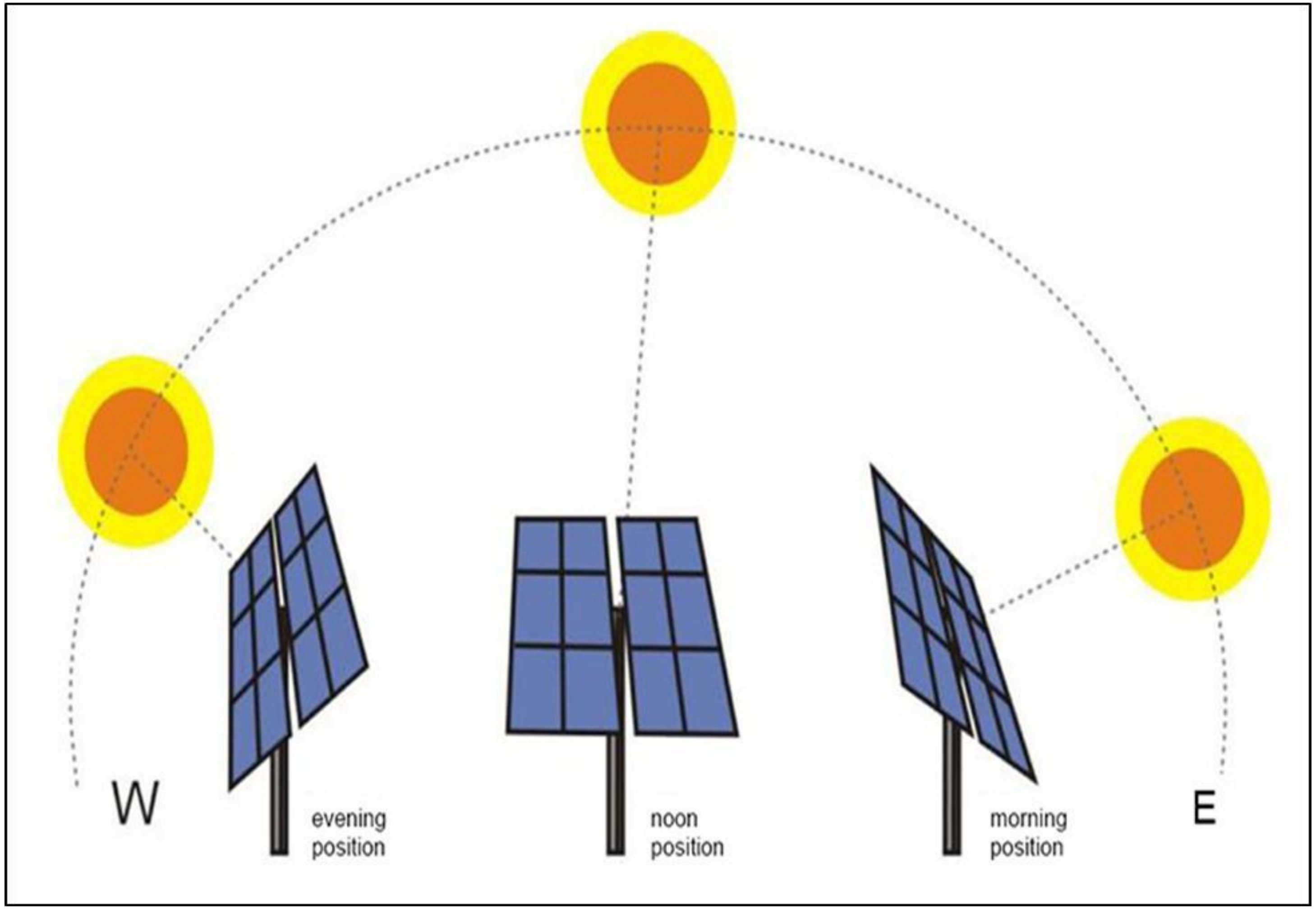



June
20/21
Summer
Winter
March
20
Spring
Autumn
December
21/22
Winter
Summer
Autumn
September
22/23
Spring
Season in Northern Hemisphere

Solar Cell Orientation & Angles

Azimuth Orientation:

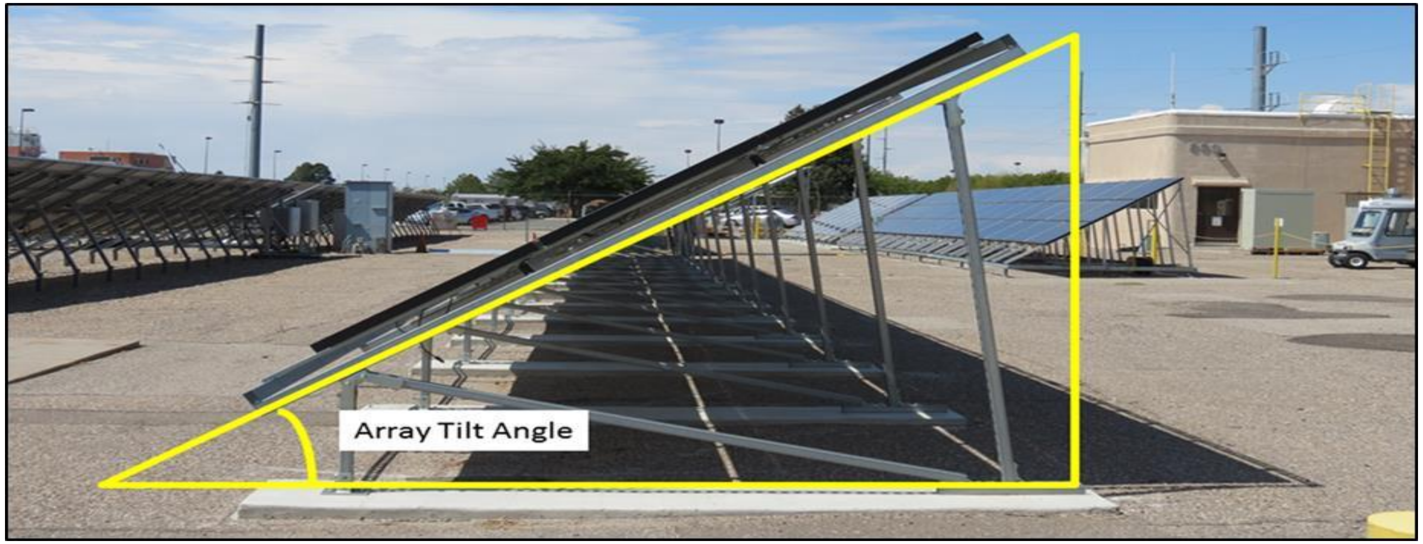
Azimuth – This is the compass angle of the sun as it moves through the sky from East to West over the course of the day. Generally, azimuth is calculated as an angle from true south.

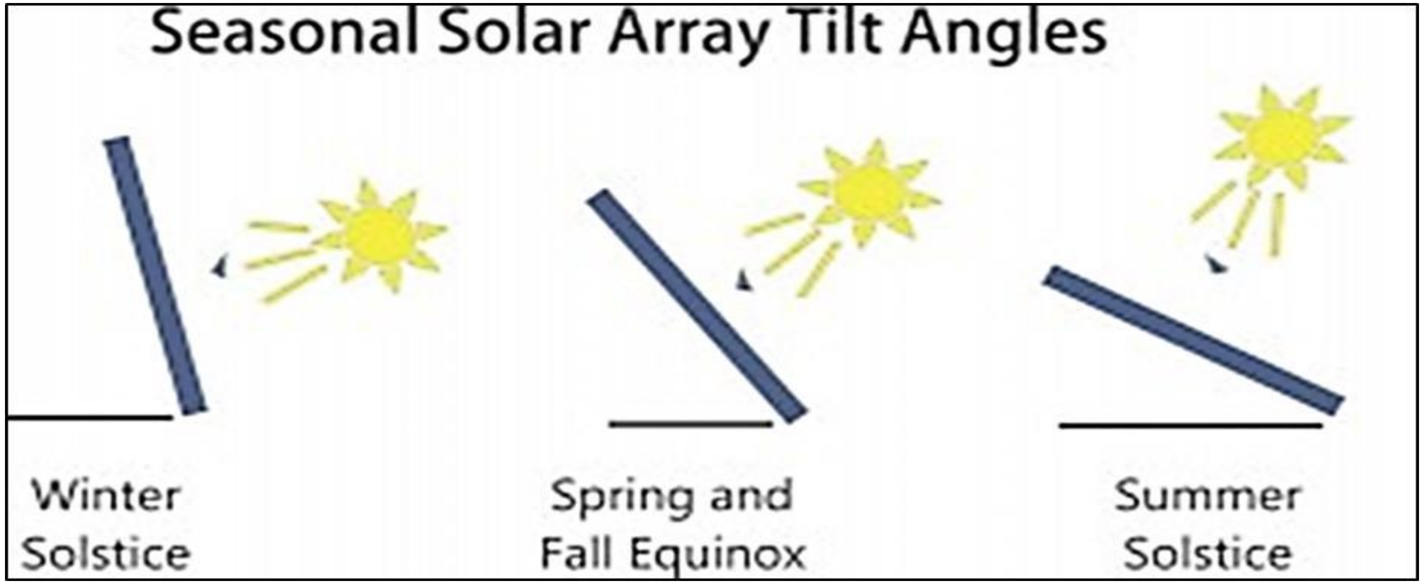


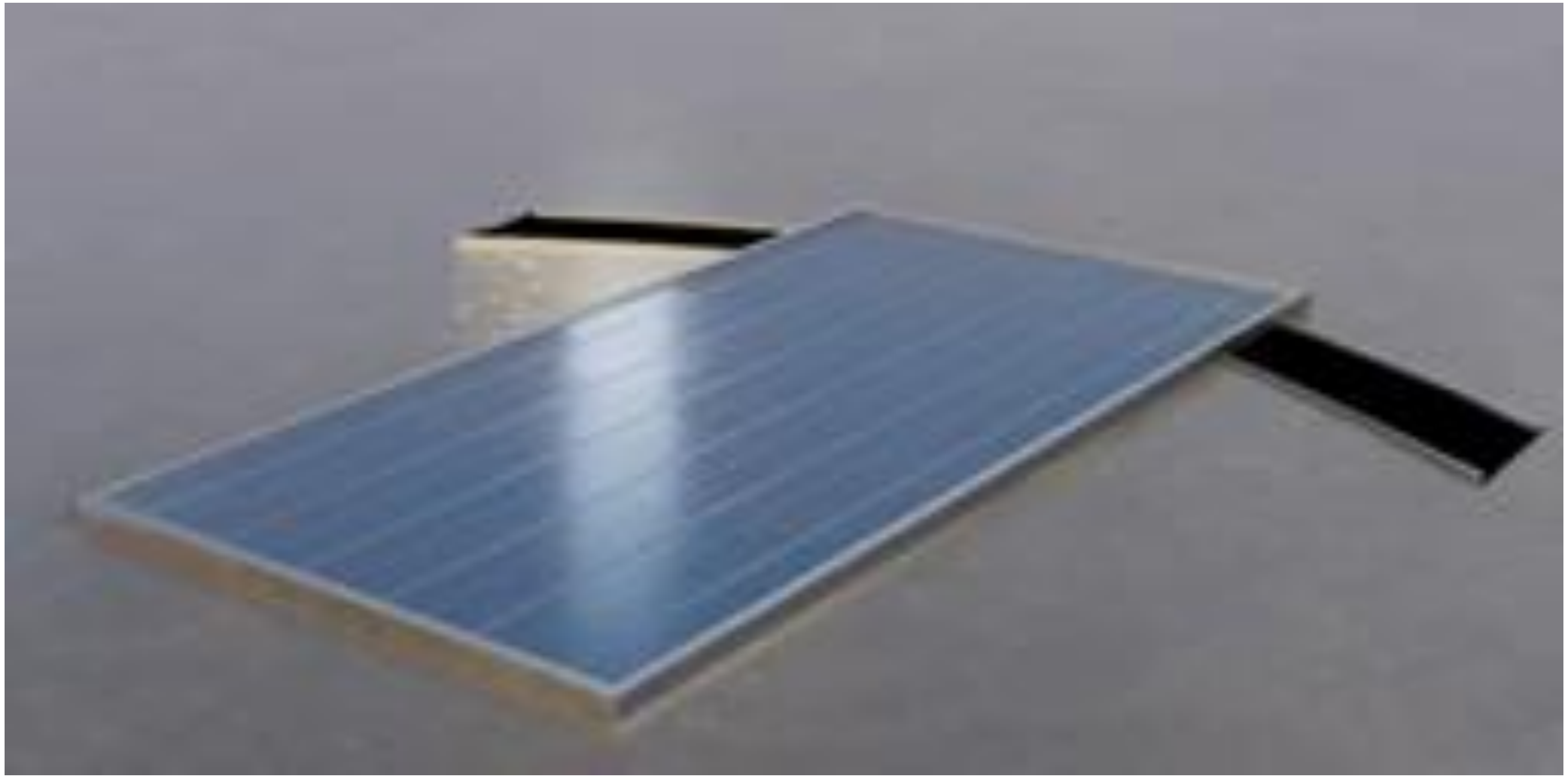
Solar Cell Orientation & Angles

Tilt Orientation:

Solar Panel Tilt refers to our zenith or elevation setting. Once the best azimuth position is found, the next parameter that is the key to producing the most solar electricity is the elevation of the PV panel.





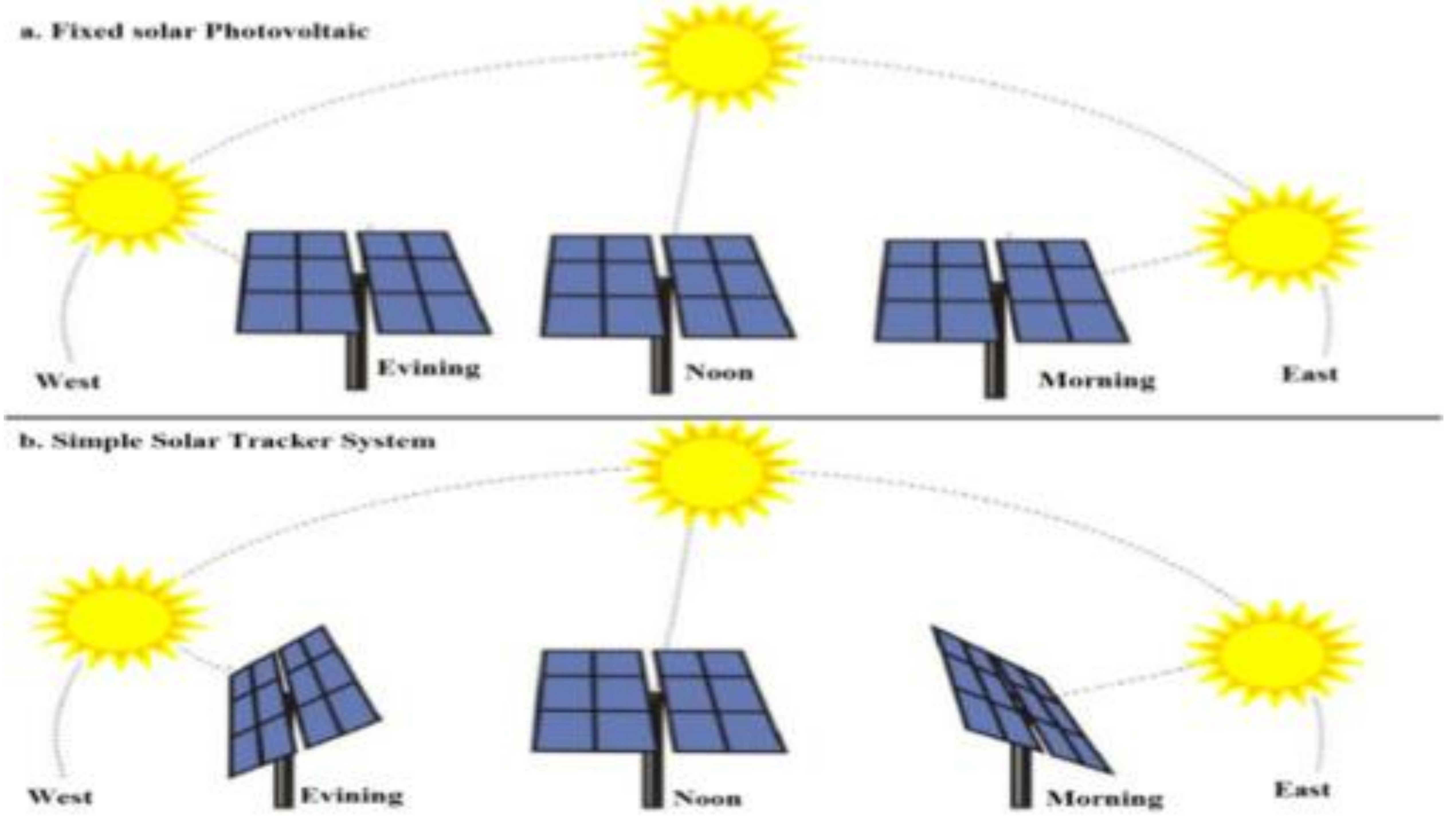


Solar Tracking

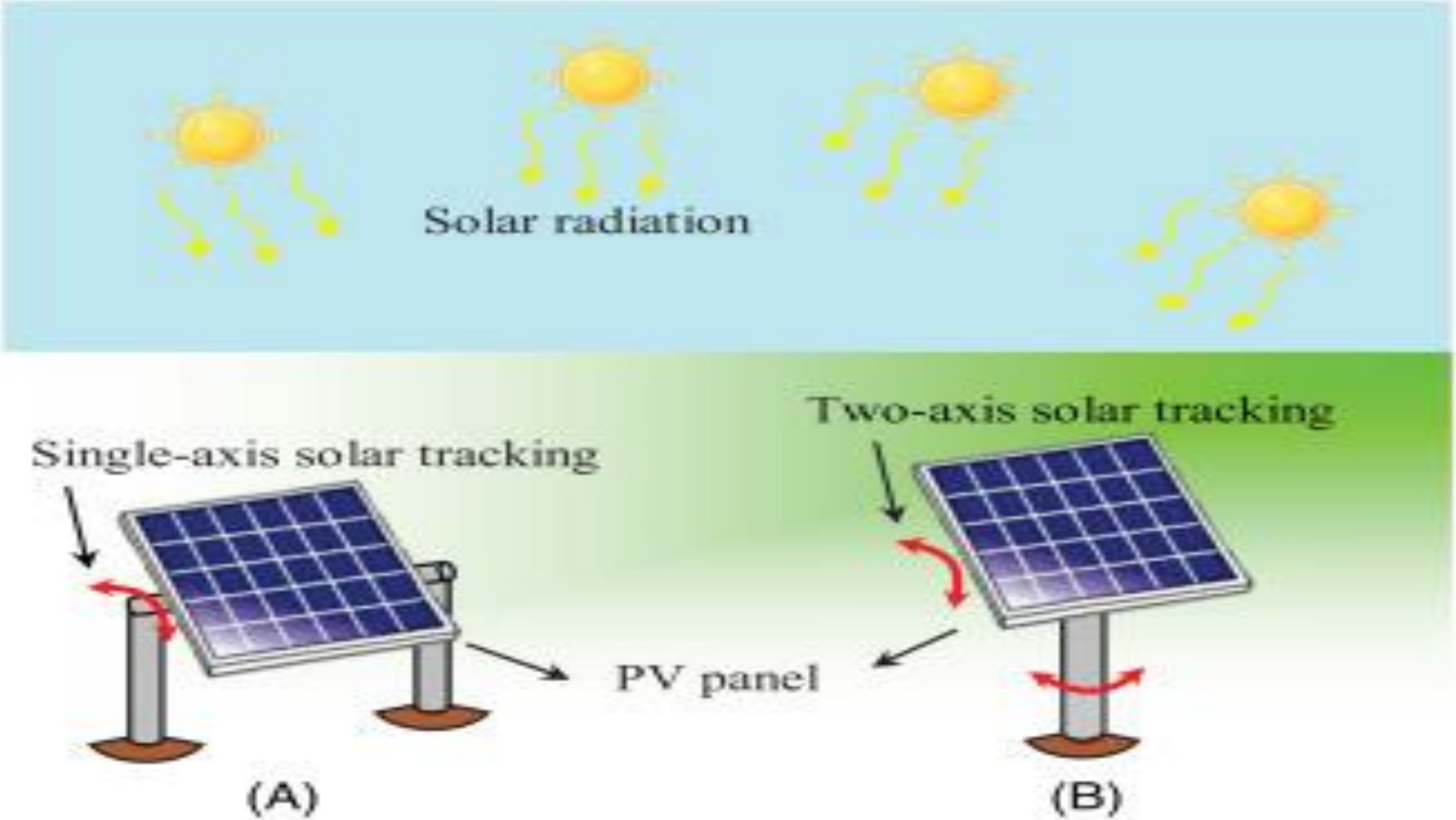
- Tracking the position of the sun in order to expose a solar panel to maximum radiation at any given time is the main purpose of a solar tracking PV system giving the best solar panel orientation at all times of the day.

- Solar tracking increases the solar radiation received by up to 25-30% compared to no tracking.

- Dual-axis tracking increase the solar radiation received by up to 33-38% compared to no tracking.


a. Fixed solar Photovoltaic
West
Evining
Noon
Morning
East
b. Simple Solar Tracker System
West
Evining
Noon
Morning
East

Anemometer
Sollink
Inverter
Reference voltage
230V / AC
Feed-in
Communication RS-485
Signal transmission anemometer
Voltage feed 24V / DC
Network cable
Safeguard
safeguard
WebBox
Internet
Router
Foundation
Cable channel


Solar radiation
Two-axis solar tracking
Single-axis solar tracking
PV panel
(A)
(B)

Solar Tracking

- **Website for Tilt Angle:**

http://solarelectricityhandbook.com/solar-angle-calculator.html

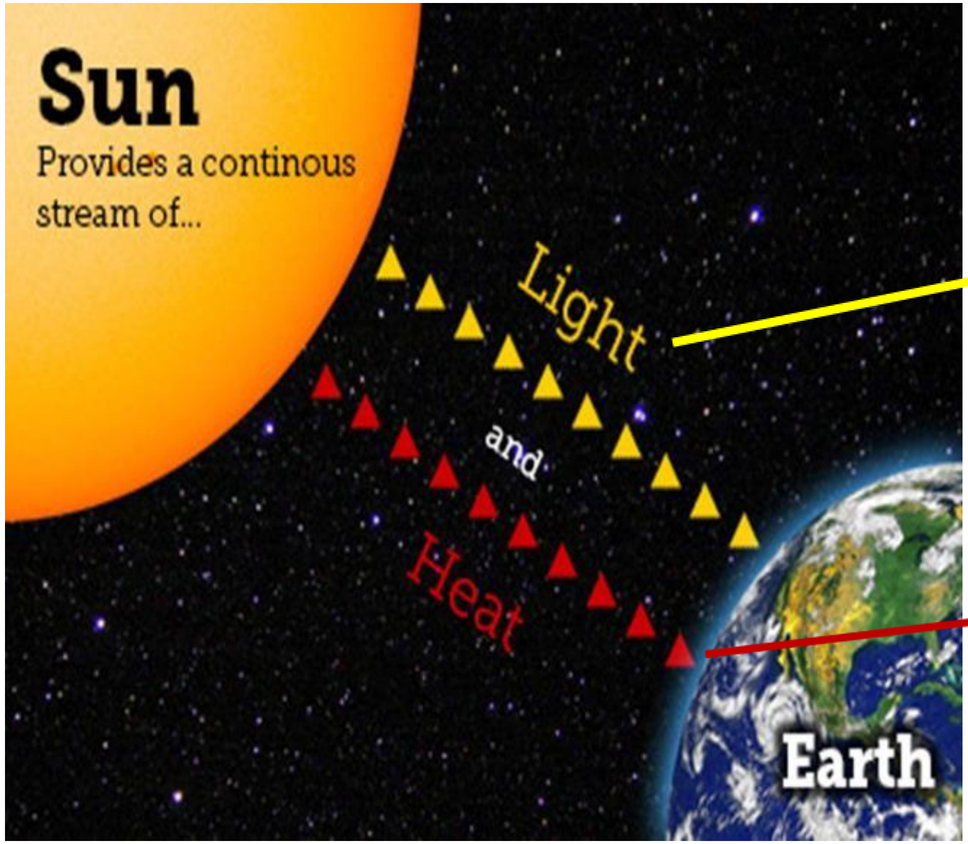
- **Websites for Sun-path Chart:**

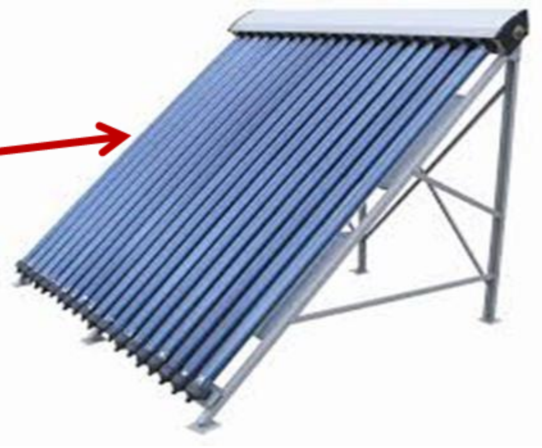
https://www.sunearthtools.com/dp/tools/pos_sun.php

http://solardat.uoregon.edu/SunChartProgram.html

Solar Energy & Application

- Solar energy is radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies.





Solar Energy & Application

- **The applications are classified according to the temperature: (Low-Medium-High)**

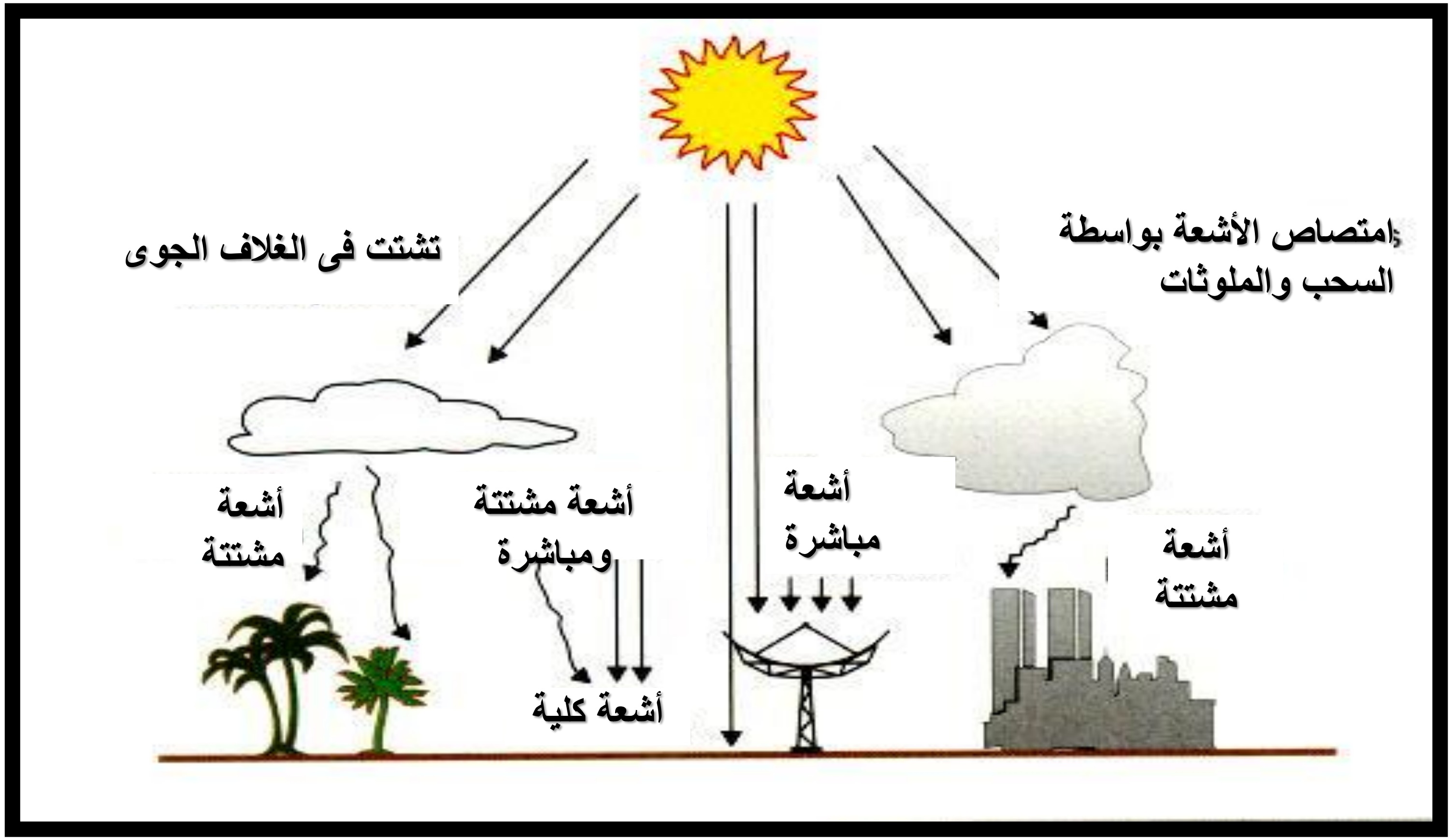
- 1) Low: (Domestic applications: Space heating, Water heating).

- 2) Medium: (Residential & Commercial applications: Cooking, Drying, Distillation).

- **3) High: (Power Generation applications).**

الطـاقة الشمسية

أنــواع الإشــعاع الشمســـي



الطــاقة الشمسية

تطبيقات الطـــاقة الشمســـية
سخـانات الميـاه الشمسيـة

التطبيقات (≥ ٨٠°م):-

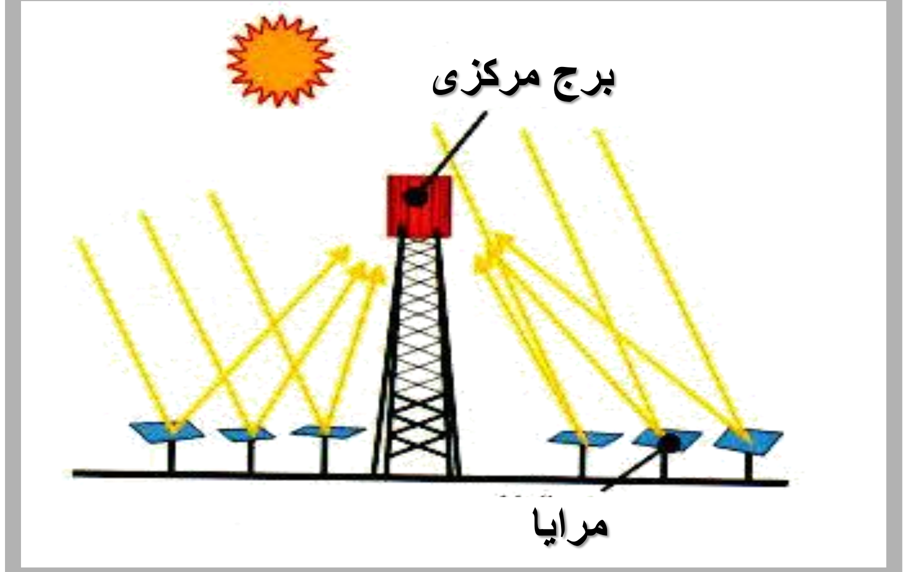
-المنازل

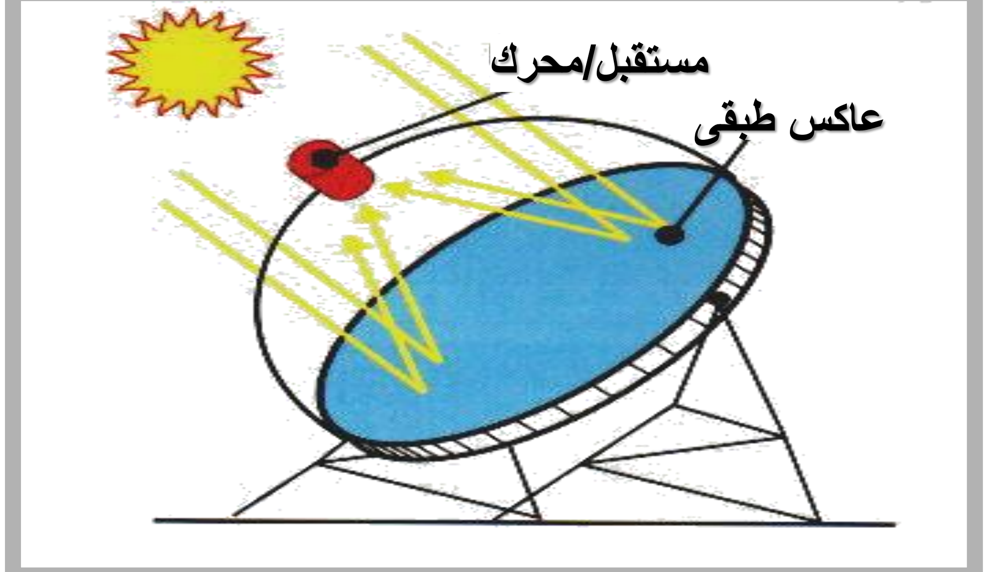
-الفنادق

-بعض المصانع

الطــاقة الشمسية

تطبيقات الطـــاقة الشمســية
المركزات الشمسيـة



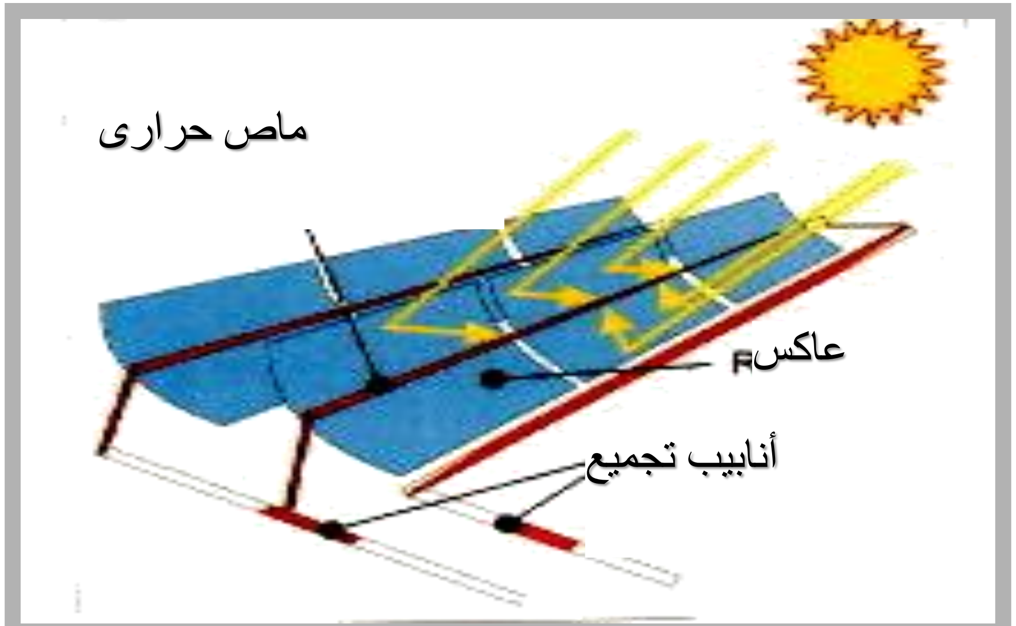


مُركزات البرج المركزي

مُـركــز طبقي

الطـاقة الشمسية

تطبيقات الطــــاقة الشمســـية
المركزات الشمسيـة

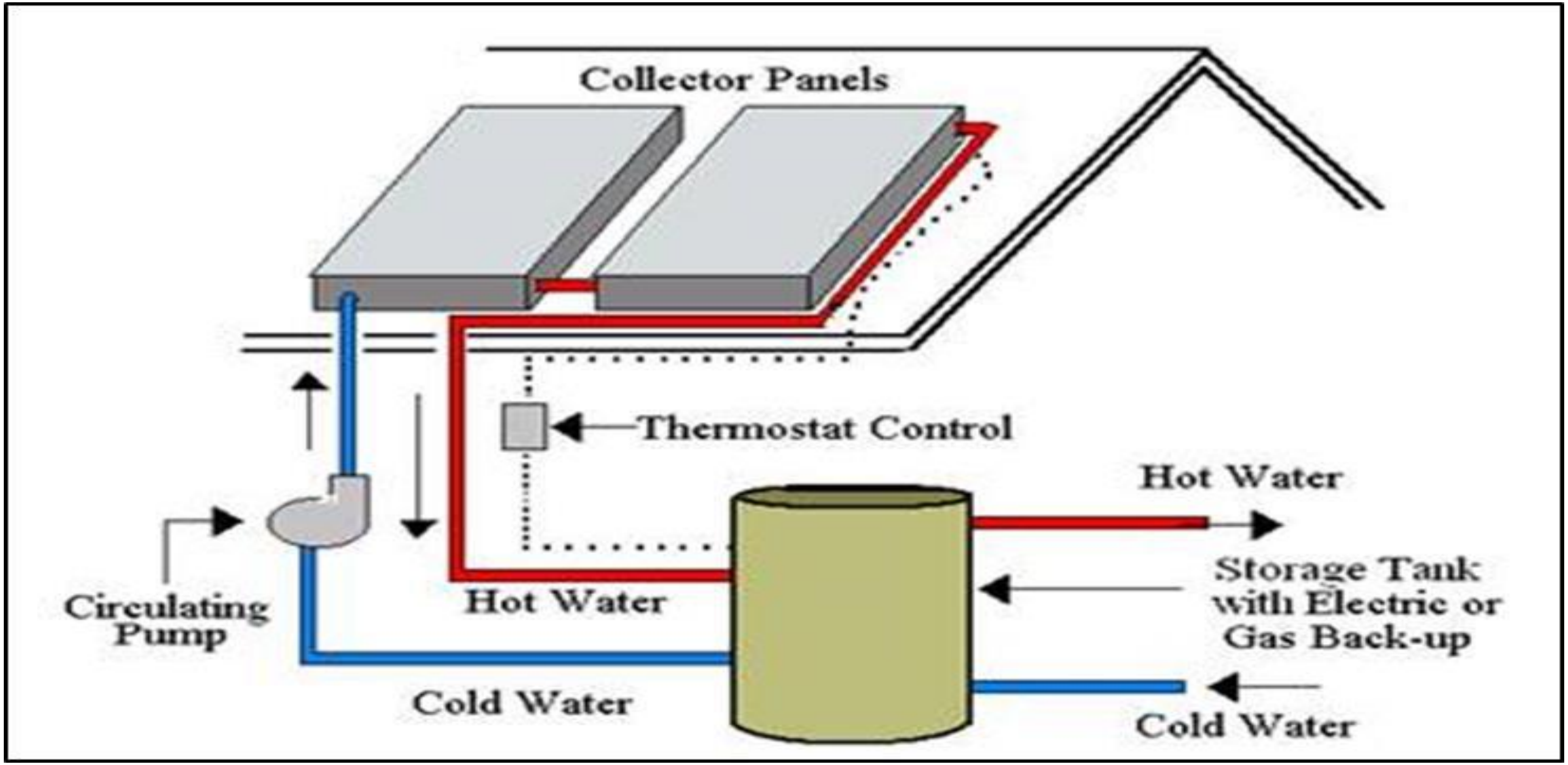


مركزات القطع المكافئ

Solar Water Heating

A solar water heating unit comprises a blackened flat plate metal collector with an associated metal tubing facing the general direction of the sun. The plate collector has a transparent glass cover above and a layer of thermal insulation beneath it.

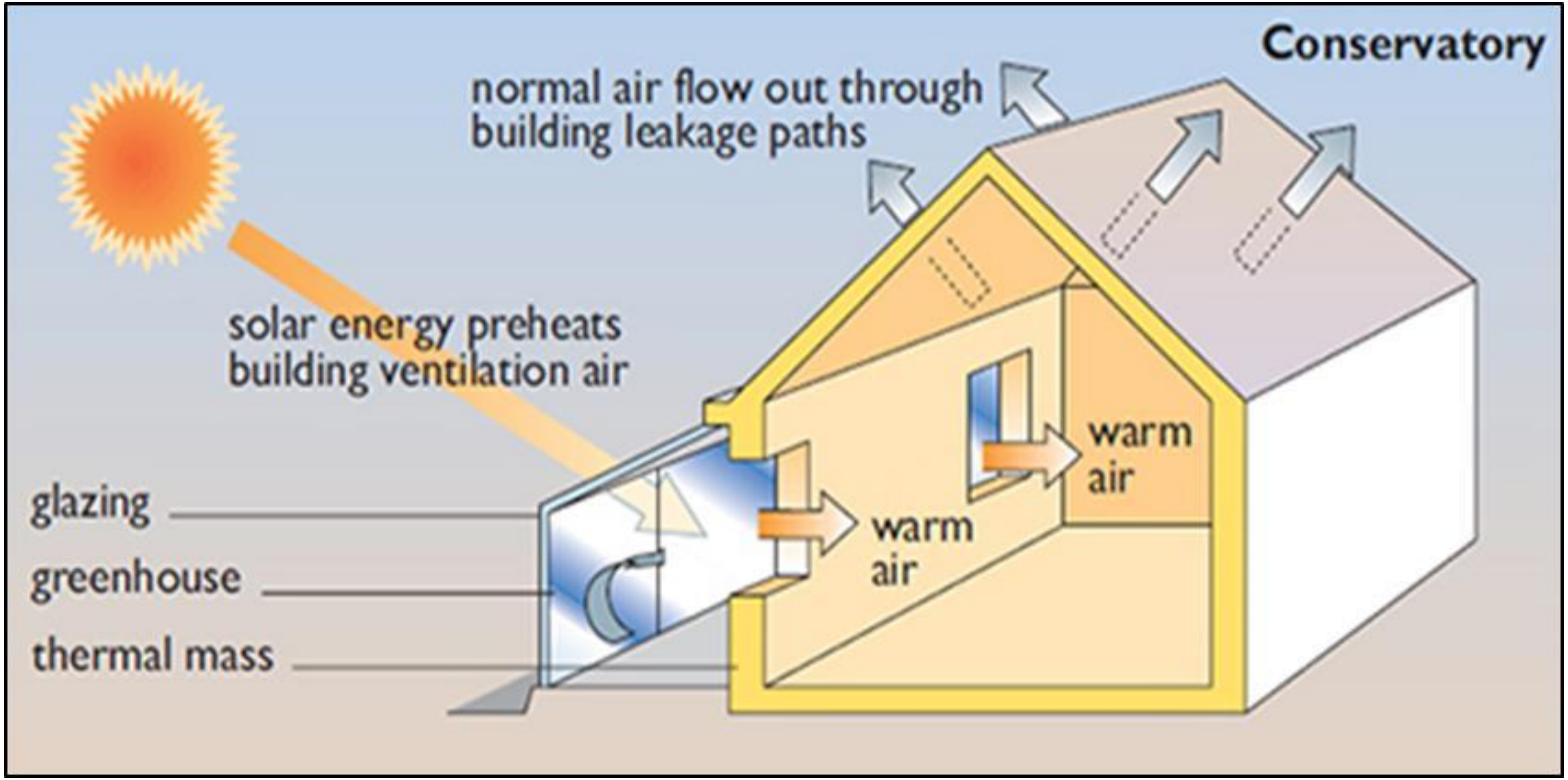
Solar Water Heating



Solar Heating of Buildings

(a) Collecting the solar radiation by some element of the building itself i.e. solar energy is admitted directly into the building through large South-facing windows.

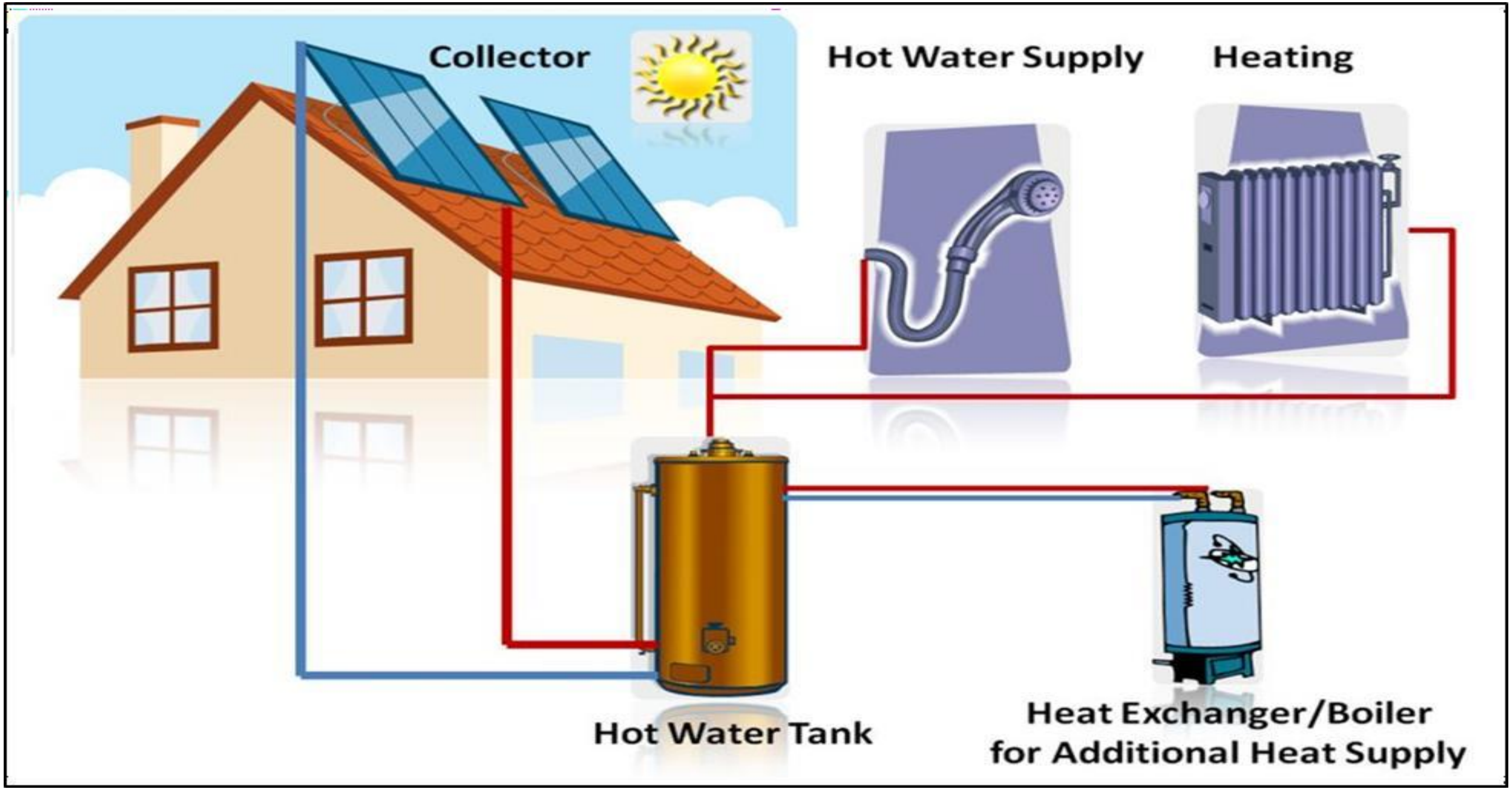
Solar Heating of Buildings



Solar Heating of Buildings

(b) Using separate solar collectors which may heat either water or air or storage devices which can accumulate the collected solar energy for use at night and during inclement days.

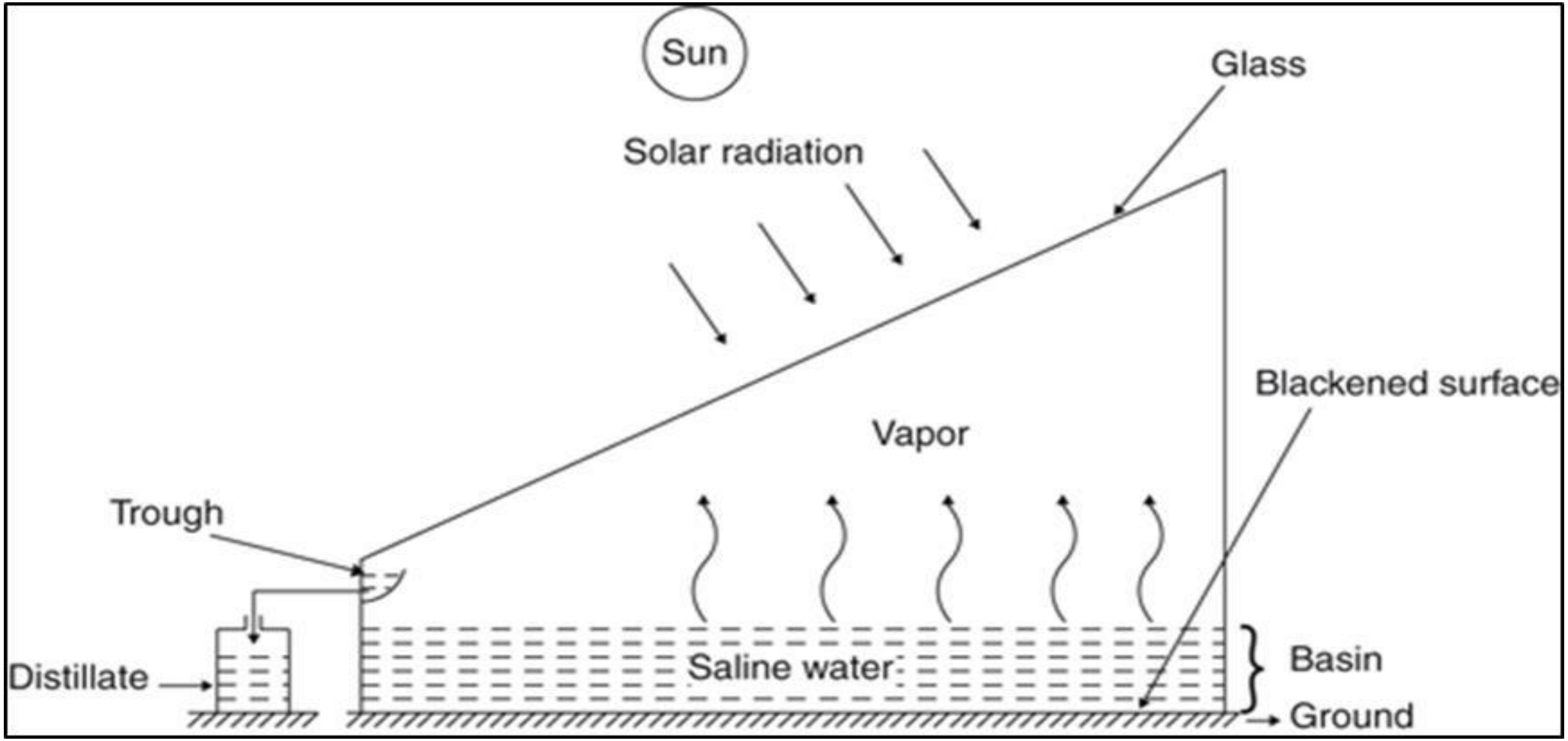
Solar Heating of Buildings



Solar Distillation

Solar radiation passes through the covers and is absorbed and converted into heat in the blackened surface causing the water to evaporate from the brine (impure saline water). The vapors produced get condensed to form purified water in the cool interior of the roof.

Solar Distillation



Solar Pumping

In solar pumping, the power generated by solar-energy is utilized for pumping water for irrigation purposes.

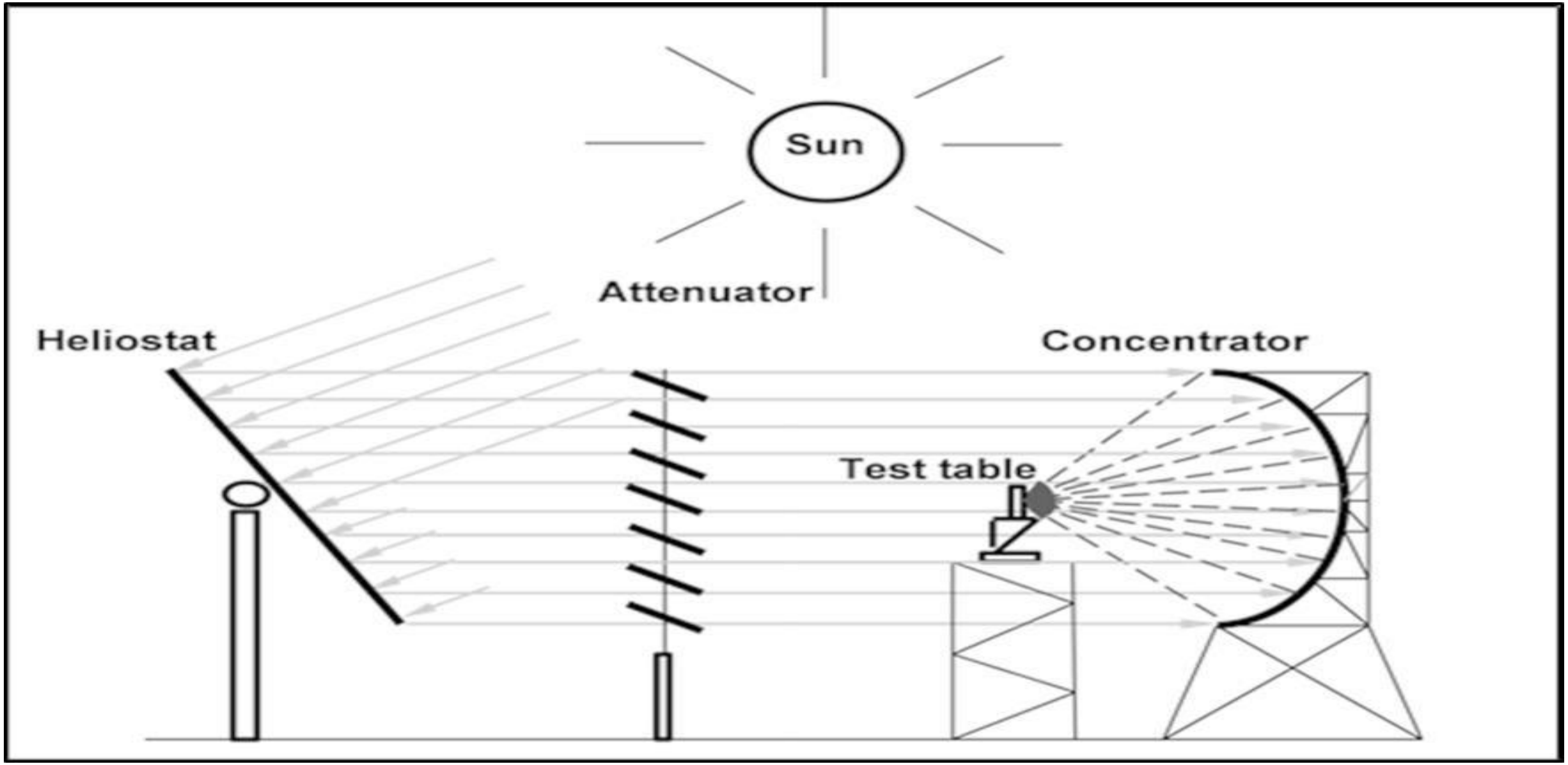
Solar Drying

Agricultural products are dried in a simple cabinet dryer which consists of a box insulated at the base, painted black on the inner side and covered with an inclined transparent sheet of glass.

Solar Furnace

In a Solar furnace, high temperature is obtained by concentrating the solar radiations onto a specimen using a number of heliostats (turn-able mirrors) arranged on a sloping surface.

Solar Furnace



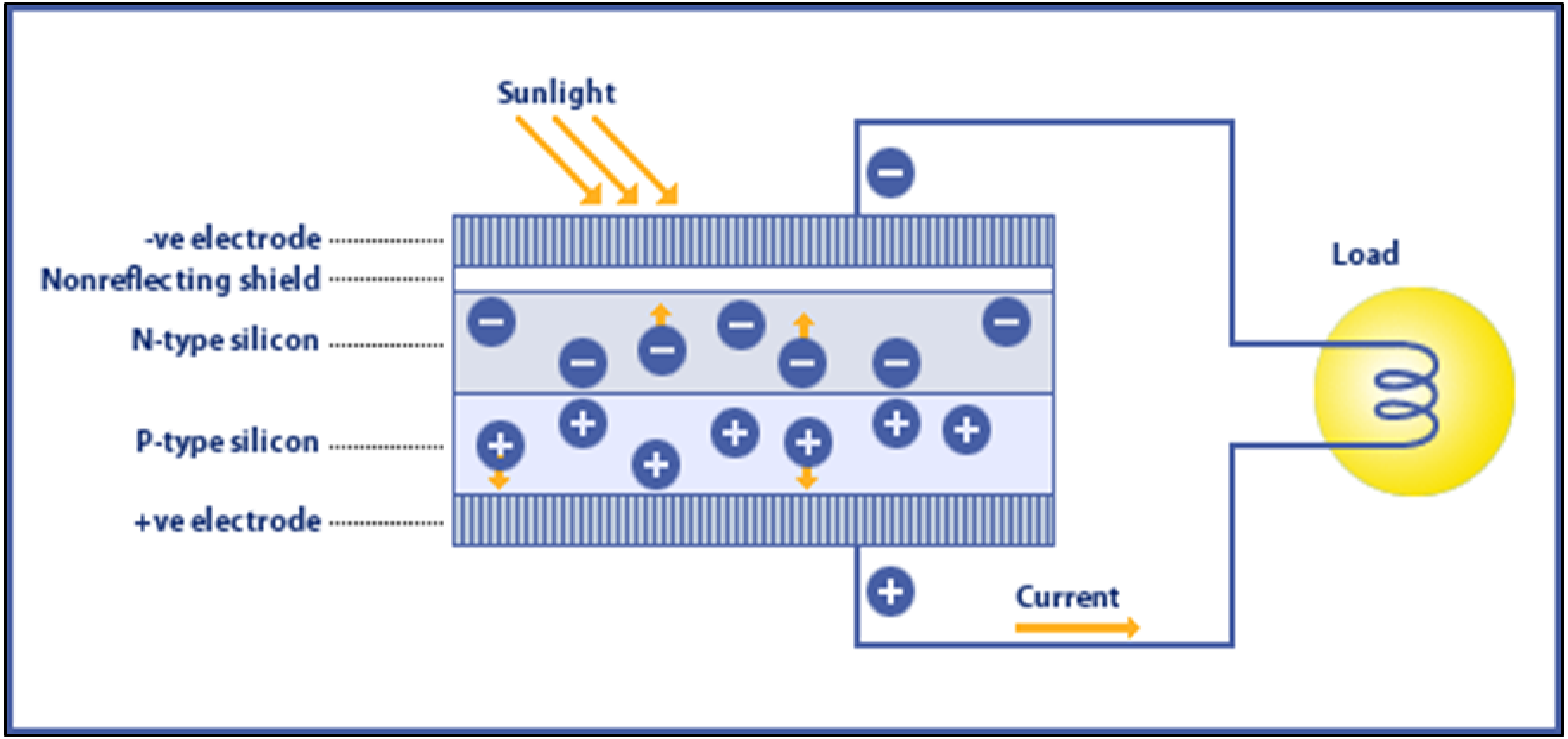
Solar Cooker

Concentrating sunlight: A mirrored surface with high specular reflectivity is used to concentrate light from the sun onto a small cooking area.

Solar Electric Power Generation

The photovoltaic cell is an energy conversion device which is used to convert photons of sunlight directly into electricity.

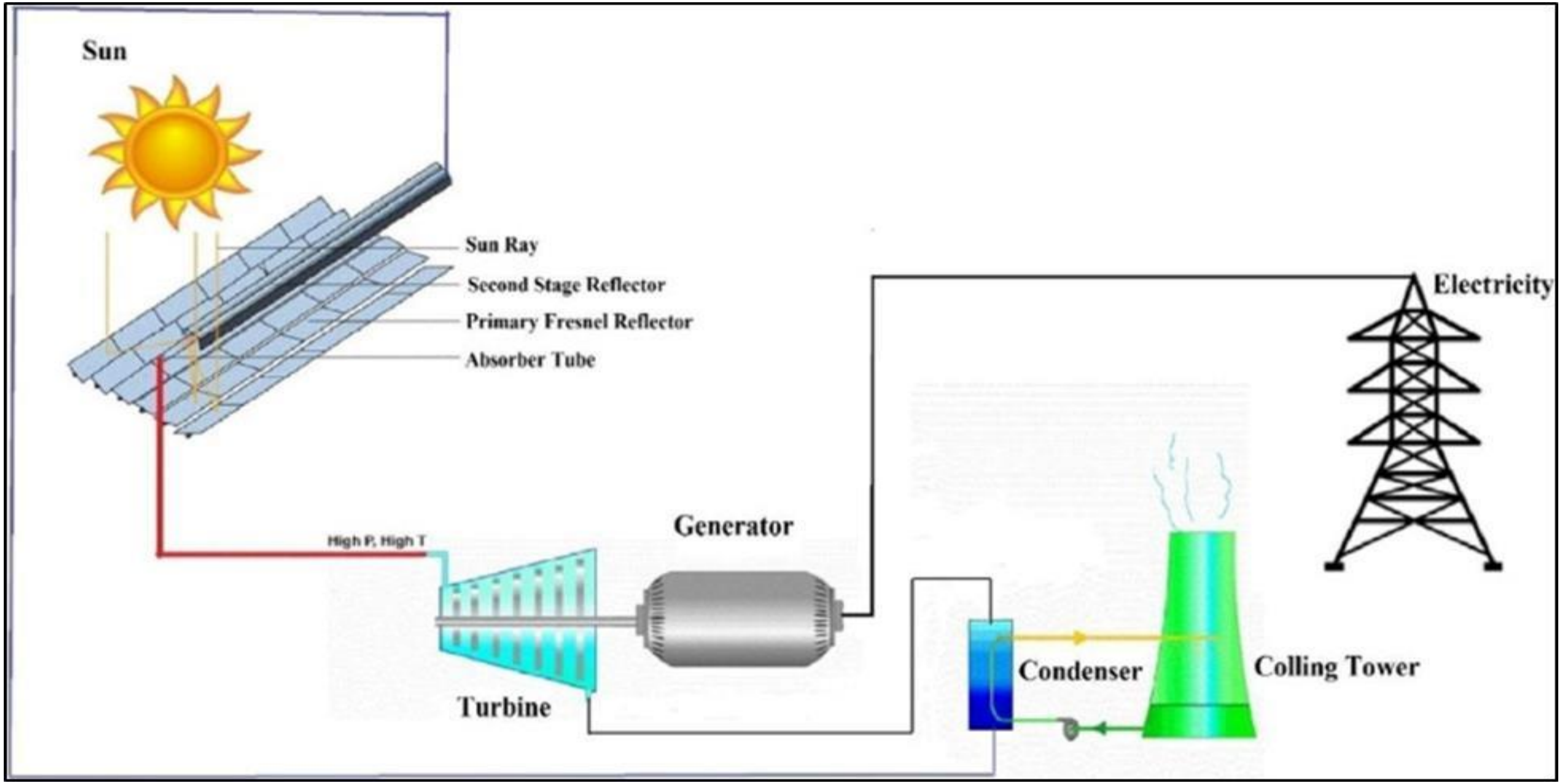
Solar Electric Power Generation



Solar Thermal Power Production

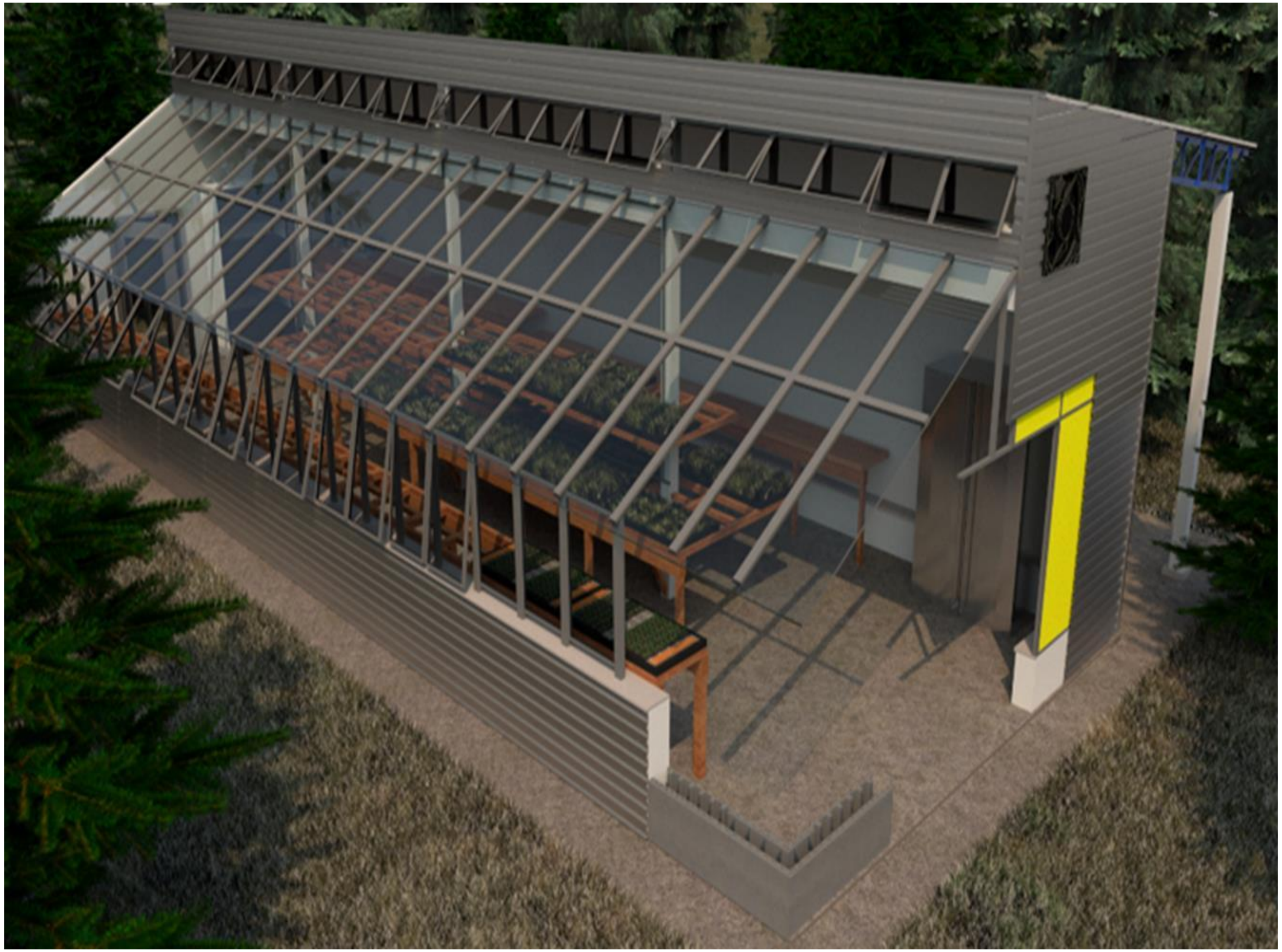
Solar energy is first utilized to heat up a working fluid. This heat energy is then converted into mechanical energy through a turbine. Finally a conventional generator coupled to a turbine converts this mechanical energy into electrical energy.

Solar Thermal Power Production



Solar Green House

A green house is a structure covered with transparent material (glass or plastic) that acts as a solar collector and utilizes solar radiant energy to grow plants.

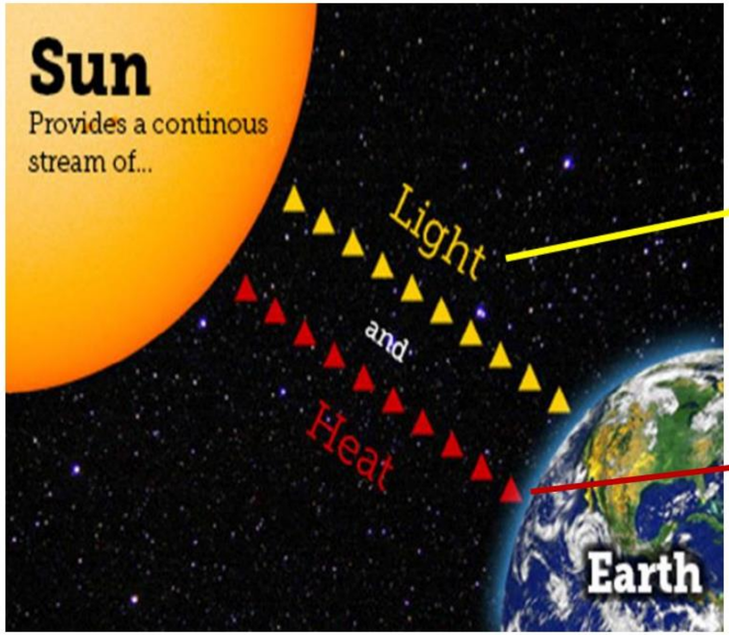


Shading

Shading of photovoltaic modules is one of the most significant causes of losses in a PV system. In fact, the shading of 10% of the area of a system could cause a loss of 50%. This disproportionate effect is caused by string design.

Solar Energy & Application

- **Solar energy is radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies.**

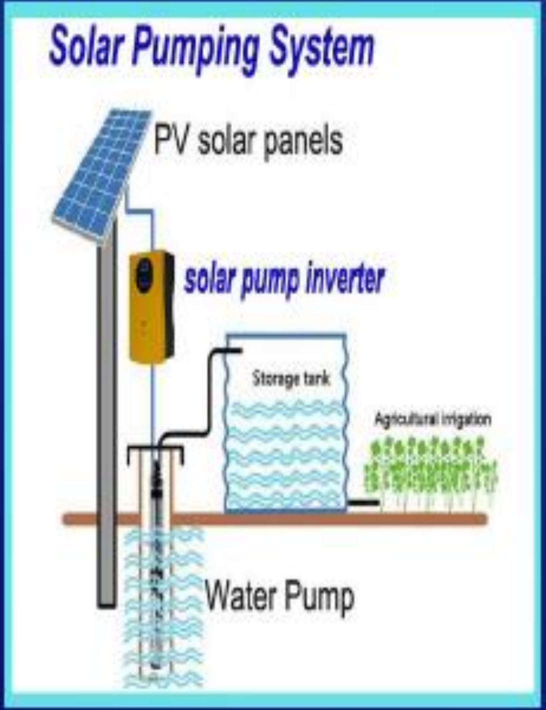


SOLAR ENERGY

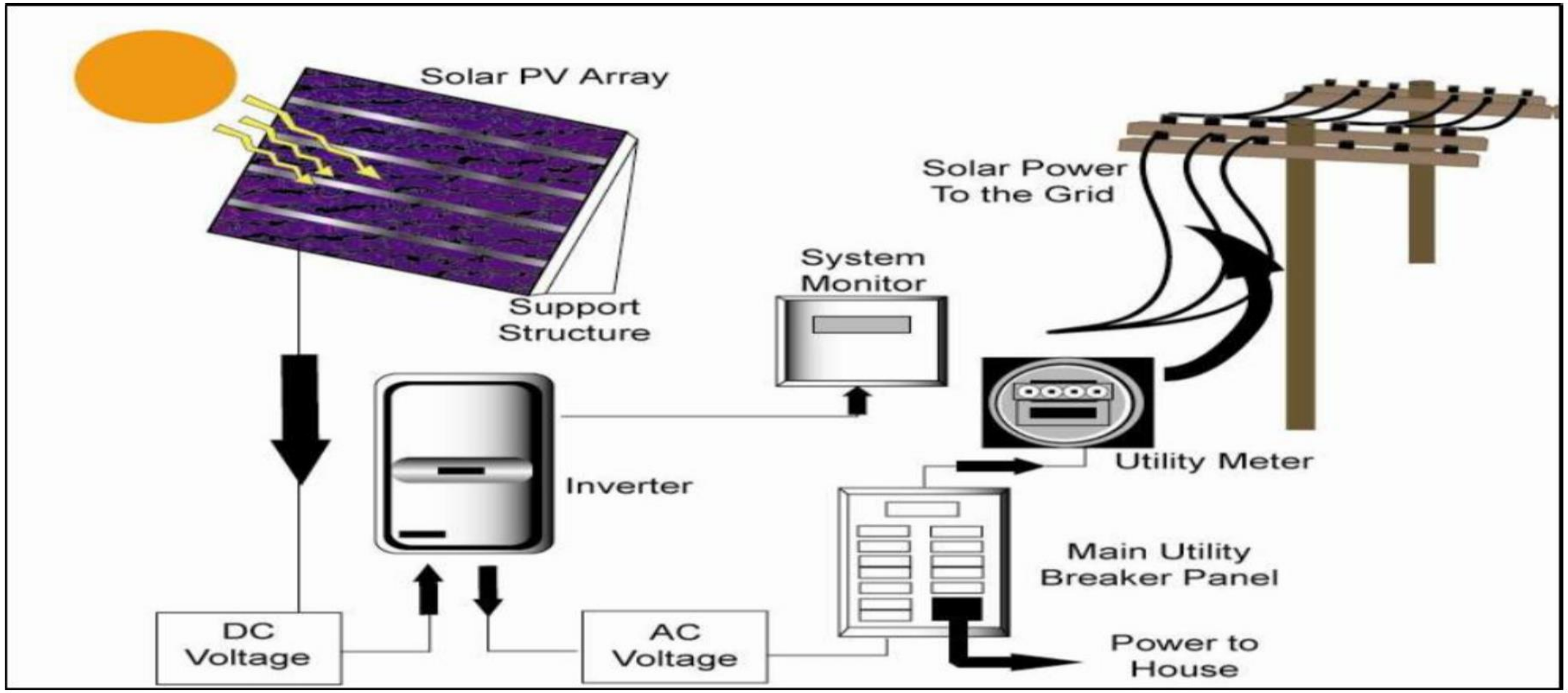
Types of solar systems

OFF Grid System

ON Grid System



Solar Photovoltaic Systems



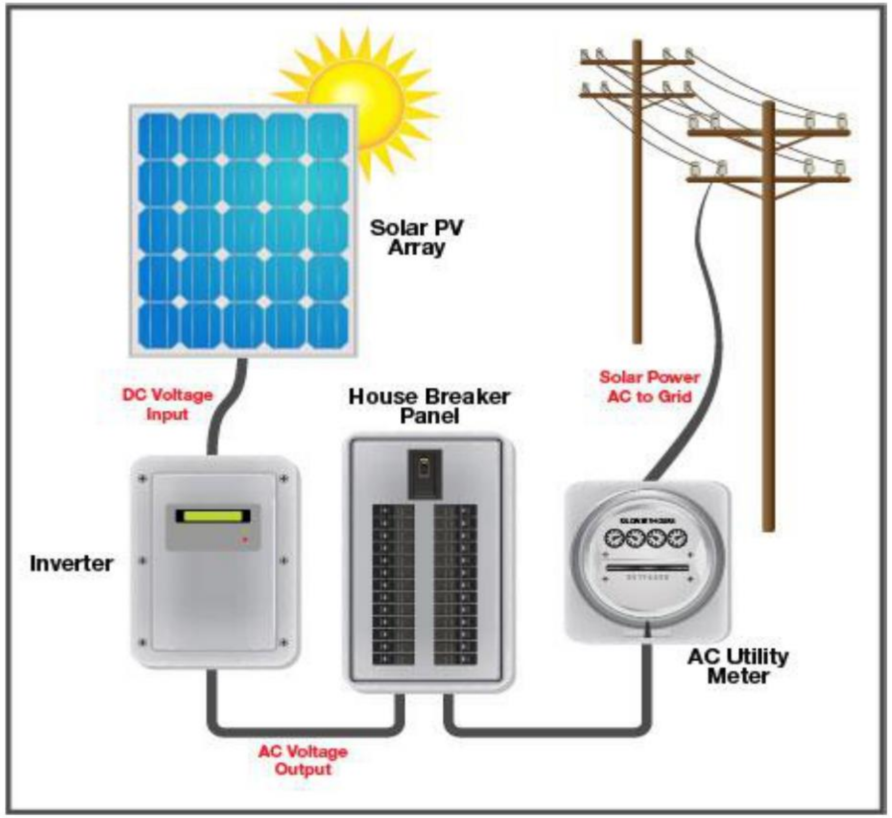
Grid-Tied PV System (ON-GRID)

Different Types of Inverter

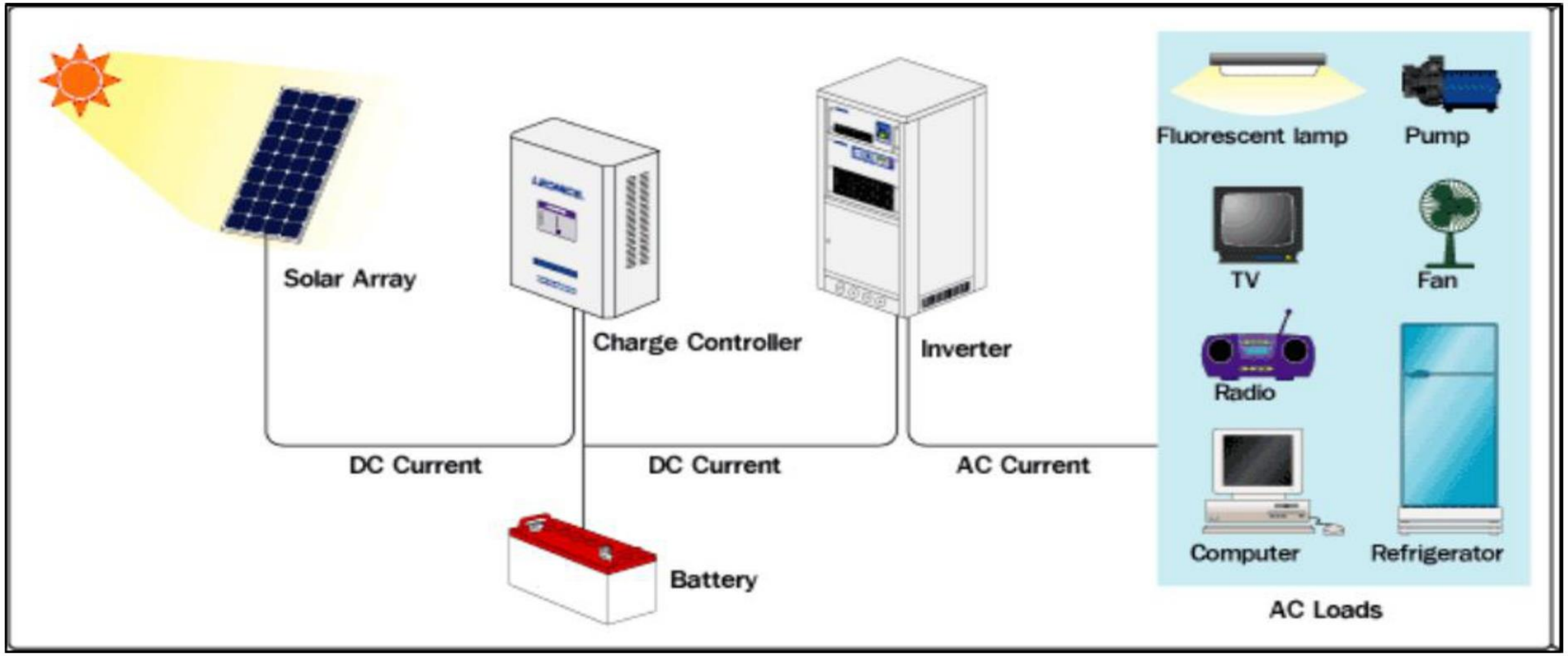
- **2. Grid Tie Inverter:**

A grid-tie inverter has a different function than the off-grid inverter. It not only converts DC current into an alternating current suitable for injecting into an electrical power grid.

To inject electrical power efficiently and safely into the grid, grid-tie inverters must accurately match the voltage sampling and synchronization and phase of the grid sine wave AC waveform.



Solar Photovoltaic Systems

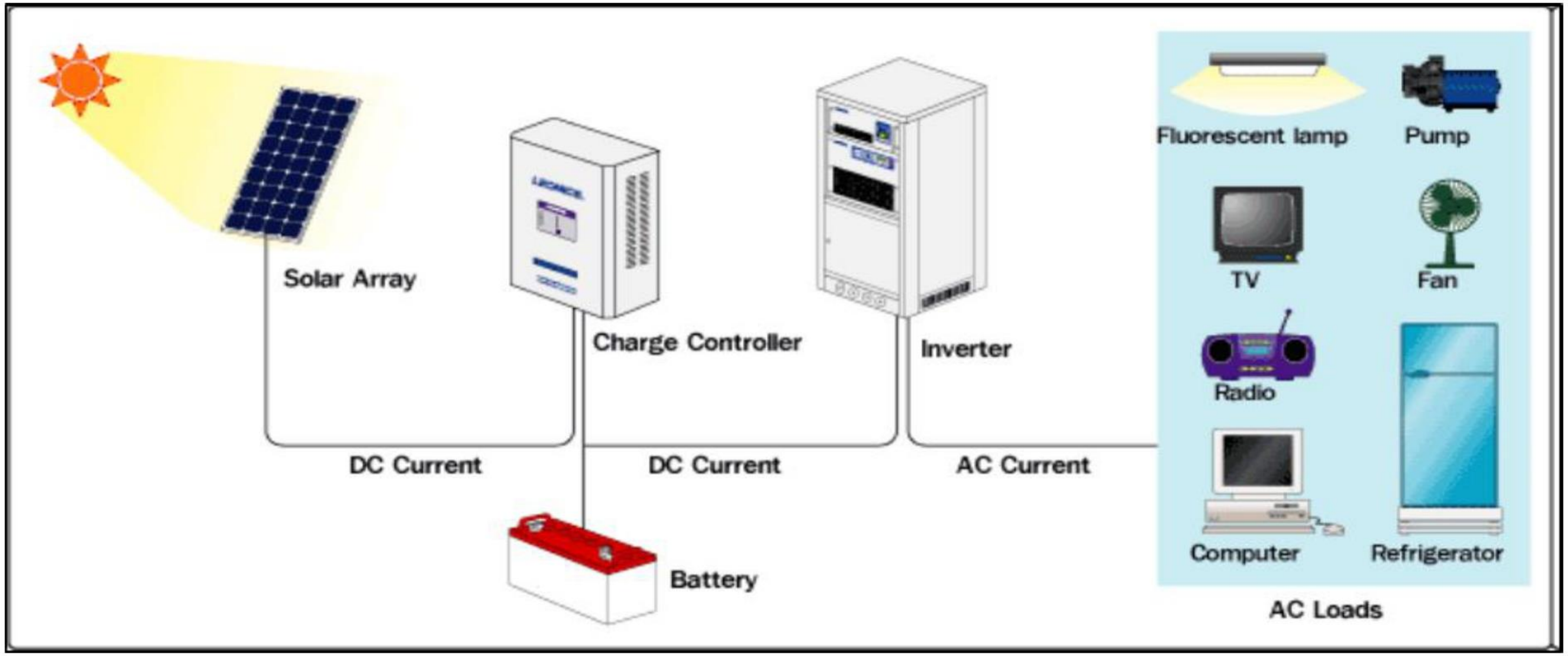


Stand Alone PV System (OFF-Grid)

Street lighting system

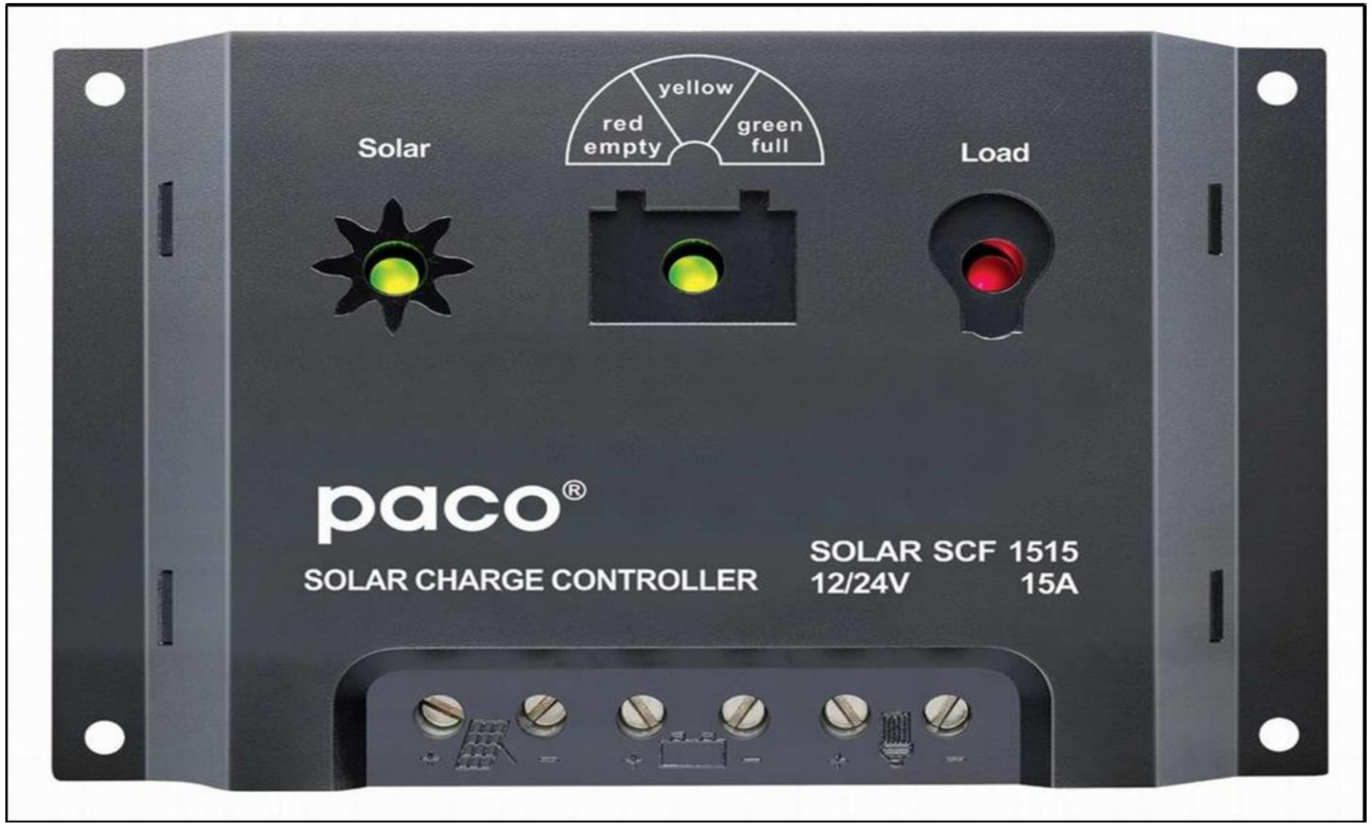
Hybrid solar system

Solar Photovoltaic Systems



Stand Alone PV System (OFF-Grid)

Charge Controller Types



Charge Controller Types

Charge Controller Types

Inverter

- The Solar Inverter is an essential device in any solar power system. Its basic function of the inverter is to change the variable Direct Current output of the solar panels into Alternating Current.

- The converted Alternating Current power is used for running your appliances like the TV, Refrigerator, Microwave, etc.

Off-Grid Inverter

Off-Grid Inverter

Batteries

- A battery is a device that is able to store electrical energy in the form of chemical energy, and convert that energy into electricity.

- **Advantages:**

– Backup for night and cloudy days.

- **Disadvantages:**

– Decreases the efficiency of PV system.
– Only 80% of energy stored retainable.
– Adds to the expense of the system.
– Finite Lifetime ~ 5 – 10 years.
– Added floor space, maintenance and safety concerns.

الطـاقة الشمسية

تطبيقات الطـــاقة الشمســـية
سخـانات الميـاه الشمسيـة

التطبيقات (≥ ٨٠°م):-

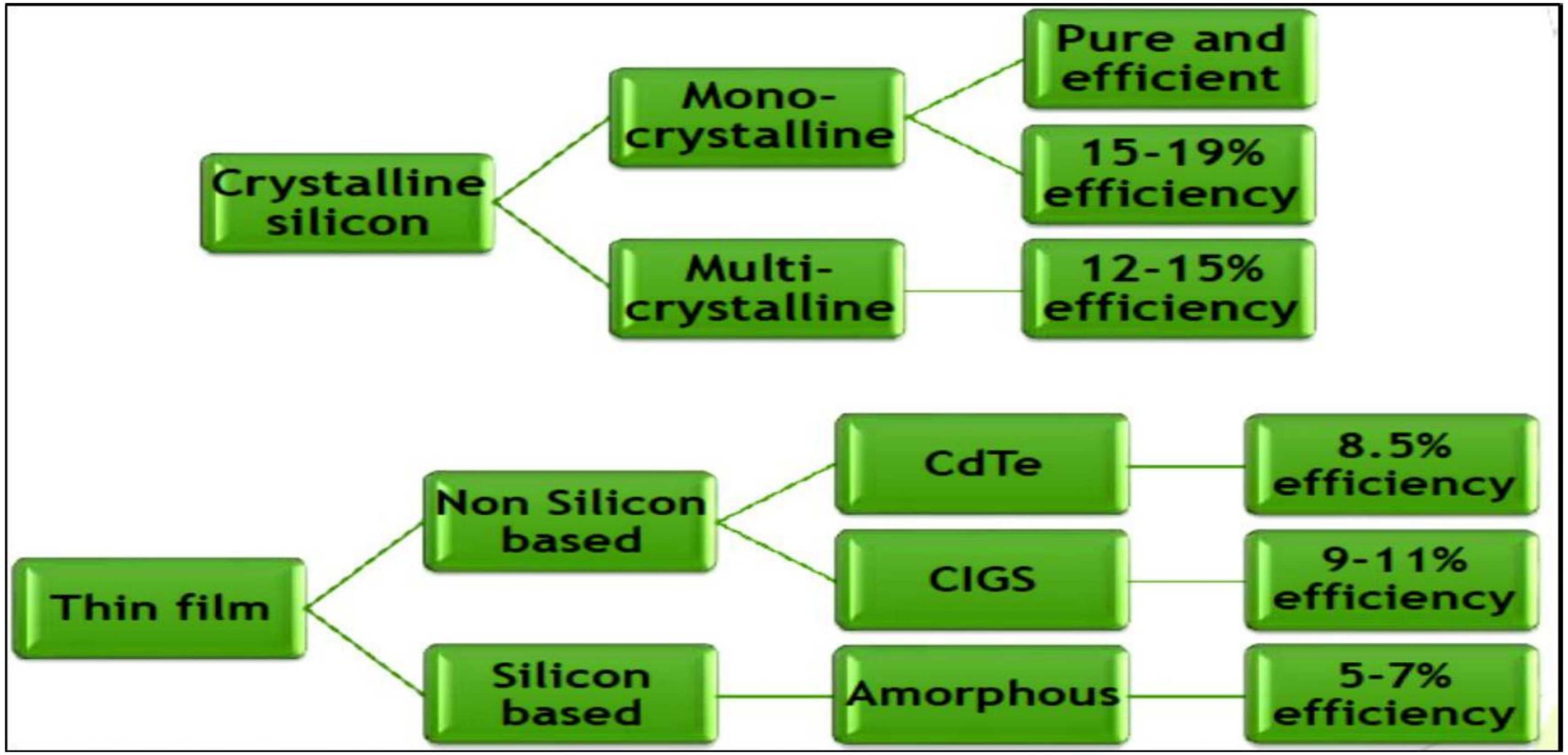
-المنازل

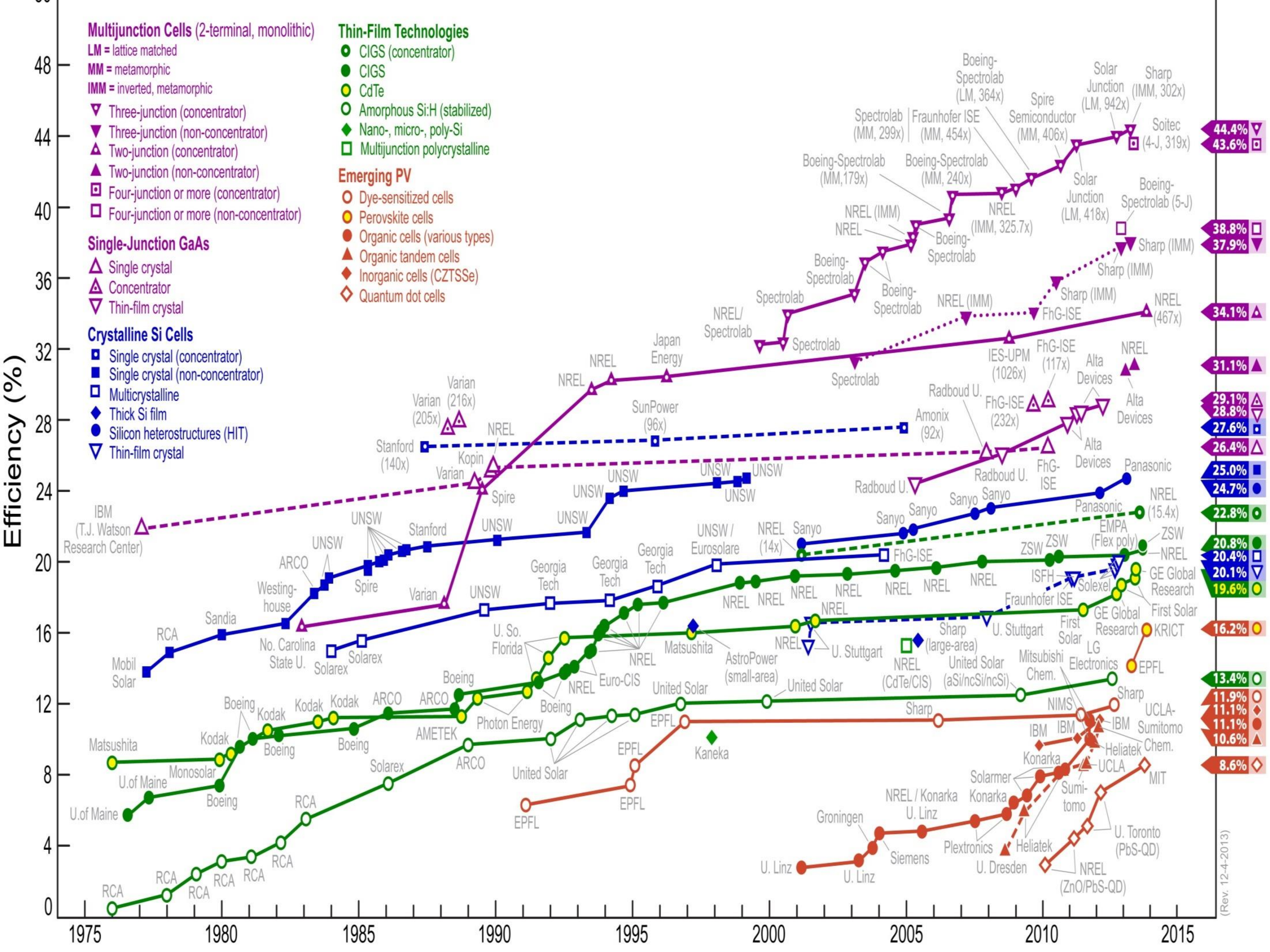
-الفنادق

-بعض المصانع


PHOTOVOLTAIC CABLE INSTALLATION GUIDE
General Cable
INSTALLATION TYPE
1
2
2
3
4
4
5
6
7

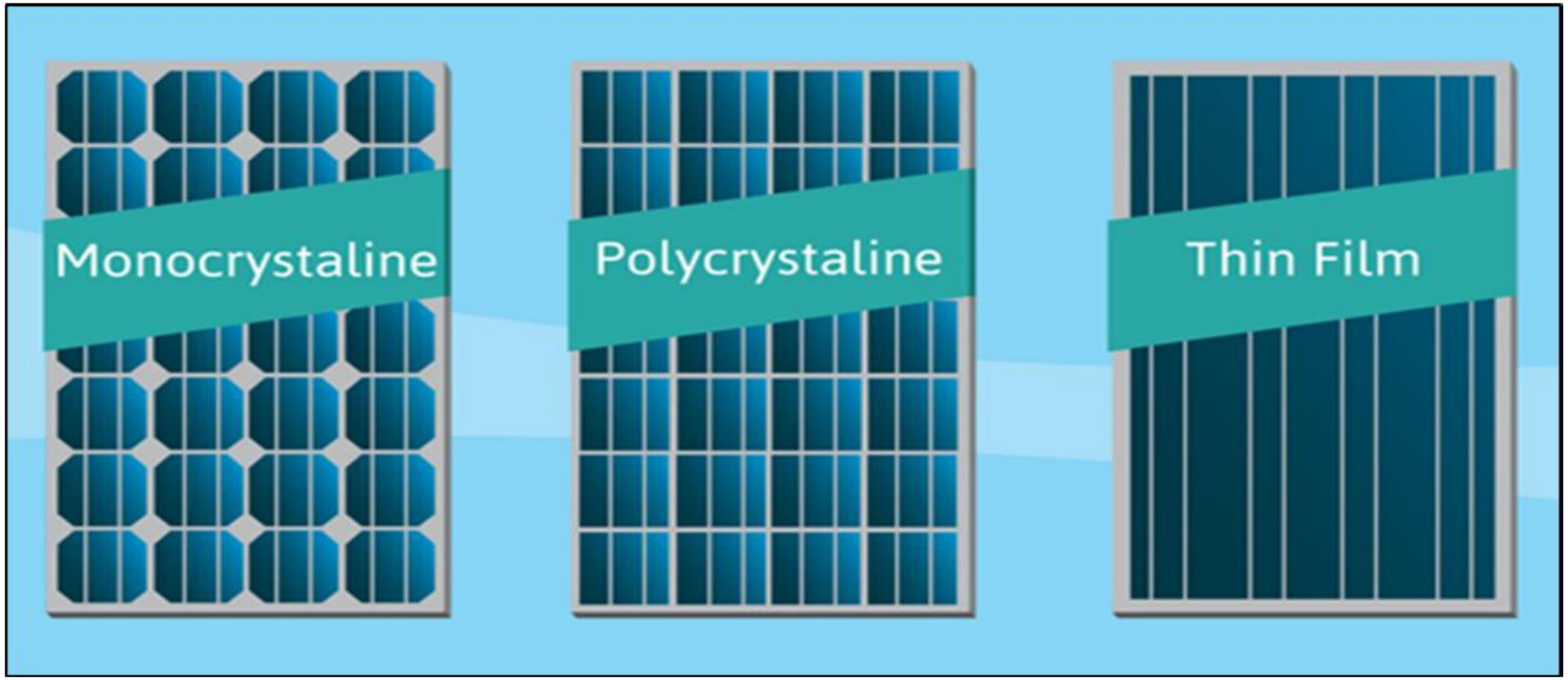
Solar Cells Different Types



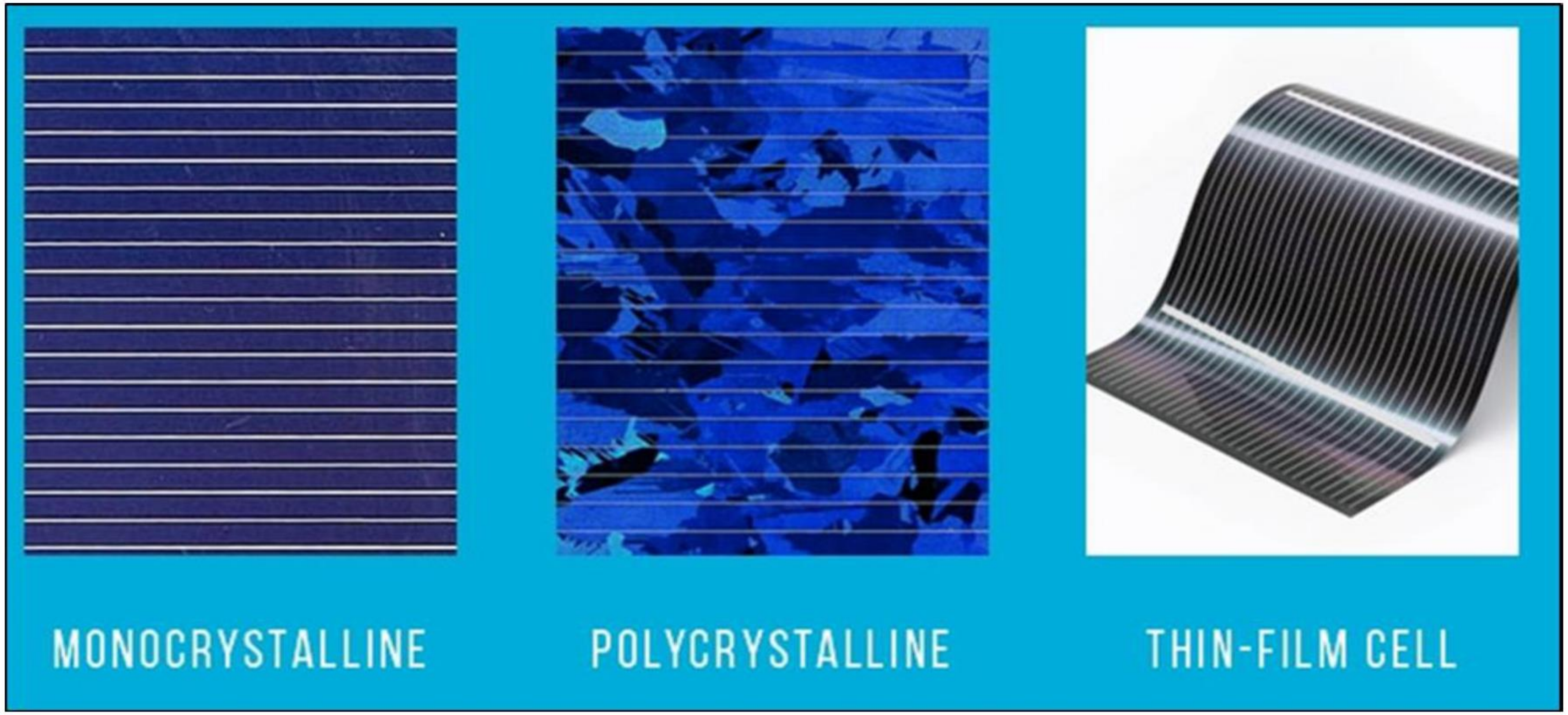


Efficiency (%)
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Thick Si film
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Nano-, micro-, poly-Si
Multijunction polycrystalline
Emerging PV
Dye-sensitized cells
Perovskite cells
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells
44.4%
43.6%
38.8%
37.9%
34.1%
31.1%
29.1%
28.8%
27.6%
26.4%
25.0%
24.7%
22.8%
20.8%
20.4%
20.1%
19.6%
16.2%
13.4%
11.9%
11.1%
11.1%
10.6%
8.6%
(Rev. 12-4-2013)
1975
1980
1985
1990
1995
2000
2005
2010
2015
0
4
8
12
16
20
24
28
32
36
40
44
48

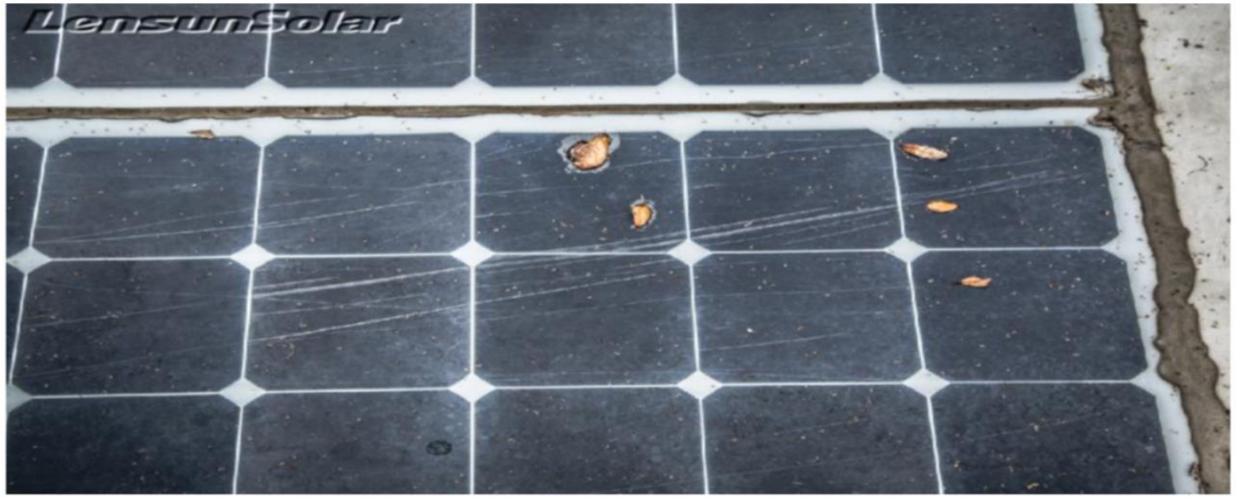
Solar Cells Different Types



Solar Cells Different Types



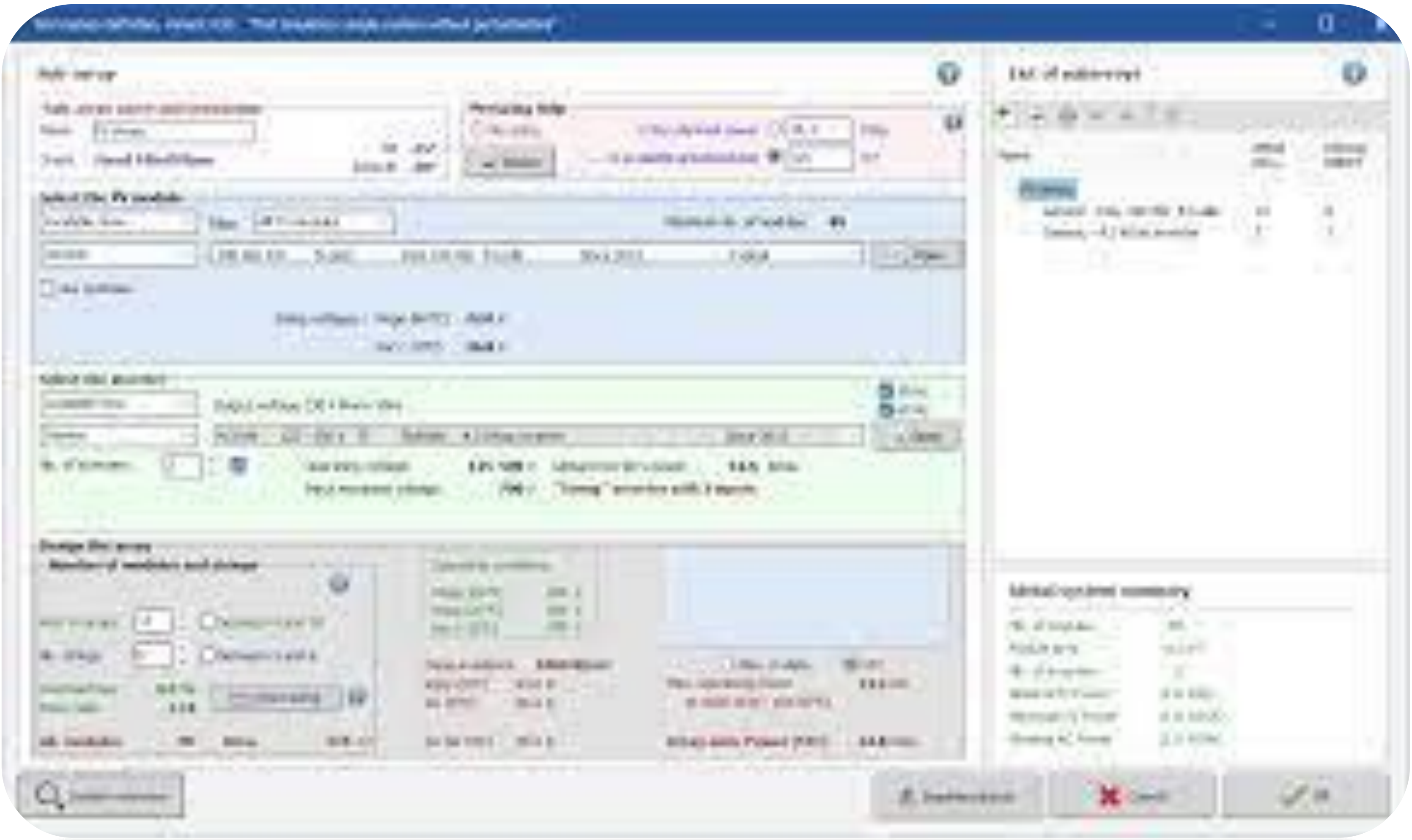
قراءة كتالوجات الخلايا والبطاريات




التعرف على برنامج PV syst
مكونات محطات التحلية تفصيلا
نظام حقن الكيماويات
نظام استعادة الطاقة
المشاكل التى تواجهنا فى تشغيل الأغشية وحلها
وانواع الانسدادات والغسيل الكيمائى
تعليمات التداول والحفظ والتخزين للأغشية
منحنى أداء الخلايا
مراجعه على أنواع أنظمة الطاقة الشمسية واللاختيار ما بينها
الإختيار المناسب للموقع الخلايا الشمسية
تصميم نظام المرتبطة بالشيكة
تأثير إستخدام الطاقة الشمسية في تكاليف التشغيل والصيانة لمحطات التحلية
المستوى
التانى
2

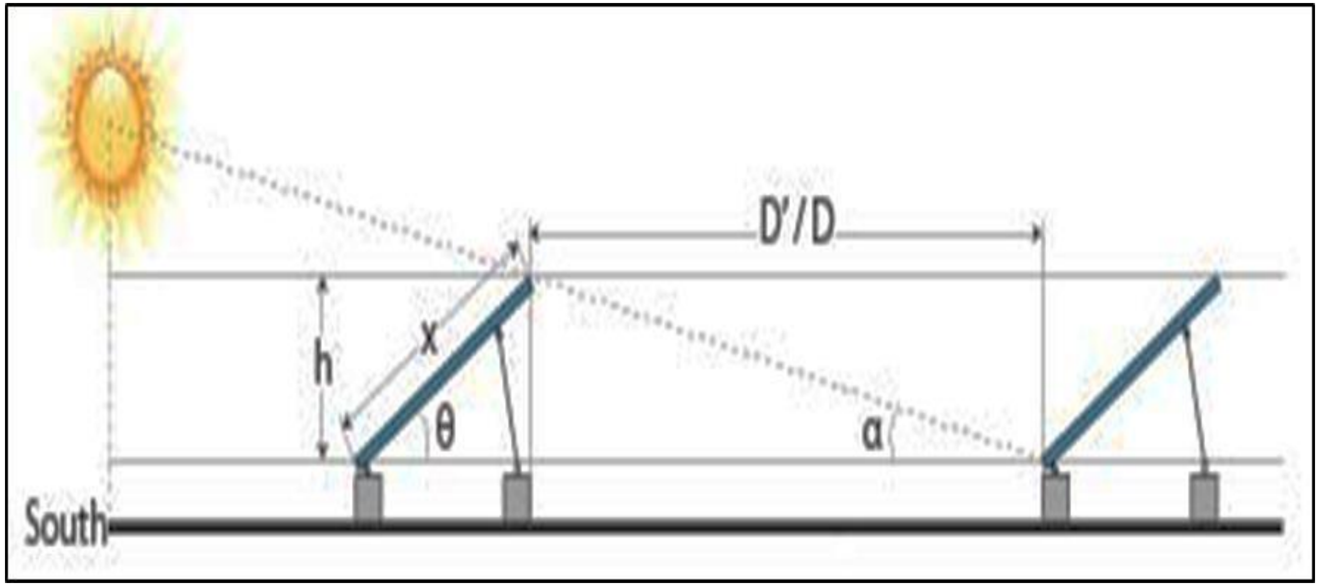
PVSYST

PHOTOVOLTAIC SOFTWARE



Self-Shading

An interesting aspect is the effect whereby rows of ground-mounted PV arrays cause shading of subsequent rows. If the rows of tilted modules are too close to each other, one row will cause a shadow on the next, causing additional losses.



Self-Shading

The procedure for calculating shadow spacing starts with the sun's position in the sky on the winter solstice, December 21st. You need to obtain the minimum solar altitude angle α, which is the minimum angle the sun makes with the ground in your shade-free solar window.

Date:	21/12/2018	
coordinates:	30.04993, 31.2486	
location:		مصر, EGY
hour	Elevation	Azimuth
6:46:41	-0.833	116.81
7:00:00	1.71	118.49
8:00:00	12.64	126.92
9:00:00	22.29	137.2
10:00:00	30.03	149.89
11:00:00	35.02	165.11
12:00:00	36.49	181.99
13:00:00	34.15	198.62
14:00:00	28.44	213.28
15:00:00	20.2	225.38
16:00:00	10.2	235.18
16:59:22	-0.833	243.18

Self-Shading

After finding the Solar Altitude and Azimuth angles, the calculations to determine row spacing can begin.

The **maximum** shadow distance can be obtained through using equation:

$$\mathbf{D}' = \frac{\mathbf{h}}{\mathbf{tan}(a)}$$

The **minimum** inter-row spacing needed to avoid shade can be obtained through using equation:

$$\mathbf{D} = \mathbf{D}' * \mathbf{cos}(\mathbf{180} - \boldsymbol{\psi})$$

α = solar altitude angle, ψ = solar azimuth angle

h = height of obstruction, x = tilted module length

θ = tilt angle, h=x* sin(θ) for tilted solar arrays

Self-Shading

Example:

For 21, Dec, the tilt angle = 45^{o} and the panel tilted length = 2 (m). Calculate the minimum and maximum inter-row spacing needed.

$$h = 2 * \sin(45) = 1.41\ (m)$$

$$maximum\ spacing\ D' = \frac{1.41}{\tan(36.49)} = 1.91\ (m)$$

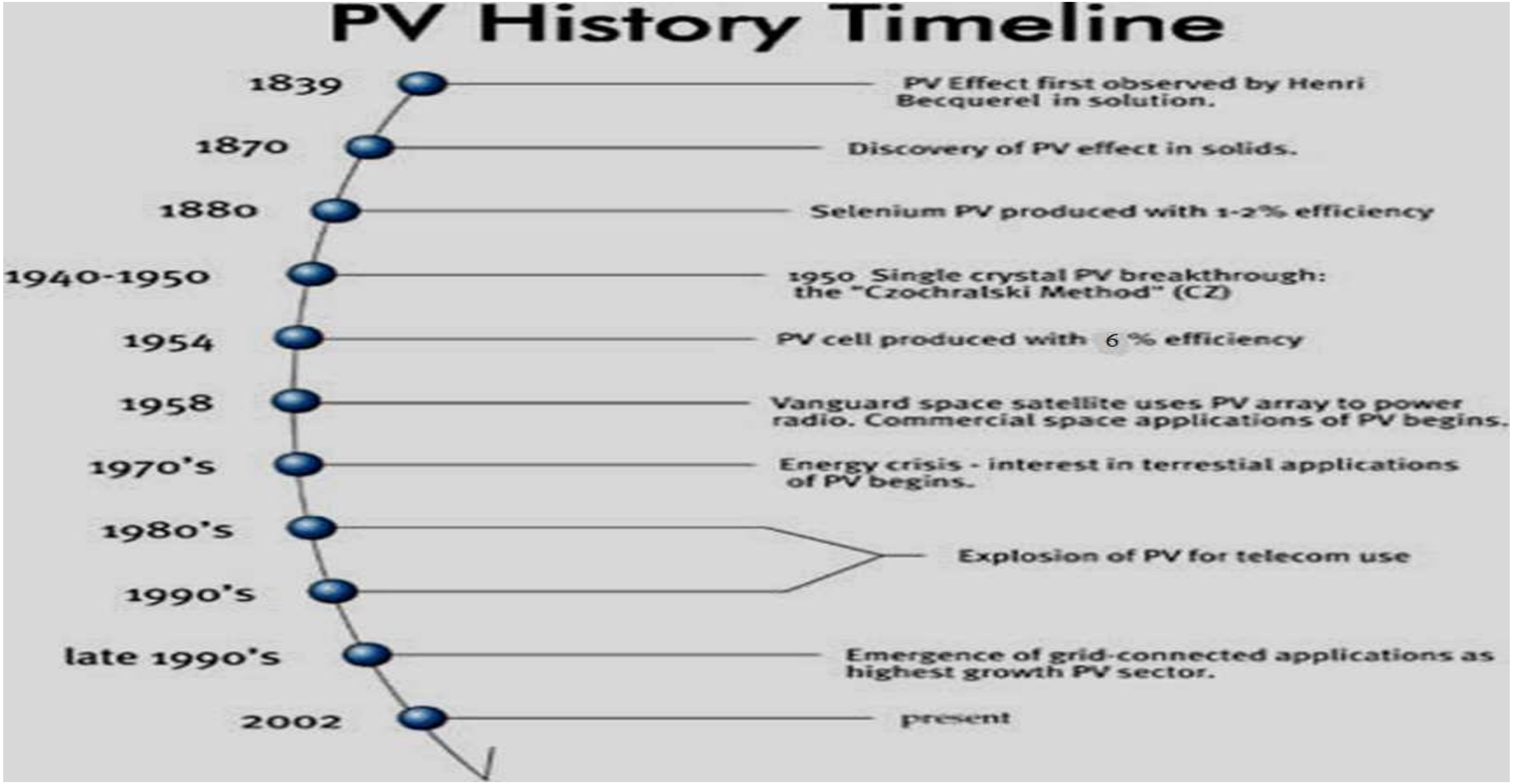
$$minimum\ spacing\ D\ @\ 9\ am\ (\psi = 137.2)$$

$$D = 1.91 * \cos(180 - 137.2) = 1.4\ (m)$$

Contents

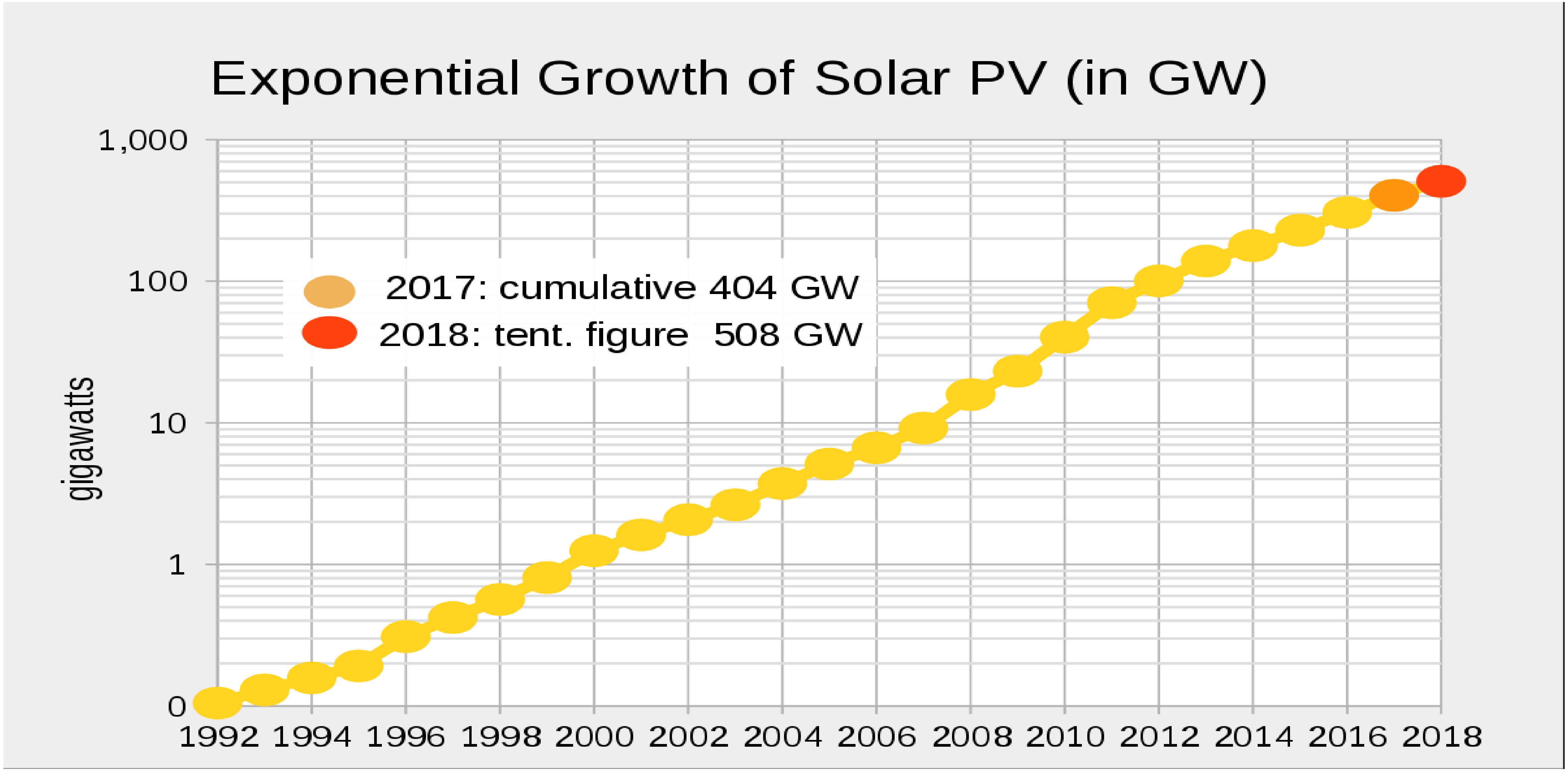
Day 2

Background


PV History Timeline
1839
PV Effect first observed by Henri Becquerel in solution.
1870
Discovery of PV effect in solids.
1880
Selenium PV produced with 1-2% efficiency
1940-1950
1950 Single crystal PV breakthrough: the "Czochralski Method" (CZ)
1954
PV cell produced with 6 % efficiency
1958
Vanguard space satellite uses PV array to power radio. Commercial space applications of PV begins.
1970's
Energy crisis - interest in terrestial applications of PV begins.
1980's
1990's
Explosion of PV for telecom use
late 1990's
Emergence of grid-connected applications as highest growth PV sector.
2002
present

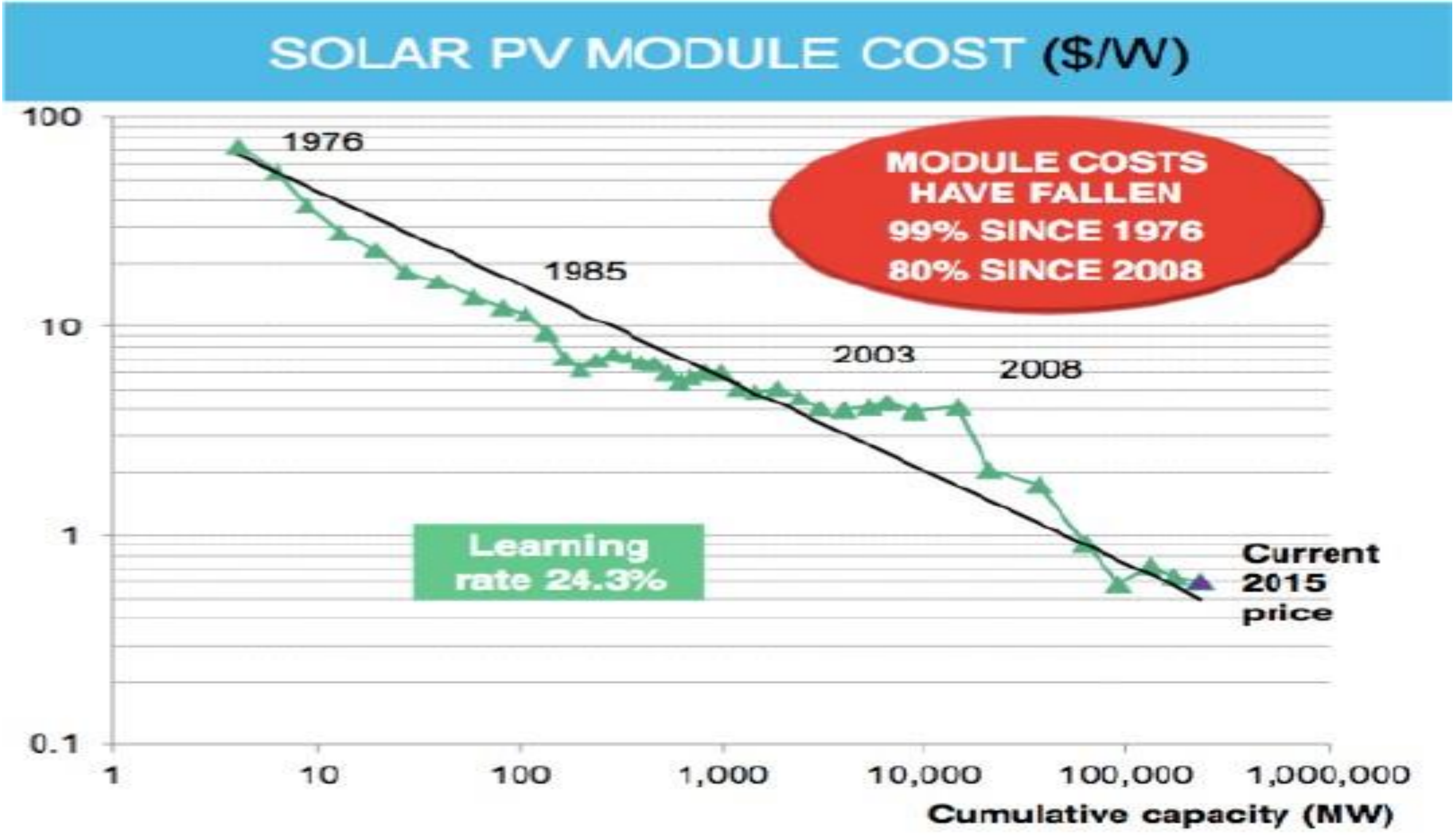
Background

Background



Exponential Growth of Solar PV (in GW)
1,000
100
10
1
0
gigawatts
2017: cumulative 404 GW
2018: tent. figure 508 GW
1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018

Background



Note: Prices are in real (2015) USD. 'Current price' is $0.61/W. Source: Bloomberg New Energy Finance, Maycock

Background

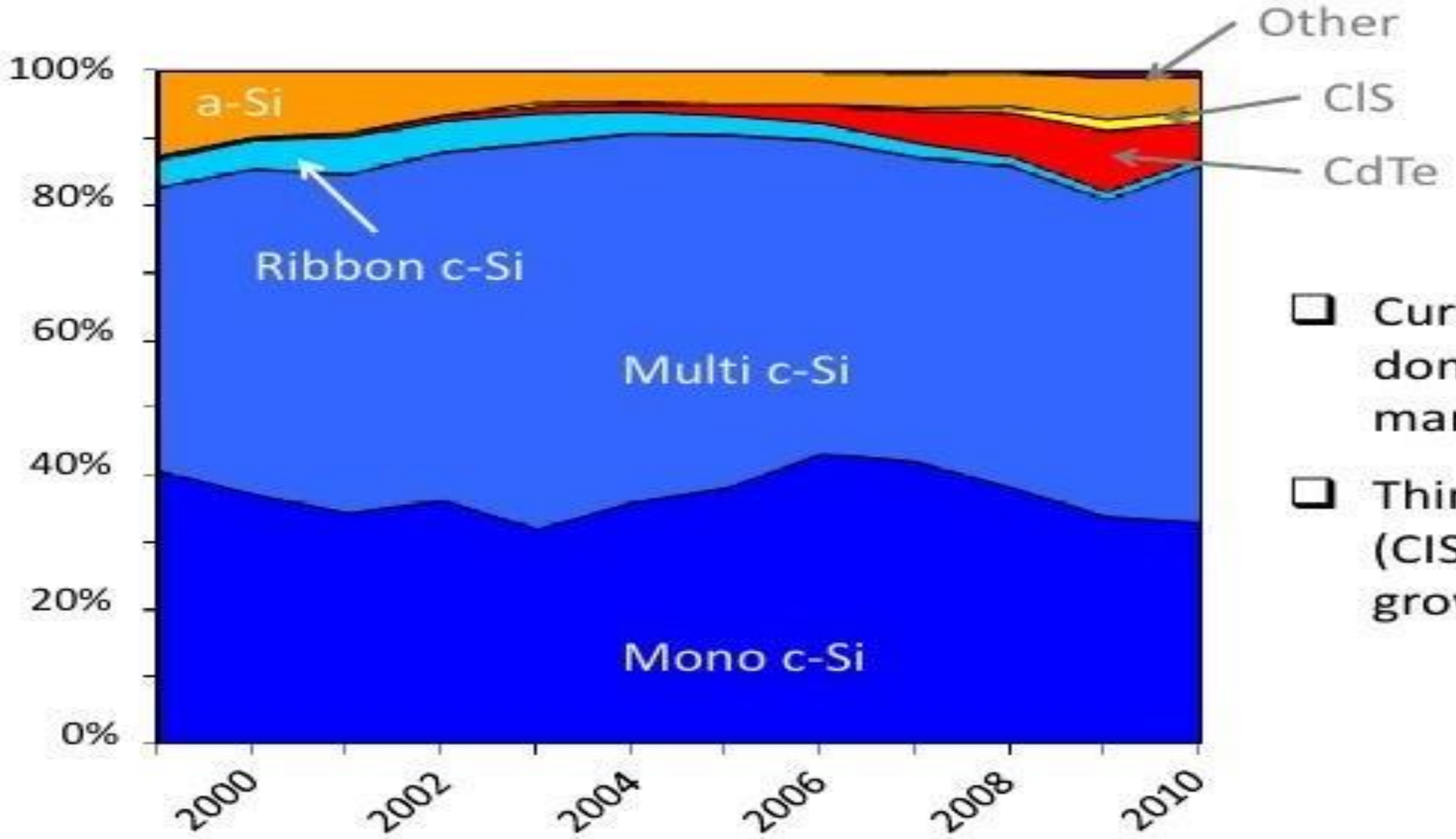
Research in PV is driven by the reduction of cost/kWh

$$\text{Levelized cost of electricity} = \frac{\text{Investment cost} + \text{Maintenance cost}}{\text{Years of operation} \times \text{Annual energy output}} + \text{Cost for energy storage (balancing)}$$

- Further reduction of the PV LCOE is possible via:
  - Reduction of cost (further scaling, standardization)
  - **Increasing performance**
  - **Increasing lifetime**
  - **Increasing energy yield**

Background

Market shares of PV technologies



- ❑ Currently, silicon dominates the PV market
- ❑ Thin film materials (CIS, CdTe, etc.) growing slowly

Source: S. Glunz, Fraunhofer ISE; Data Photon Magazine 2011

Background

- **Reasons for Crystalline SI-based Solar Cells:**

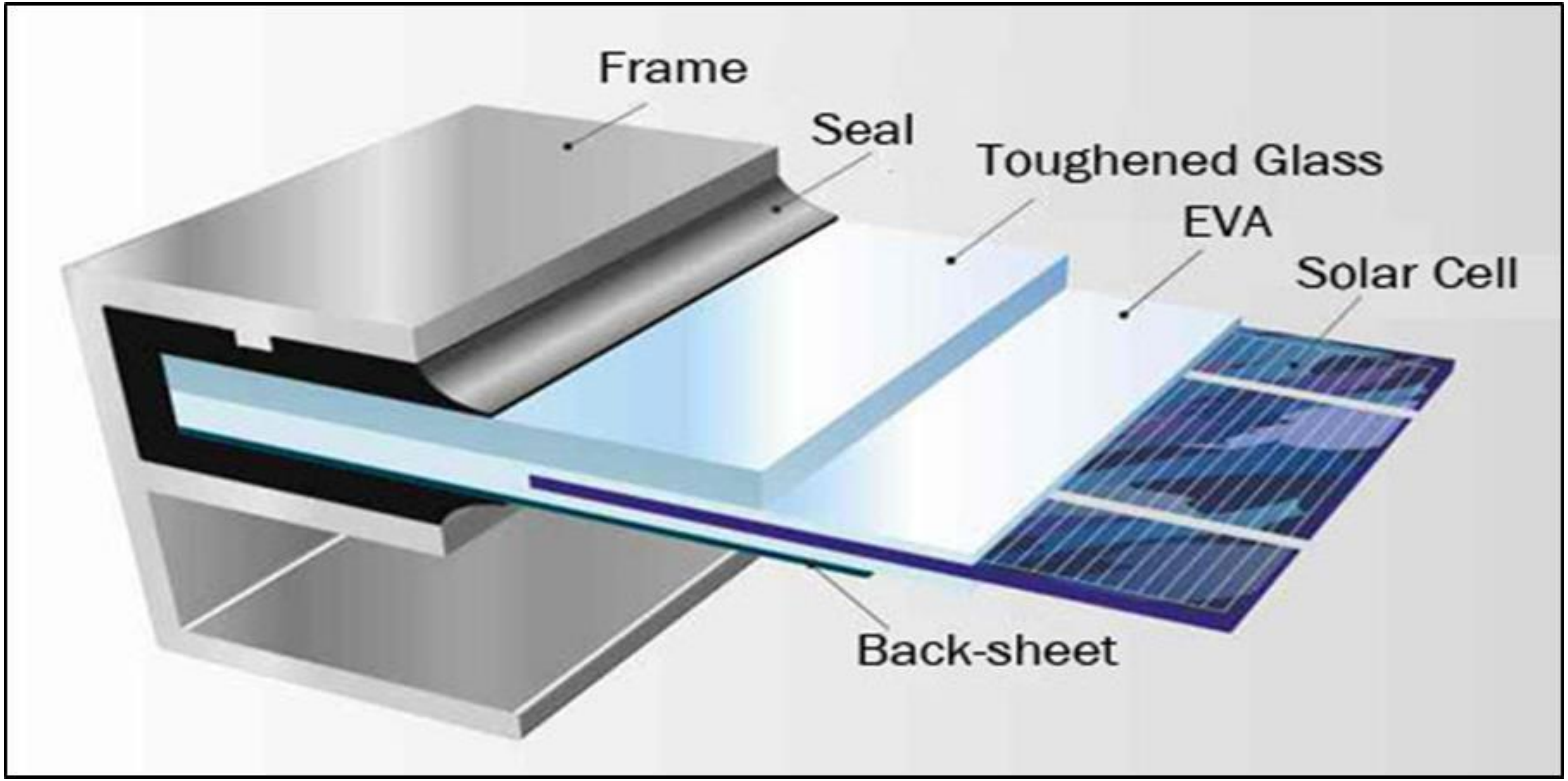
1- Abundant Materials (~ 25% of Earth's Crust)

2- Non-Toxic to human (Green Materials)

3 High Energy Conversion Efficiency (>20%)

4 Long-term stable in outdoor performance (>20 years)

Raw Materials



Raw Materials

- The solar module consists of the silicon semiconductor surrounded by protective material in a metal frame.
- The protective material consists of an encapsulated of transparent silicon rubber or butyryl plastic bonded around the cells, which are then embedded in ethylene vinyl acetate (EVA).
- A polyester film (such as mylar or tedlar) makes up the backing.
- A glass cover is found on terrestrial arrays, a lightweight plastic cover on satellite arrays.
- The electronic parts are standard and consist mostly of copper. The frame is either steel or aluminum.

The Manufacturing Process

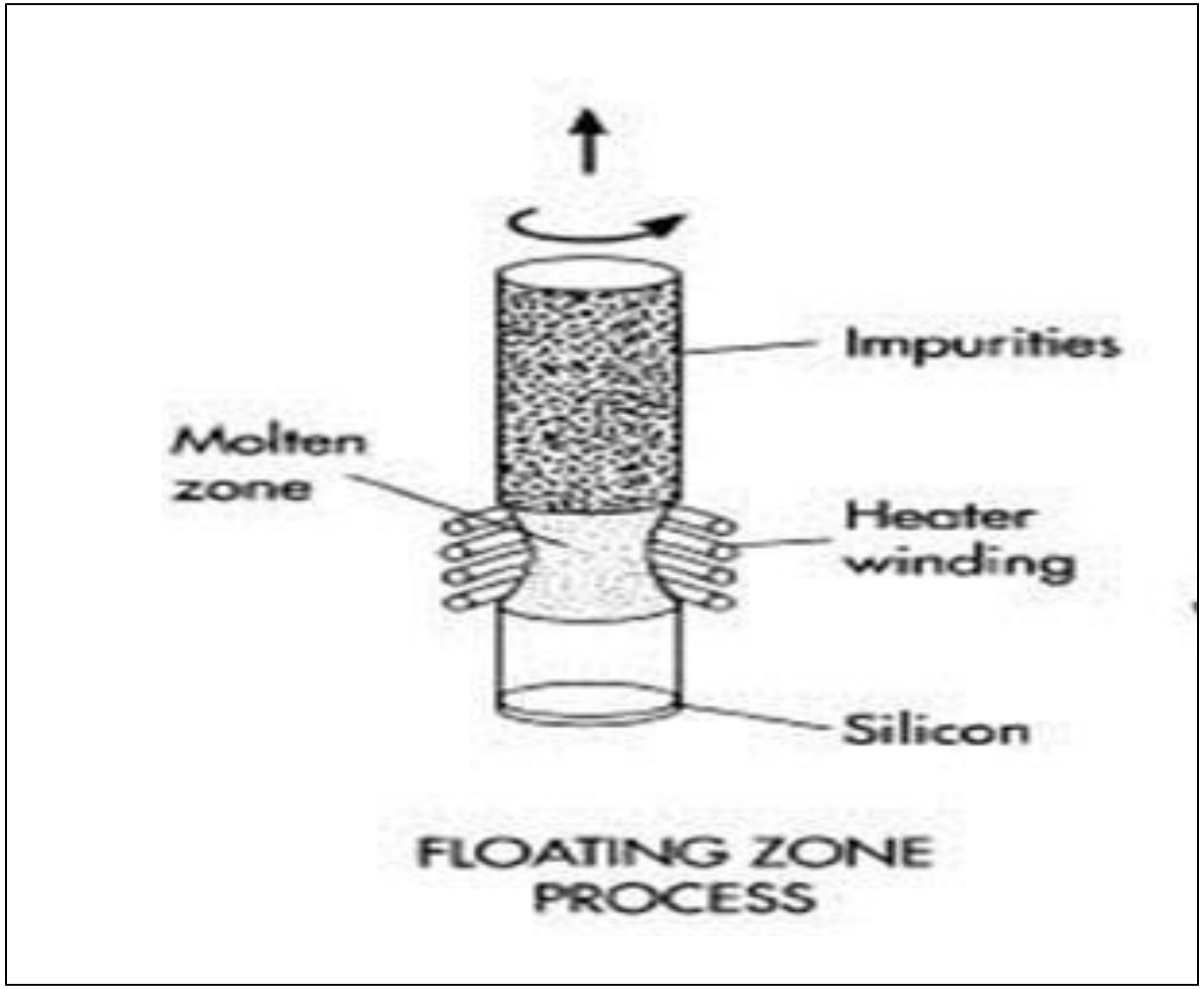
- **Purifying the silicon:**

The silicon dioxide of either quartzite gravel or crushed quartz is placed into an electric arc furnace. A carbon arc is then applied to release the oxygen. The products are carbon dioxide and molten silicon. This simple process yields silicon with one percent impurity, useful in many industries but not the solar cell industry.

The Manufacturing Process

- **Making single crystal silicon:**

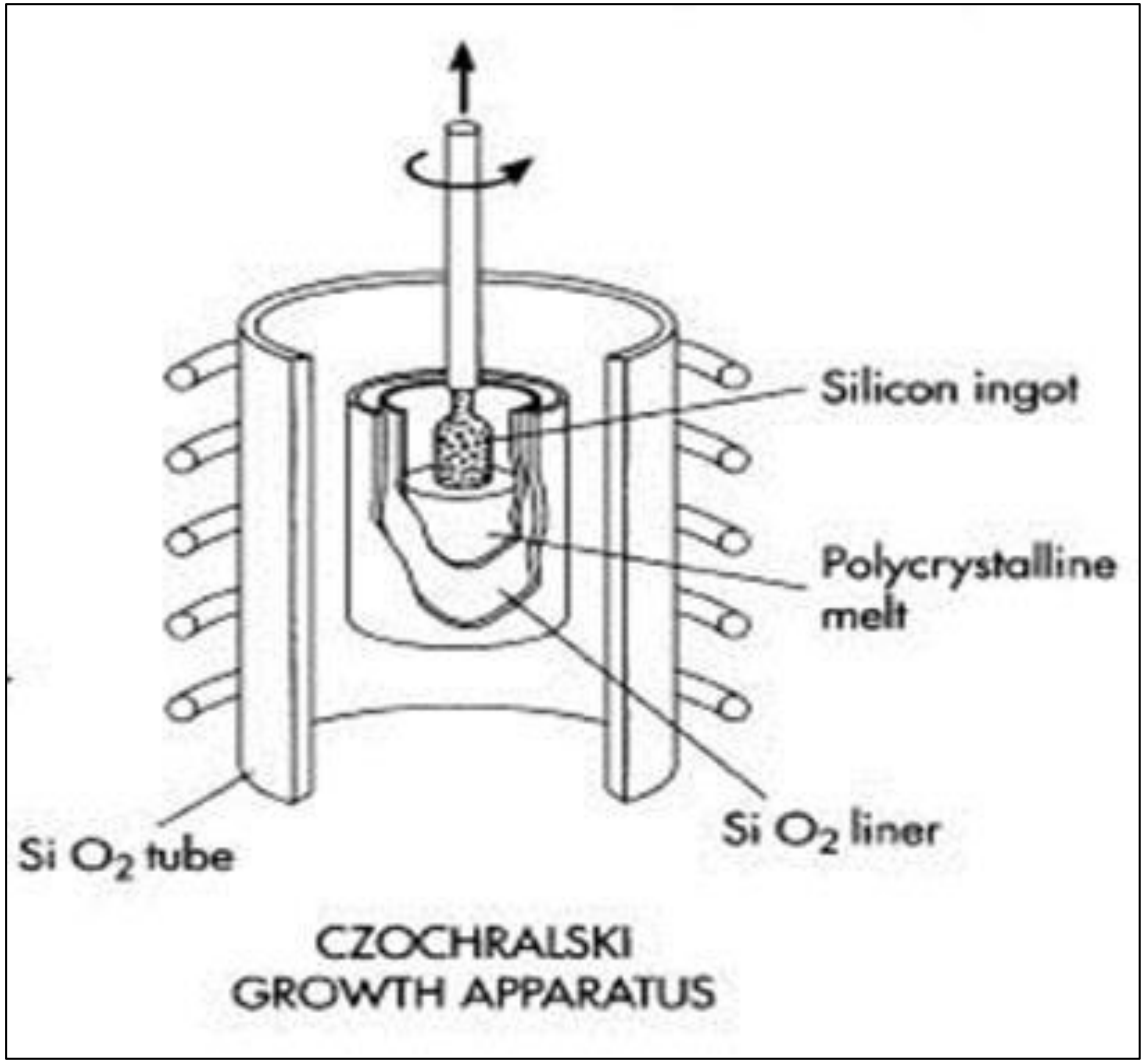
The 99 % pure silicon is purified even further using the floating zone technique.



The Manufacturing Process

- **Making single crystal silicon:**

The most commonly used process for creating the boule for solar cells production is called the Czochralski method.



The Manufacturing Process

- **Making silicon wafers:**

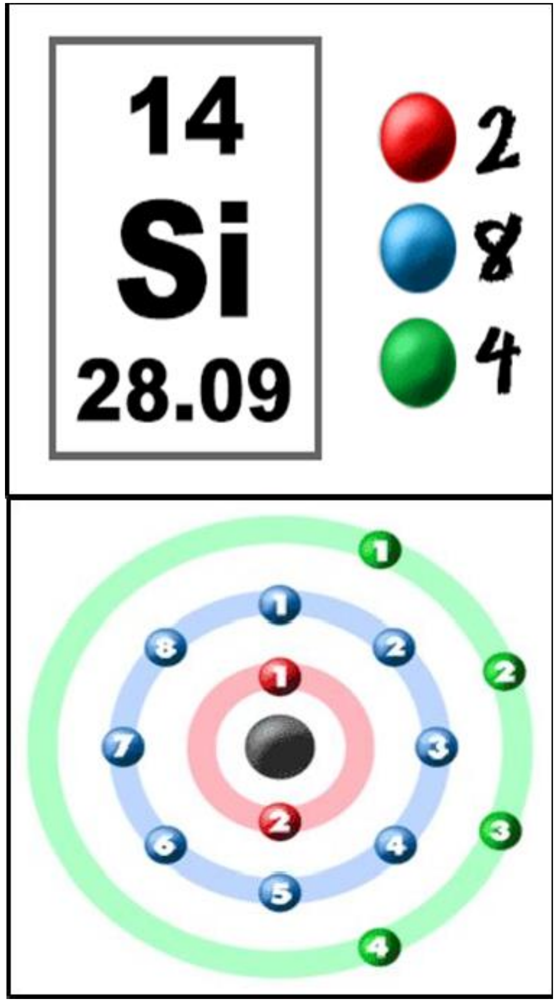
a) **From the boule, silicon wafers are sliced one at a time using a circular diamond saw whose inner diameter cuts into the rod, or many at once with a multiwire saw.**

b)The wafers are then polished to remove saw marks. (It has recently been found that rougher cells absorb light more effectively, therefore some manufacturers have chosen not to polish the wafer.)

The Manufacturing Process

- **Doping:**

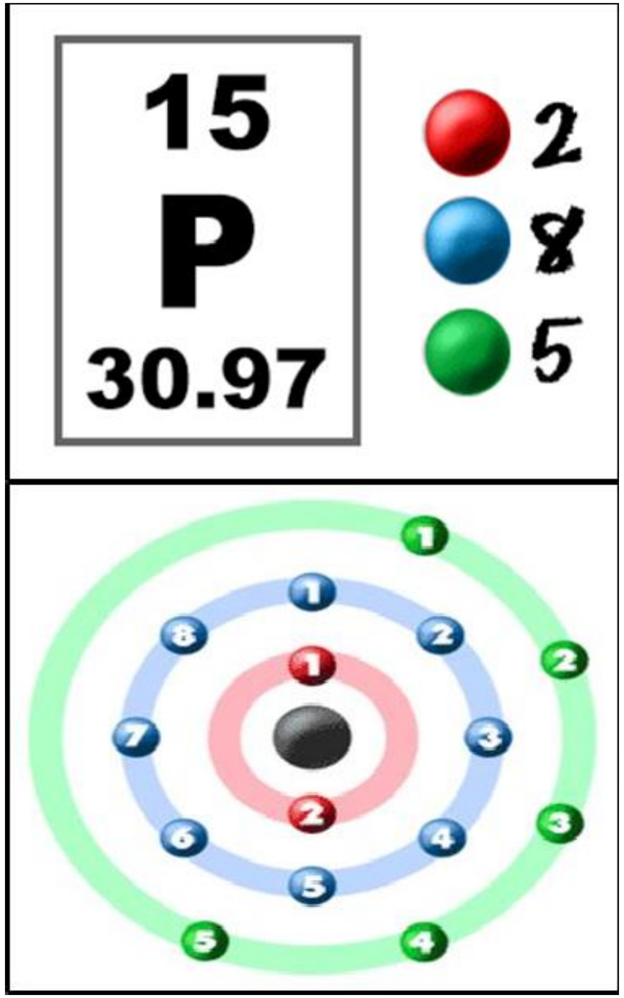
The traditional way of doping (adding impurities to) silicon wafers with boron and phosphorous is to introduce a small amount of boron during the Czochralski process. Doping is a technique used to vary the number of electrons and holes in semiconductors.



The Manufacturing Process

- **Doping:**

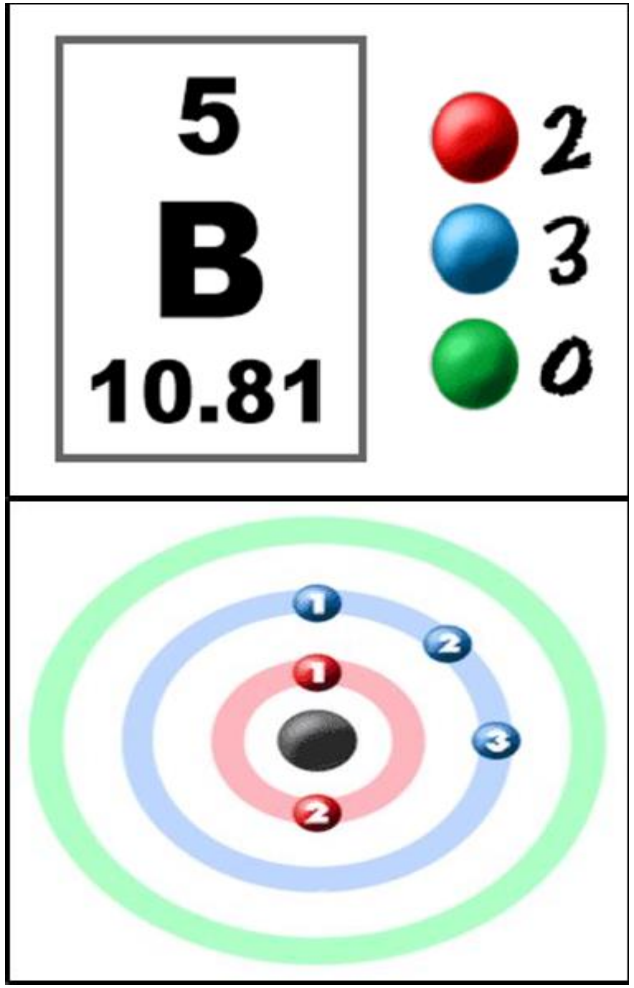
Doping creates N-type material when semiconductor materials doped with elements of pentavalent such as Phosphorus N-type materials increase the conductivity of a semiconductor by increasing the number of available electrons.



The Manufacturing Process

- **Doping:**

P-type materials are created when semiconductor materials doped with elements of trivalent such as Boron. P-type materials increase conductivity by increasing the number of holes present.



The Manufacturing Process

- The anti-reflective coating:

Because pure silicon is shiny, it can reflect up to 35 percent of the sunlight. To reduce the amount of sunlight lost, an anti-reflective coating is put on the silicon wafer.

The method is to allow the silicon itself to react with oxygen- or nitrogen-containing gases to form silicon dioxide or silicon nitride. Commercial solar cell manufacturers use silicon nitride.

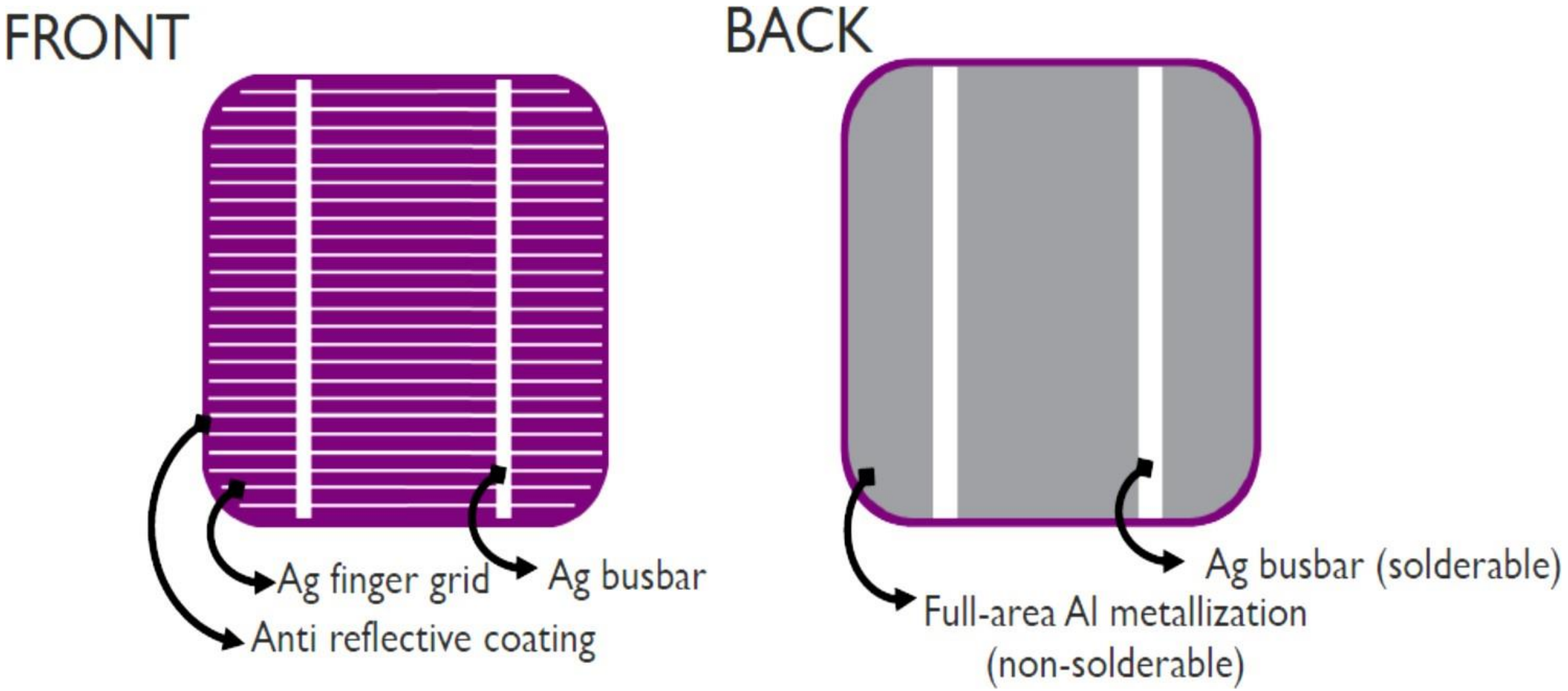
The Manufacturing Process

- **Placing electrical contacts:**

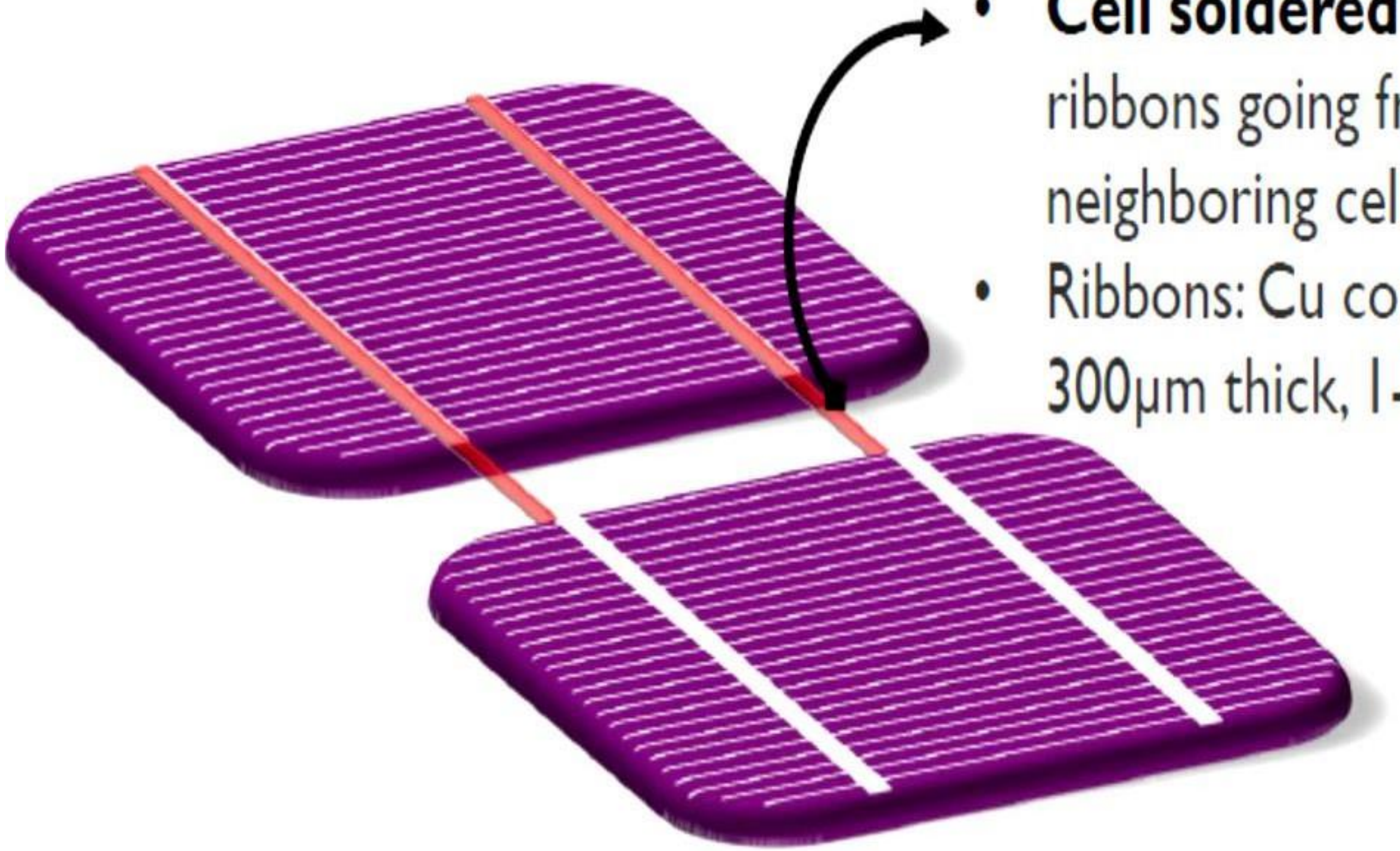
Electrical contacts connect each solar cell to another and to the receiver of produced current. Metals such as palladium/silver, nickel, or copper are vacuum-evaporated through a photoresist, silkscreened, or merely deposited on the exposed portion of cells that have been partially covered with wax

After the contacts are in place, thin strips ("fingers") are placed between cells. The most commonly used strips are tin-coated copper.

The Manufacturing Process



The Manufacturing Process



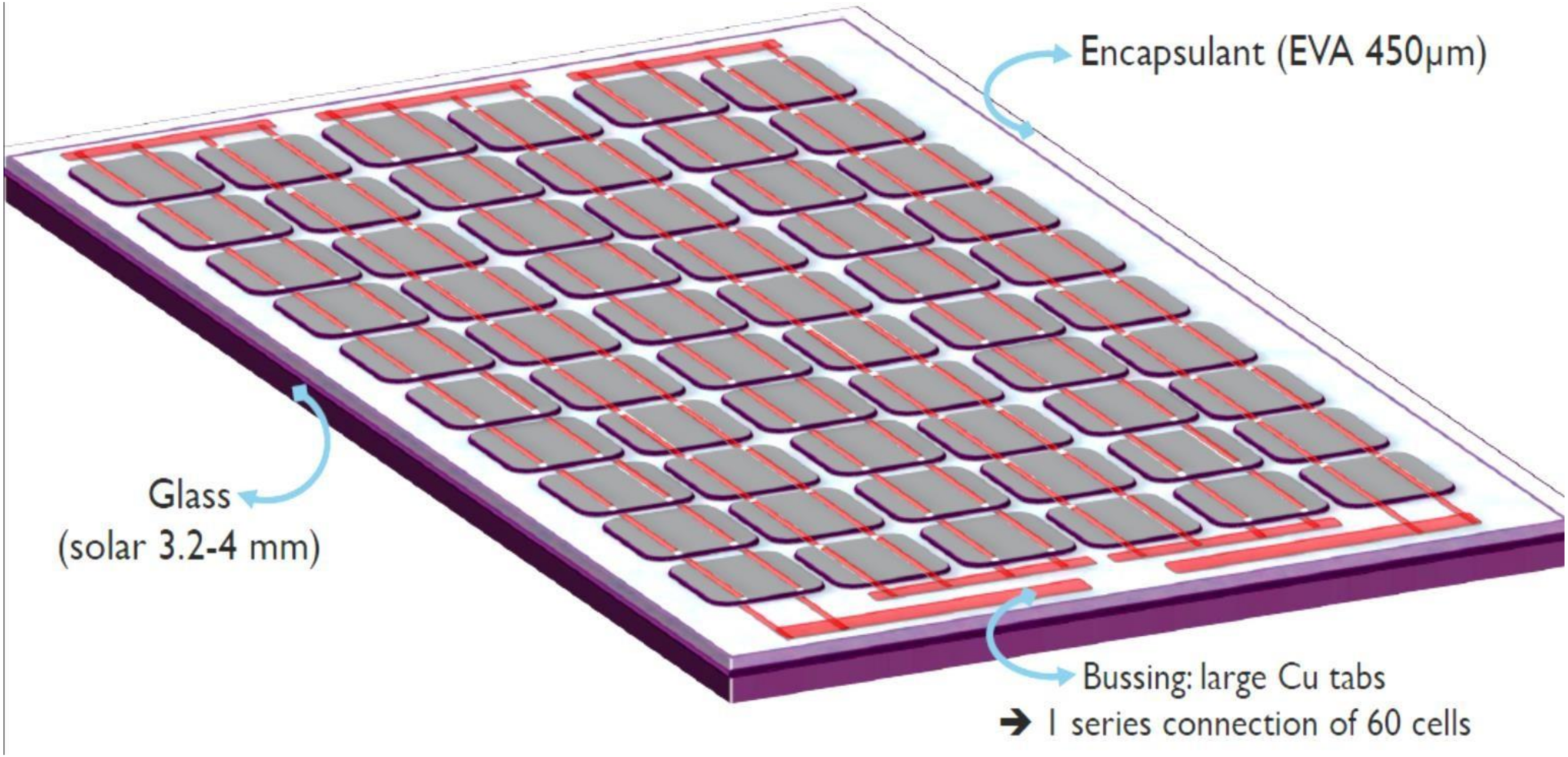
- **Cell soldered in series connection** using ribbons going from the front to back of neighboring cells
- Ribbons: Cu core with Sn Pb(Ag) coating with 100-300μm thick, 1-3mm wide

The Manufacturing Process

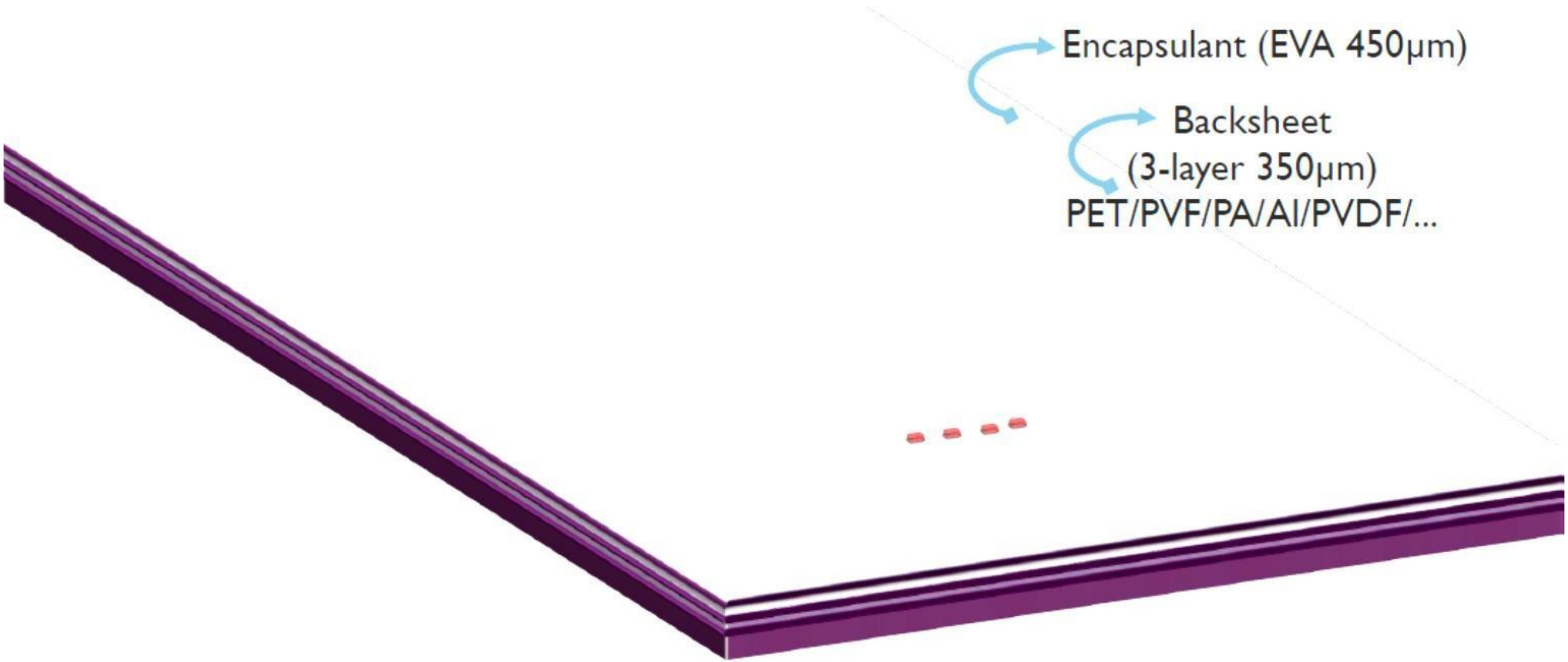
- **Encapsulating the cell:**

The finished solar cells are then encapsulated; that is, sealed into silicon rubber or ethylene vinyl acetate. The encapsulated solar cells are then placed into an aluminum frame that has a mylar or tedlar backsheet and a glass or plastic cover.

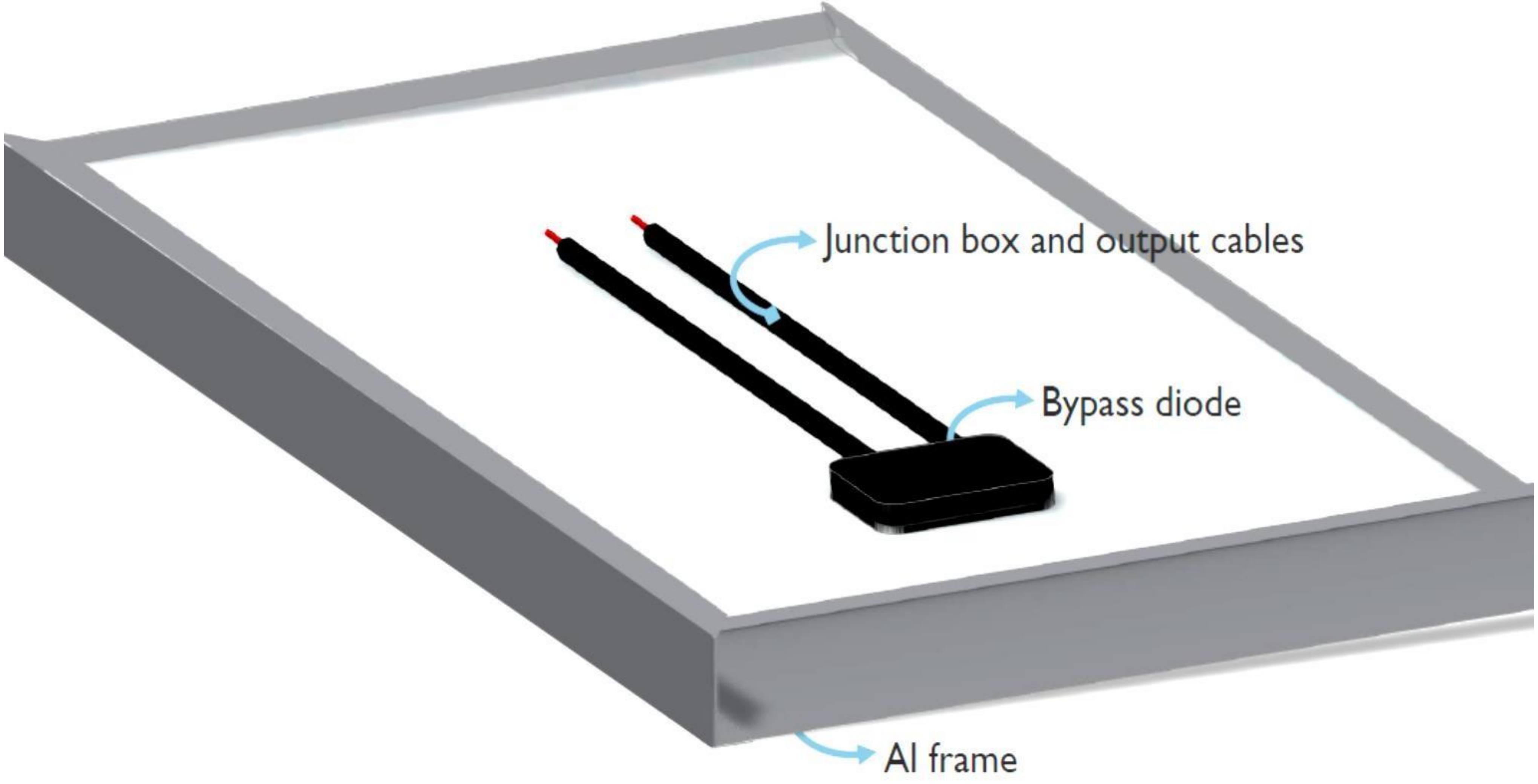
The Manufacturing Process



The Manufacturing Process



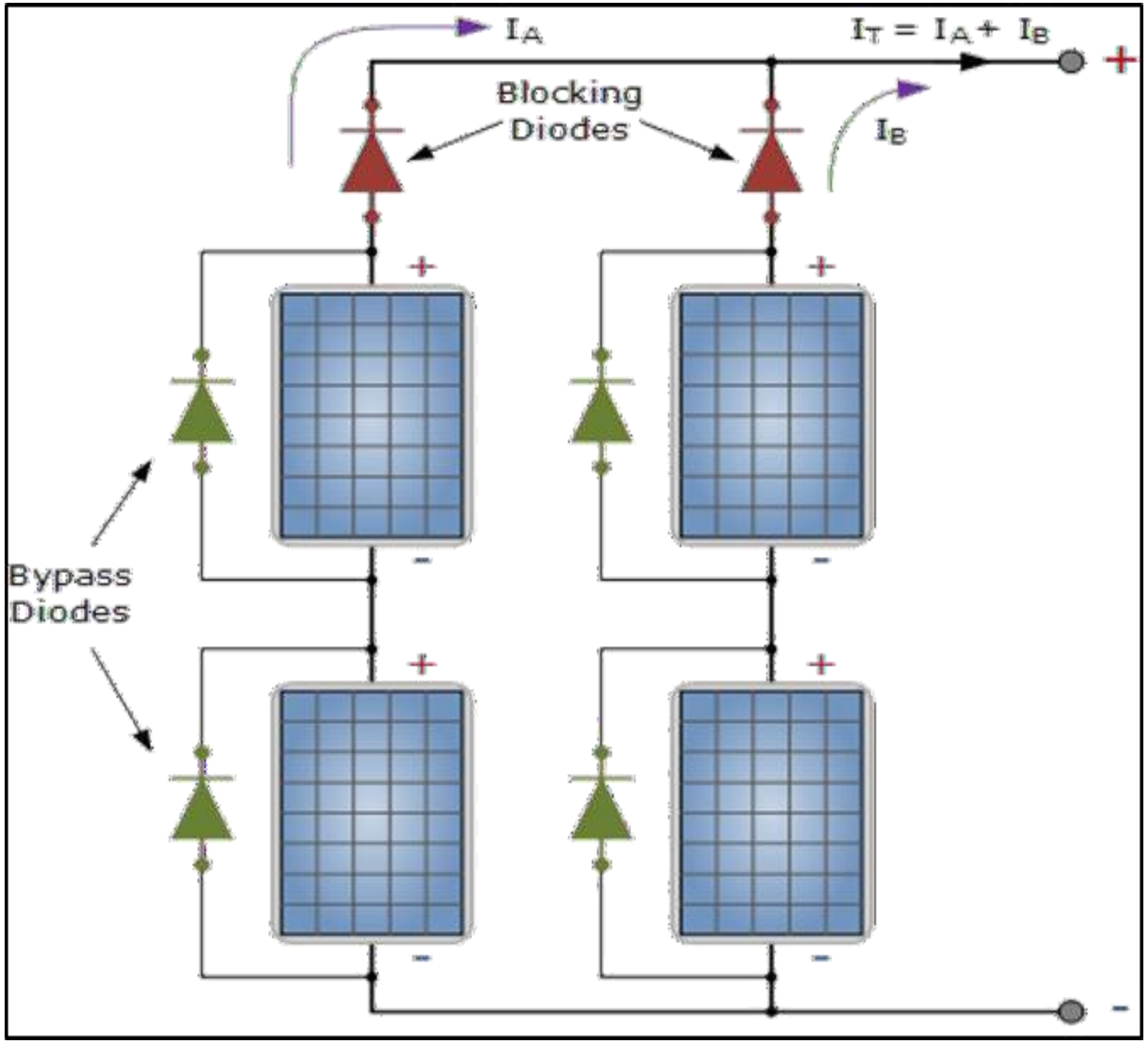
The Manufacturing Process



Block & Bypass Diodes

- **Blocking diode** is used in series with the panels and battery in reverse biasing to prevent reverse flow of the current.

- **Bypass Diodes** are used in parallel with either a single or a number of photovoltaic solar cells to prevent the current(s) flowing from good, well-exposed to sunlight solar cells overheating and burning out weaker or partially shaded solar cells by providing a current path around the bad cell.



Junction Box

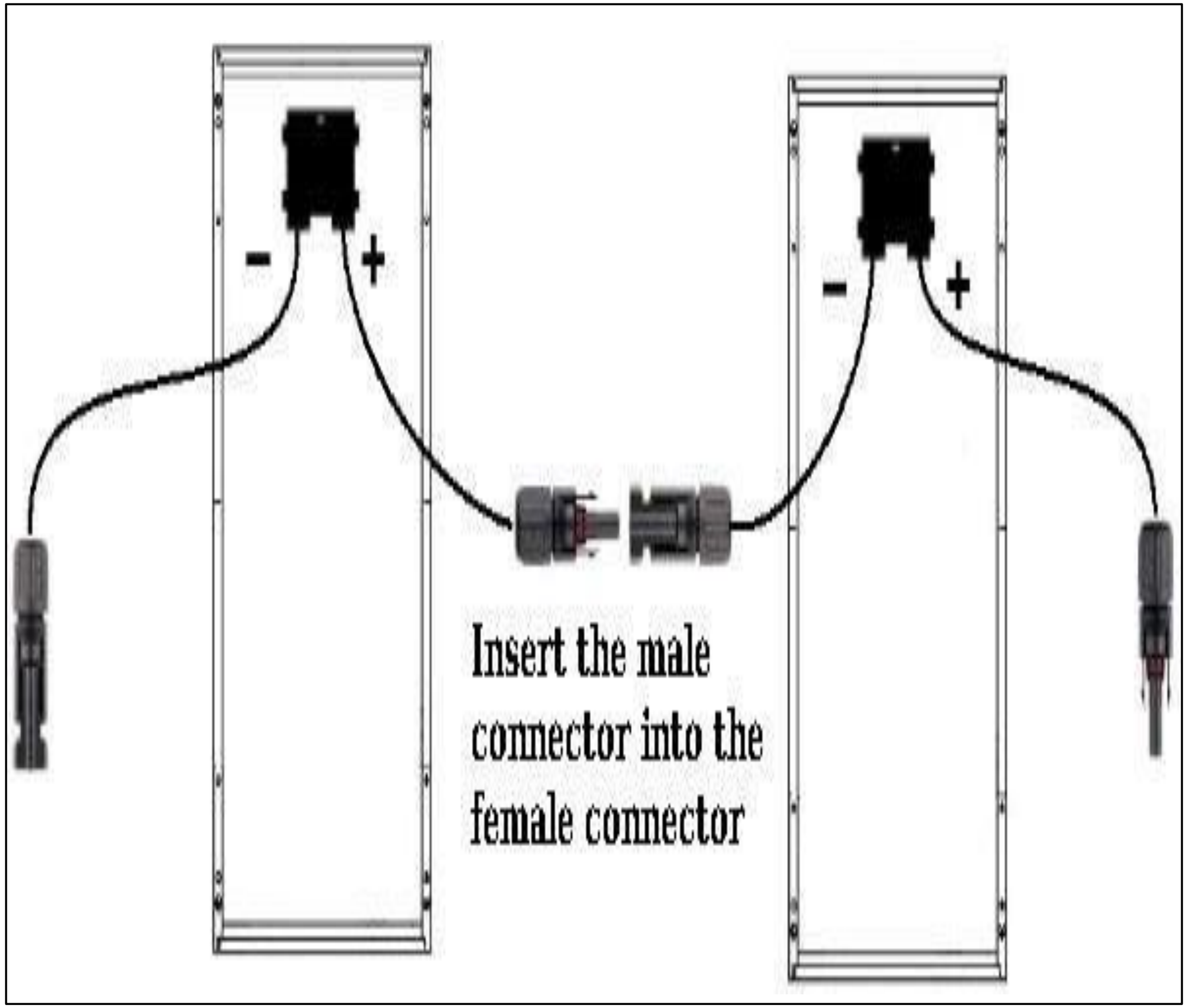
- **The solar panel junction box** is an enclosure placed at the underside of the solar PV module (solar back sheet). It is an important part through which two or more solar PV panels are interconnected.

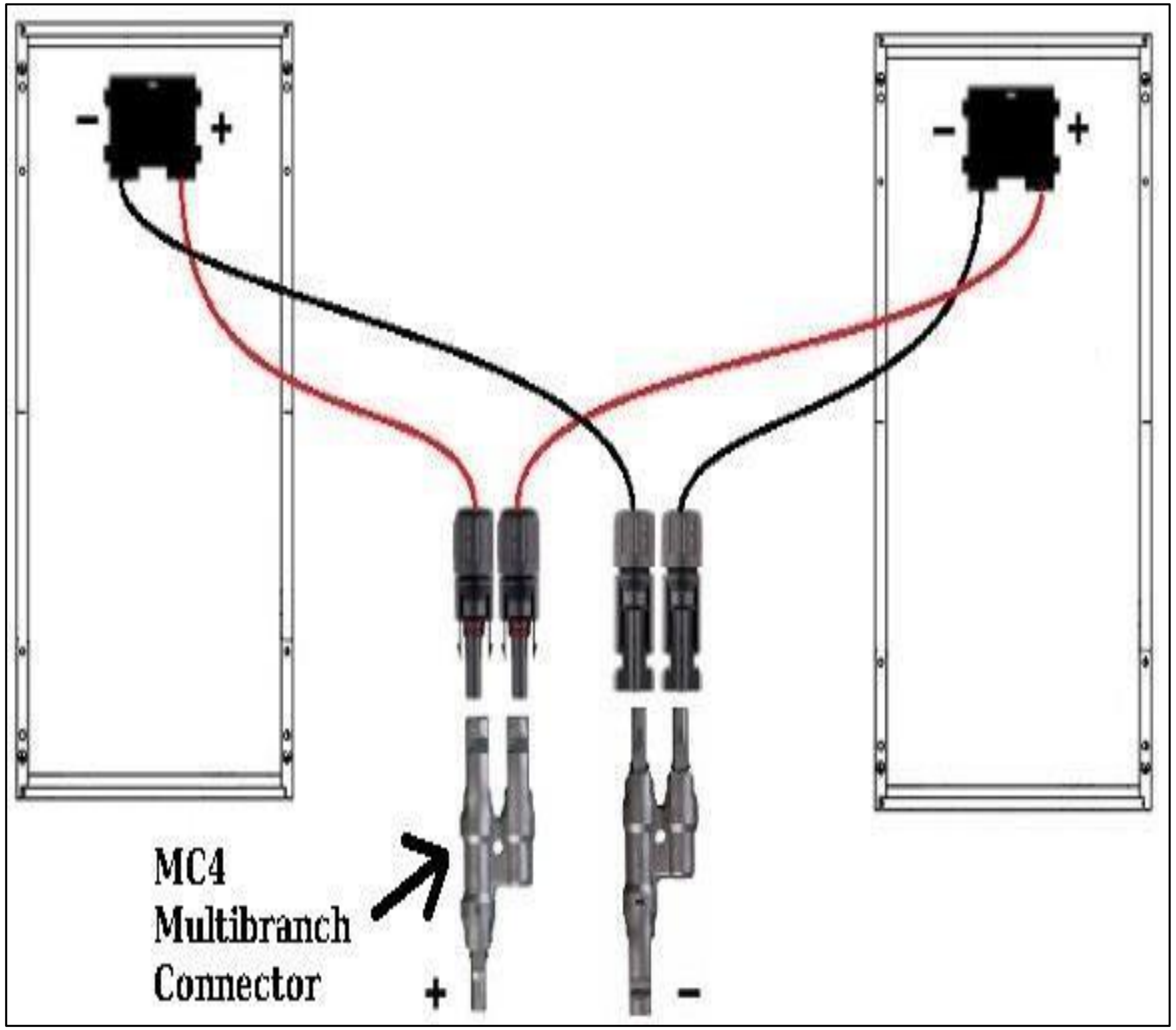
- Each solar junction box has two wires. One wire is the DC positive (+), and the other is the DC negative (-).

Junction Box

- The cables from a solar panel junction box transport the electricity from the solar PV module to the string. Modern PV solar panels tend to use the MC4 connectors because they make wiring the PV array much simpler and faster.
- The MC in MC4 stands for the manufacturer Multi-Contact and the 4 for the 4mm diameter contact pin.

Junction Box





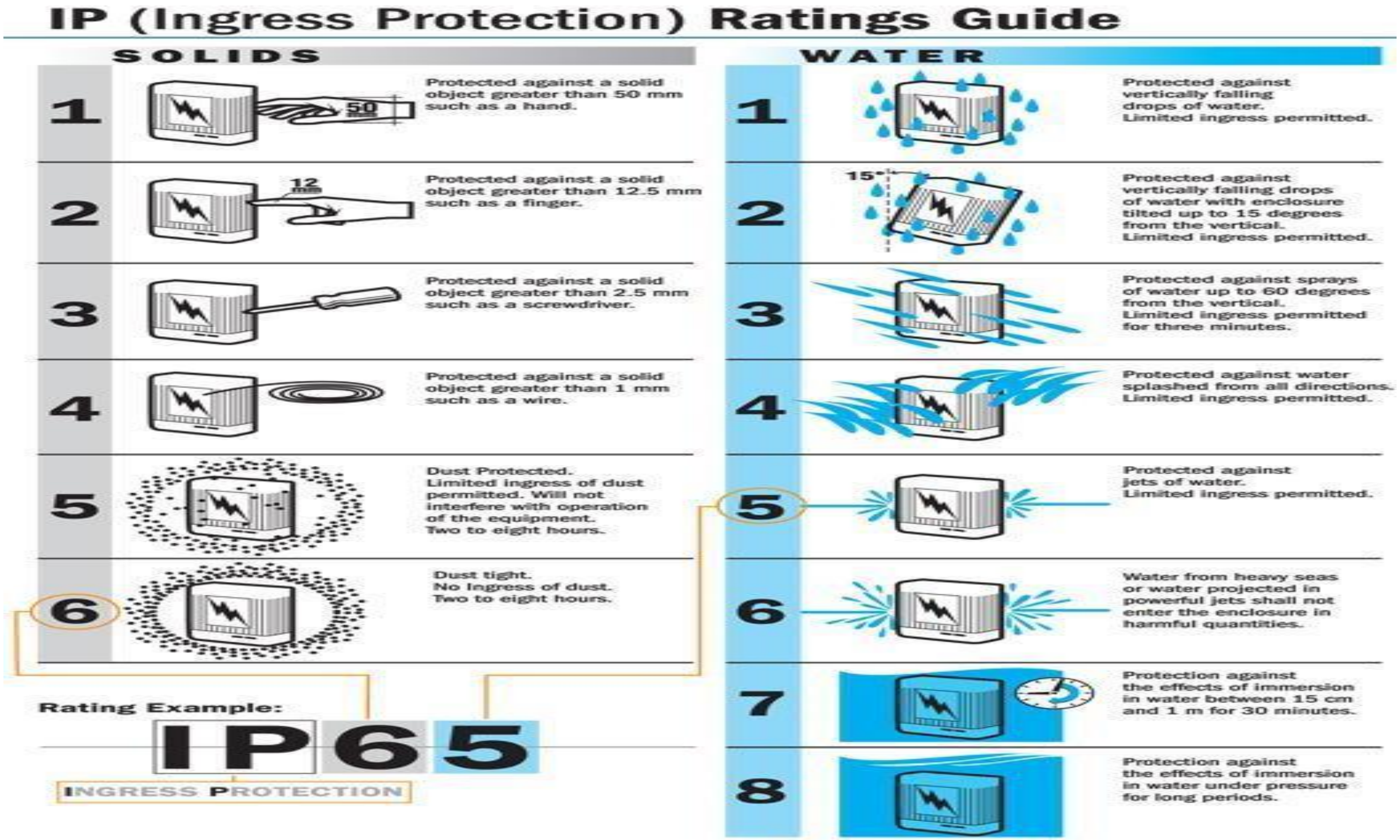
Junction Box

- PV junction box encapsulates solar **bypass diodes** that keep solar power flowing in one direction and prevent it from feeding back to the solar PV panels.
- A quality solar panel junction box minimizes corrosion at the terminals; as it will exclude that moisture enters the PV panel. The majority of solar junction boxes have at least an **IP65 rating.**

Junction Box

- IP is an acronym used for Ingress Protection.
- The IP rating of an enclosure is a two digit numeric code that tells you how resistant a particular box is to dust and fluid ingress.
- The rating consists of the IP abbreviation (IP) followed by a two digit code. Each digit represents the degree of tolerance against one of the environmental factors.
- The first digit is the degree of tolerance against solid particles ingress while the second digit shows the same for liquid particle ingress.

Junction Box



The Manufacturing Process

- **Why thin film technology for photovoltaic ?**

The competitiveness of a photovoltaic module is largely determined by the cost per unit power output. They have certain advantages in manufacturing compared to traditional silicon photovoltaic cells:

• Lower consumption of materials.
• Independence from shortages of silicon supplies.
• Fewer processing steps.
• Simplified materials handling.
• Process lends itself to automation.
•Integrated, monolithic circuit design; no assembly of individual solar cells into final products.

The Manufacturing Process

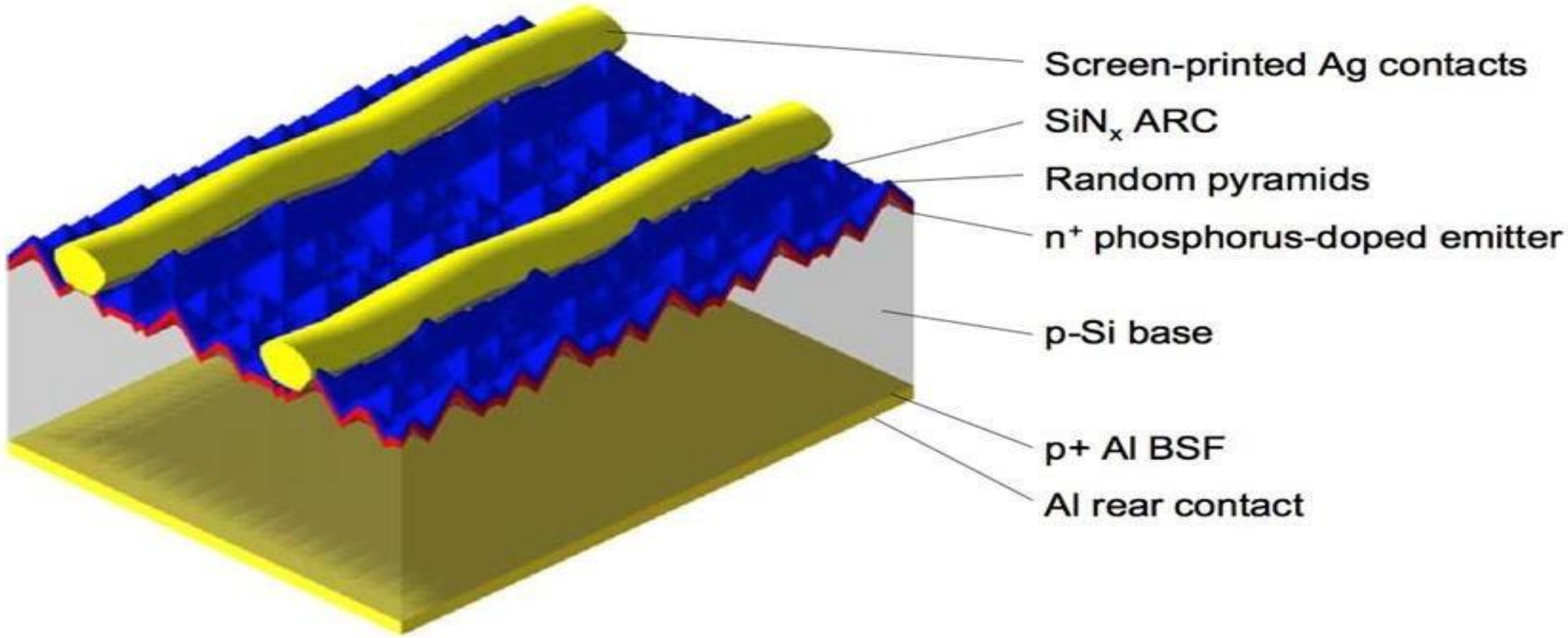
- **The different thin film technologies**

Different thin film photovoltaic technologies have been studied en developed for terrestrial applications. Those with the greatest potential to significantly reduce manufacturing costs are already commercially available. These are:

- amorphous silicon (a-Si)
- cadmium telluride (CdTe)
- copper indium gallium selenide / sulfide (CIGS)
- thin film silicon (Si-film)

The Manufacturing Process

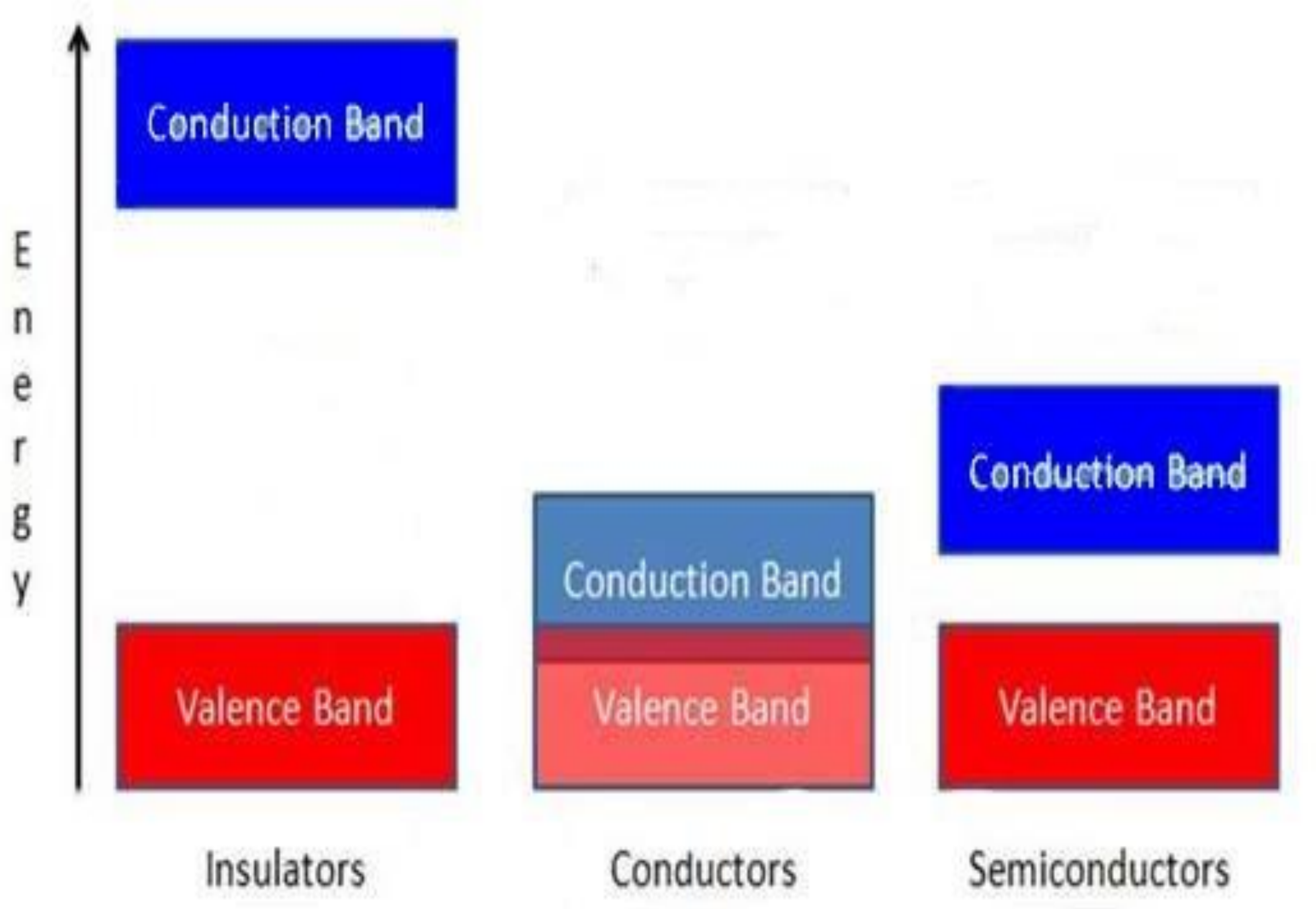
How Solar Photovoltaic Cells Work



Structure of Al-BSF solar cell

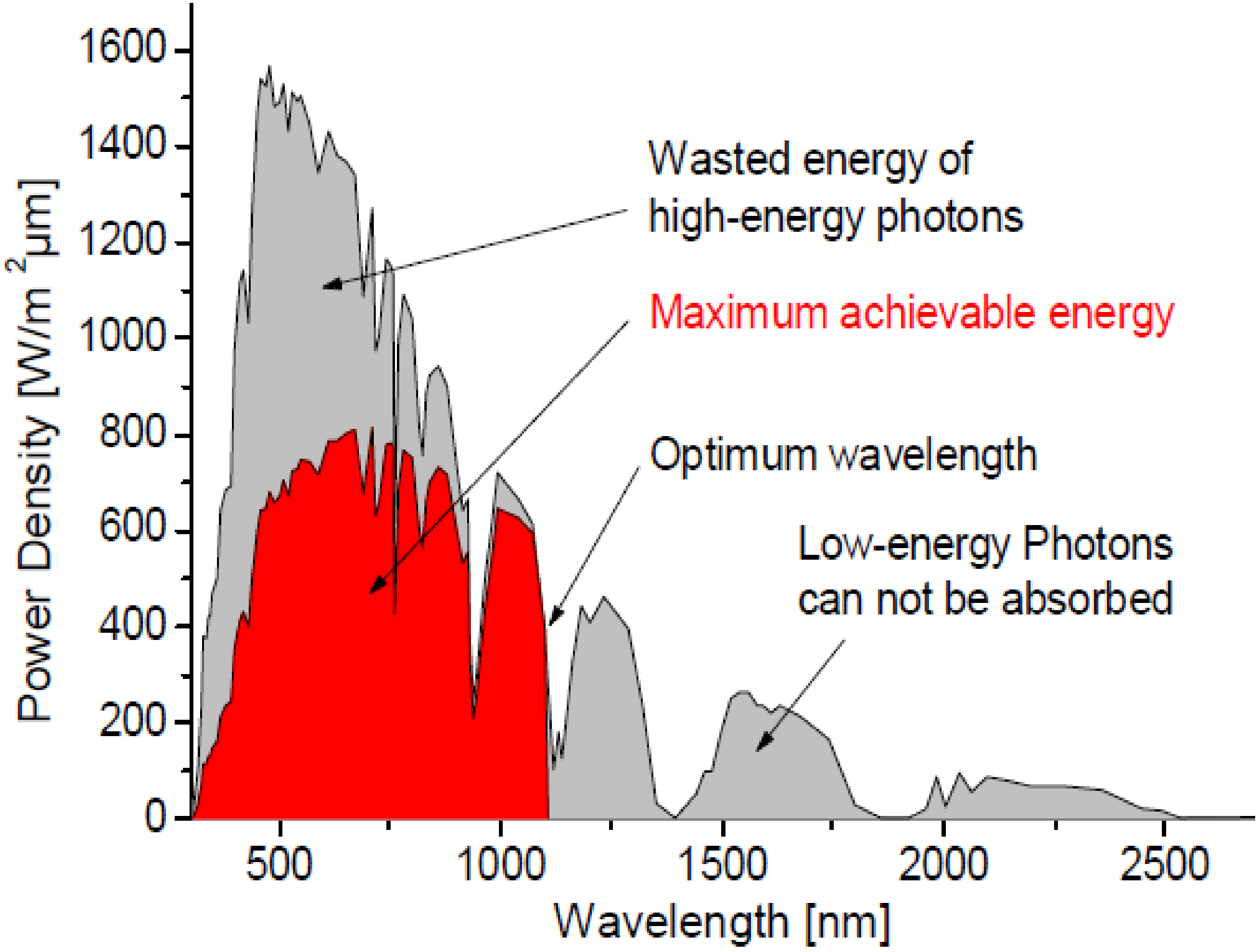
How Solar Photovoltaic Cells Work

The energy difference between the highest occupied energy state of the valence band and the lowest unoccupied state of the conduction band is called the band gap and is indicative of the electrical conductivity of a material.

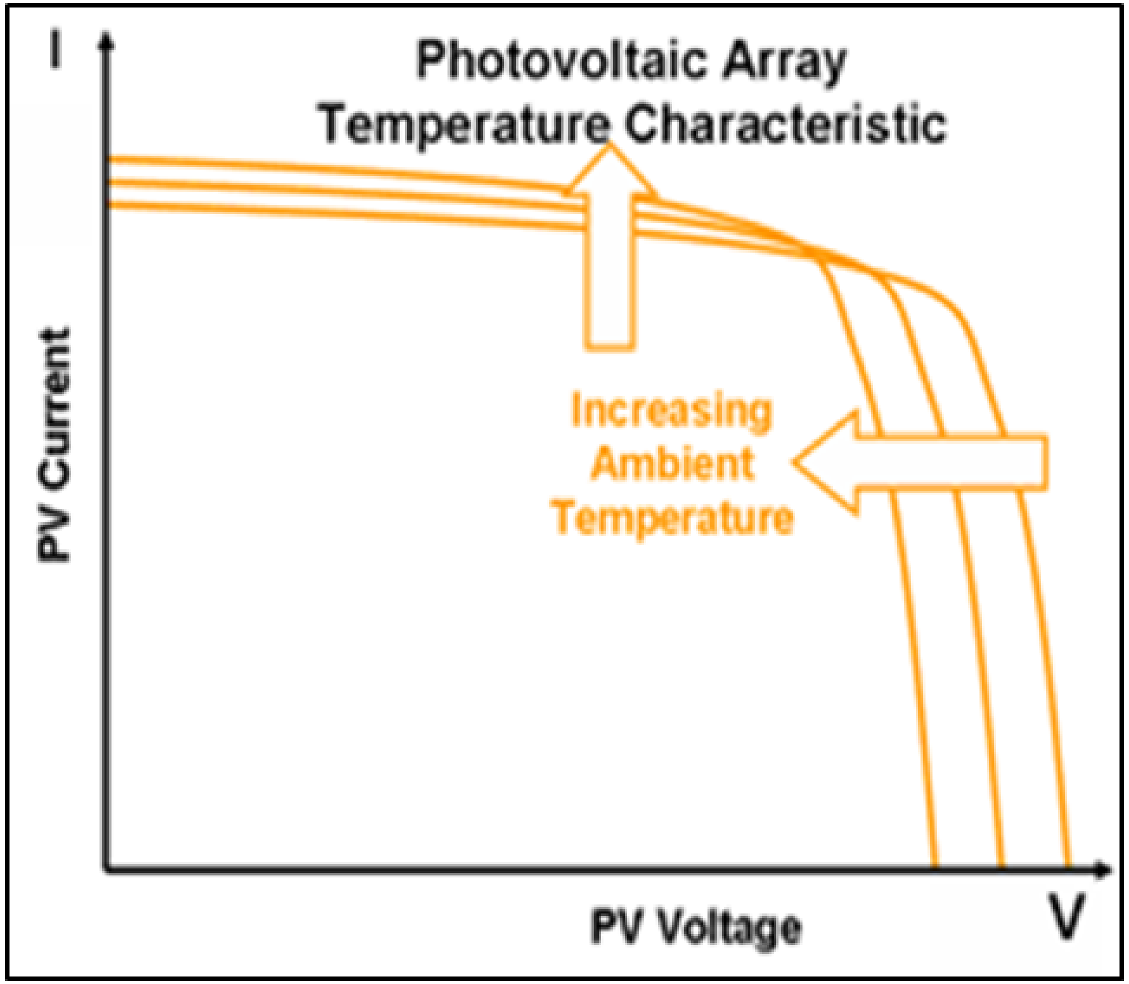


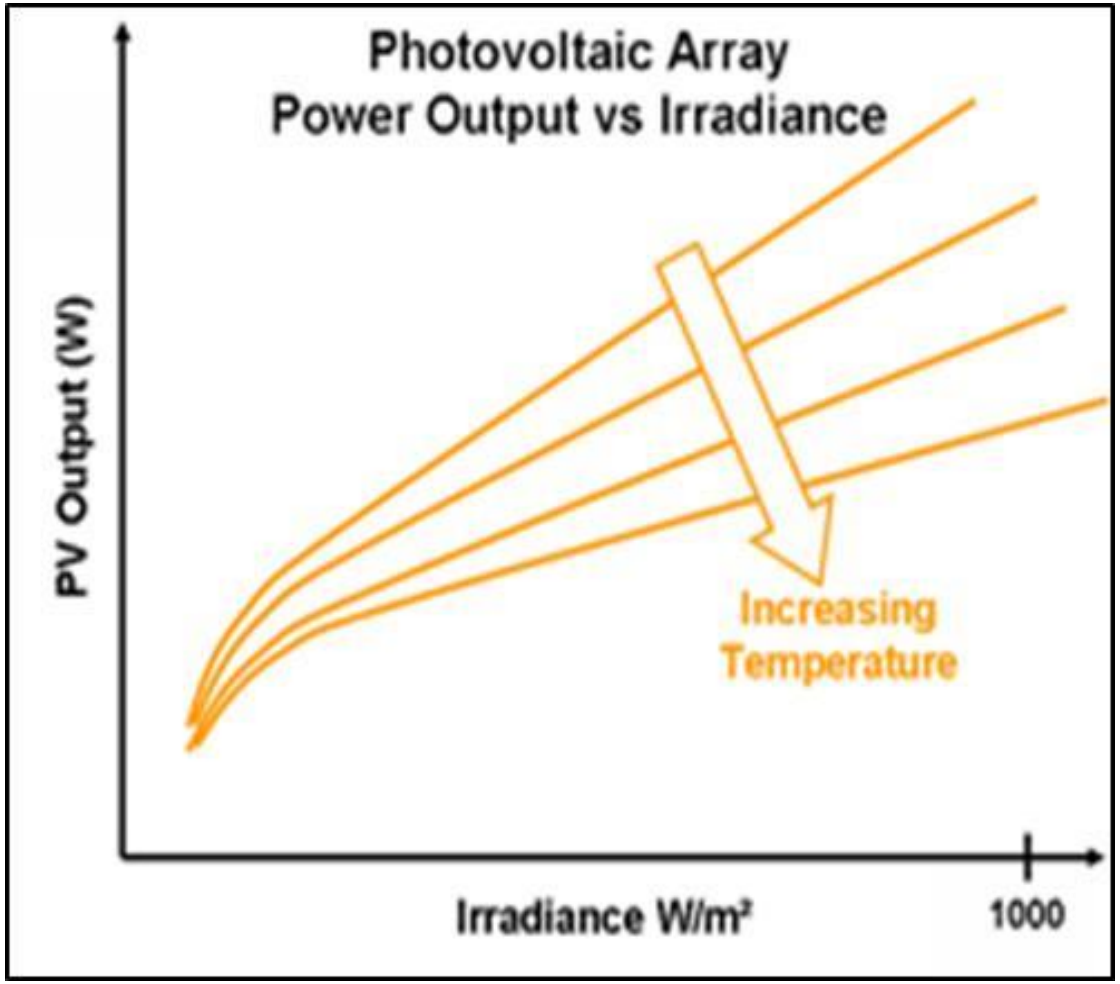
How Solar Photovoltaic Cells Work

This band gap also allows semiconductors to convert light into electricity in photovoltaic cells (1.12 ev for silicon).

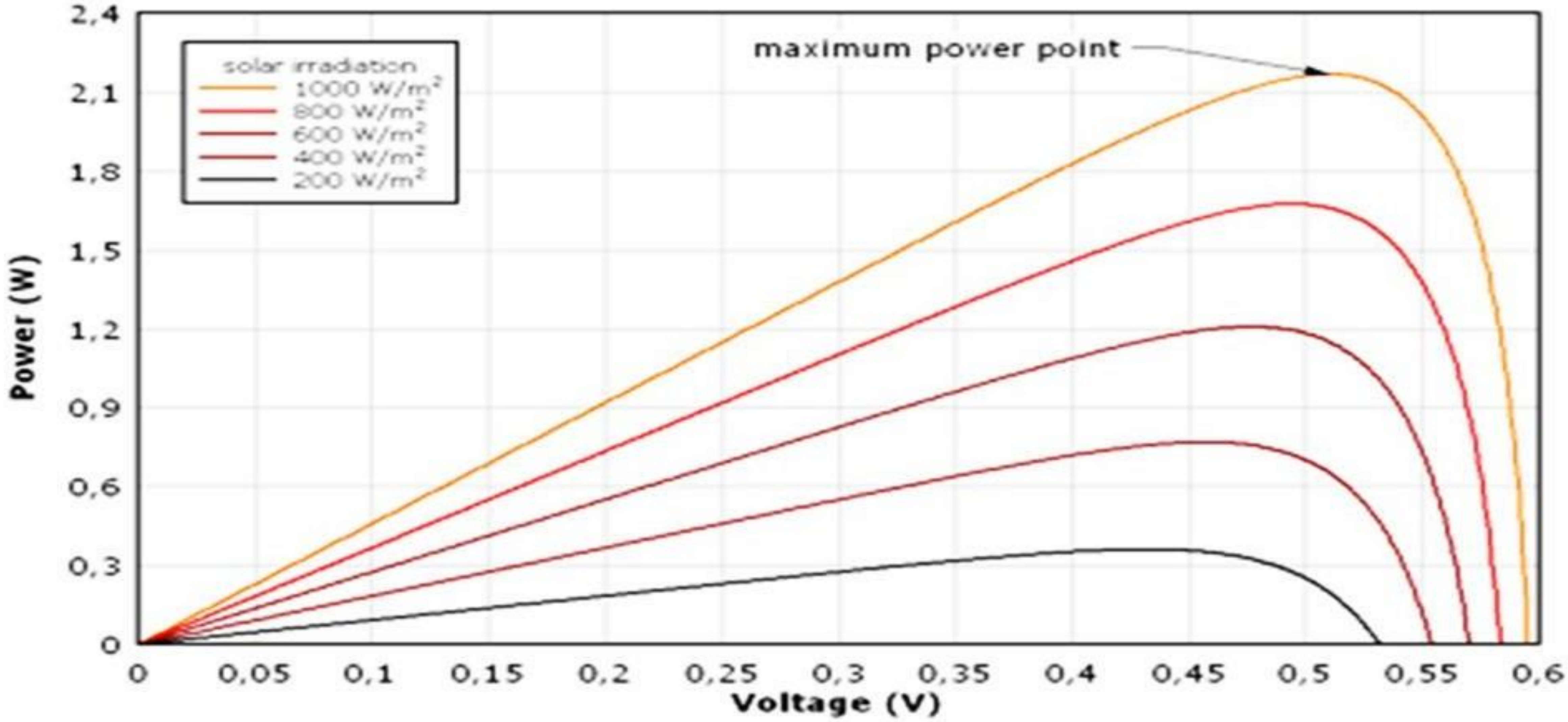


Factors Affecting Solar Cells

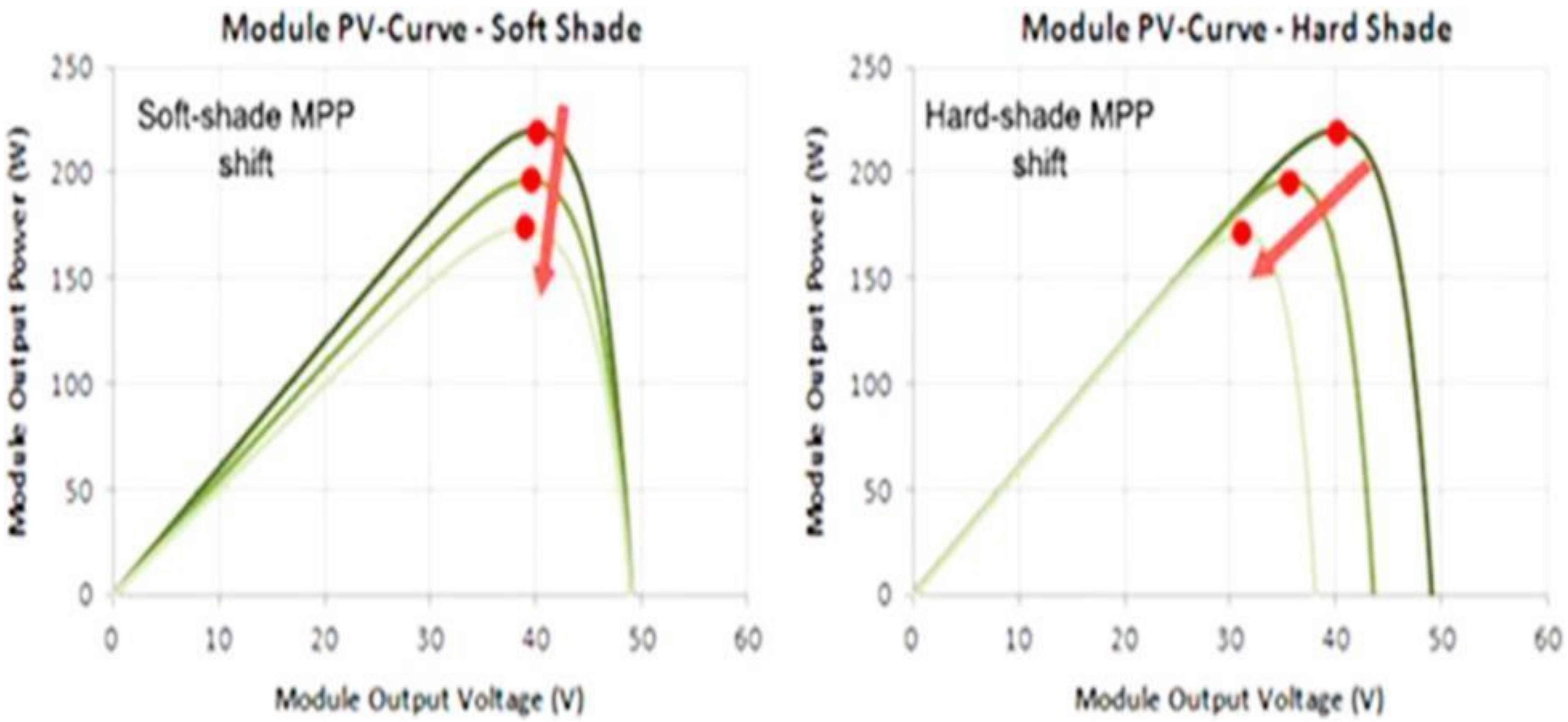




Factors Affecting Solar Cells



Factors Affecting Solar Cells



Factors Affecting Solar Cells

- In addition to these factors, the amount of energy delivered by a PV module is dependent on other factors such as the reliability of other components of the overall system and other environmental conditions.

A. Nameplate DC Rating.

B. Mismatch losses.

C. Soiling losses.

D. DC and AC Wiring.

E. Sun-Tracking loss.

Solar Cells Different Types

Gallium Arsenide:

- Gallium arsenide has a similar crystal structure to that of mono-crystalline silicon, but with alternating gallium and arsenic atoms.

- Due to its higher light absorption coefficient and wider band gap, GaAs cells are much more efficient than those made of silicon. Additionally, GaAs cells can operate at much higher temperatures without considerable performance degradation, making them suitable for concentrated photovoltaics.

- GaAs cells are produced by depositing layers of gallium and arsenic onto a base of single crystal GaAs, which defines the orientation of the new crystal growth. This process makes GaAs cells much more expensive than silicon cells, making them useful only when high efficiency is needed, such as space applications.

Solar Cells Different Types

Multi-Junction:

- Multi-junction cells have 2 or more junctions layered on top of each other, allowing energy to be collected from multiple portions of the spectrum.

- Multi-junction cells are produced in the same way as gallium arsenide cells—slowly depositing layers of material onto a single crystal base, making them very expensive to produce, and only commercially viable in concentrated PV systems and space applications.

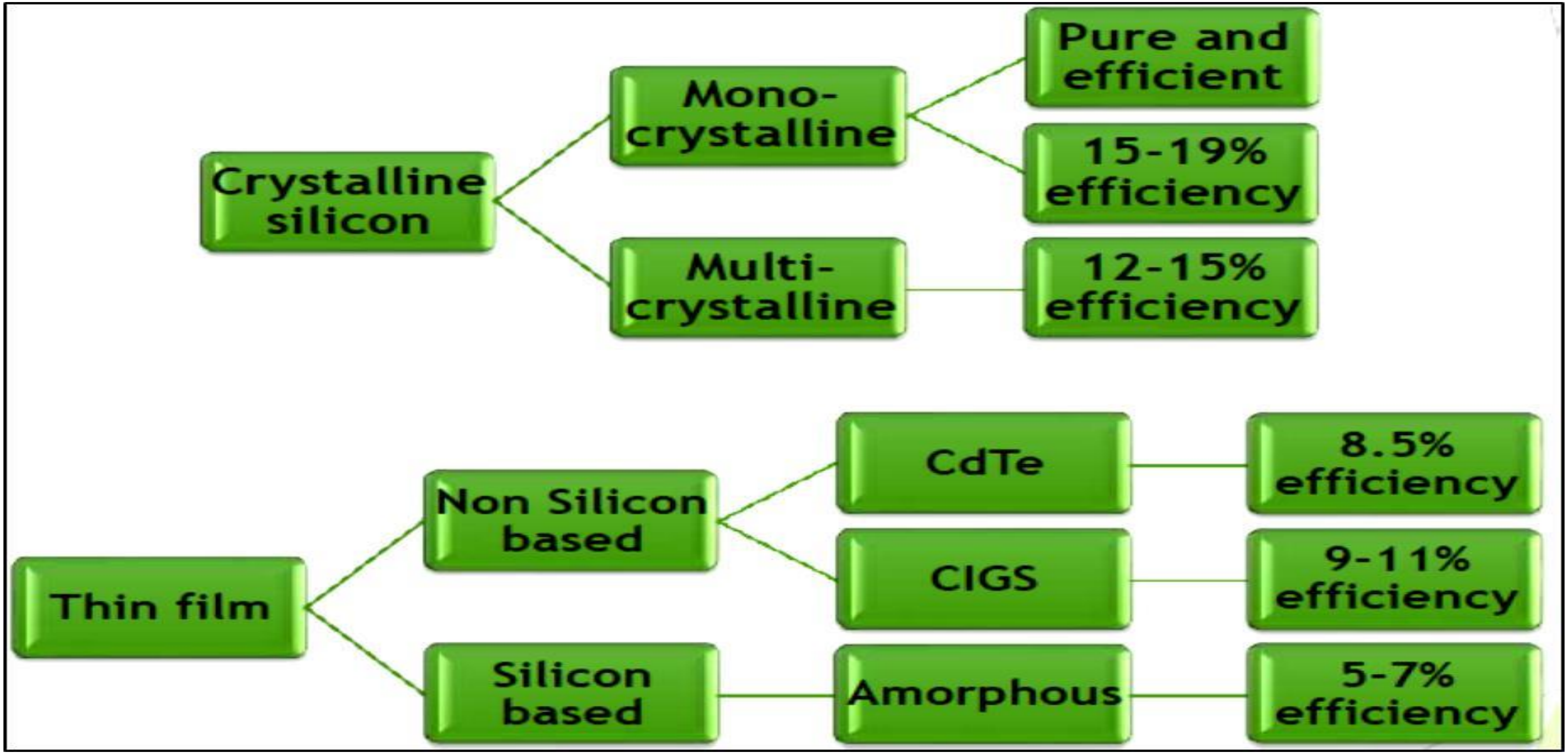
Solar Cells Different Types

- **Emerging Cell Technologies:**

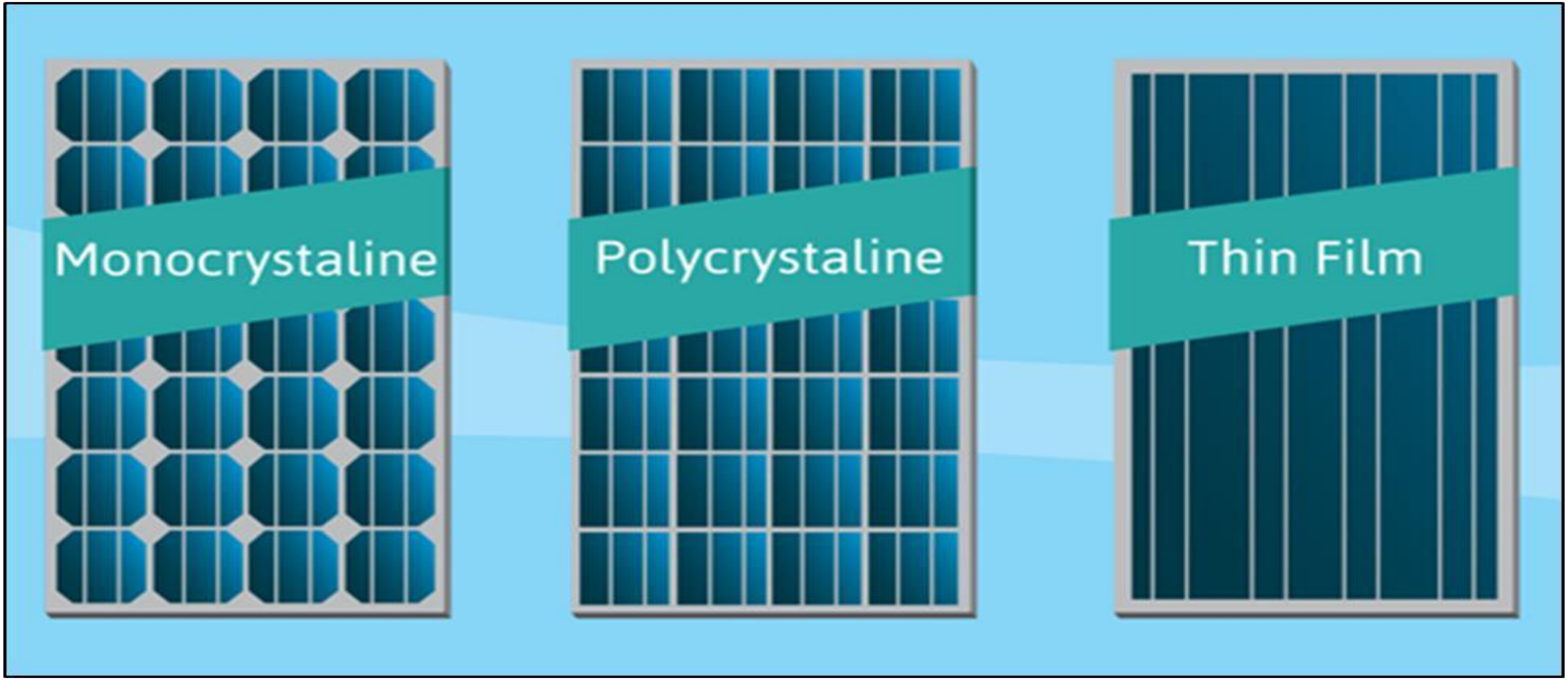
- Perovskite solar cells, named after their specific crystal structure, can be produced from organic compounds of lead and elements such as chlorine, bromine or iodine.

- They are relatively cheap to produce and can boast efficiencies close to those of commercially available silicon cells but they are currently limited by a short lifespan.

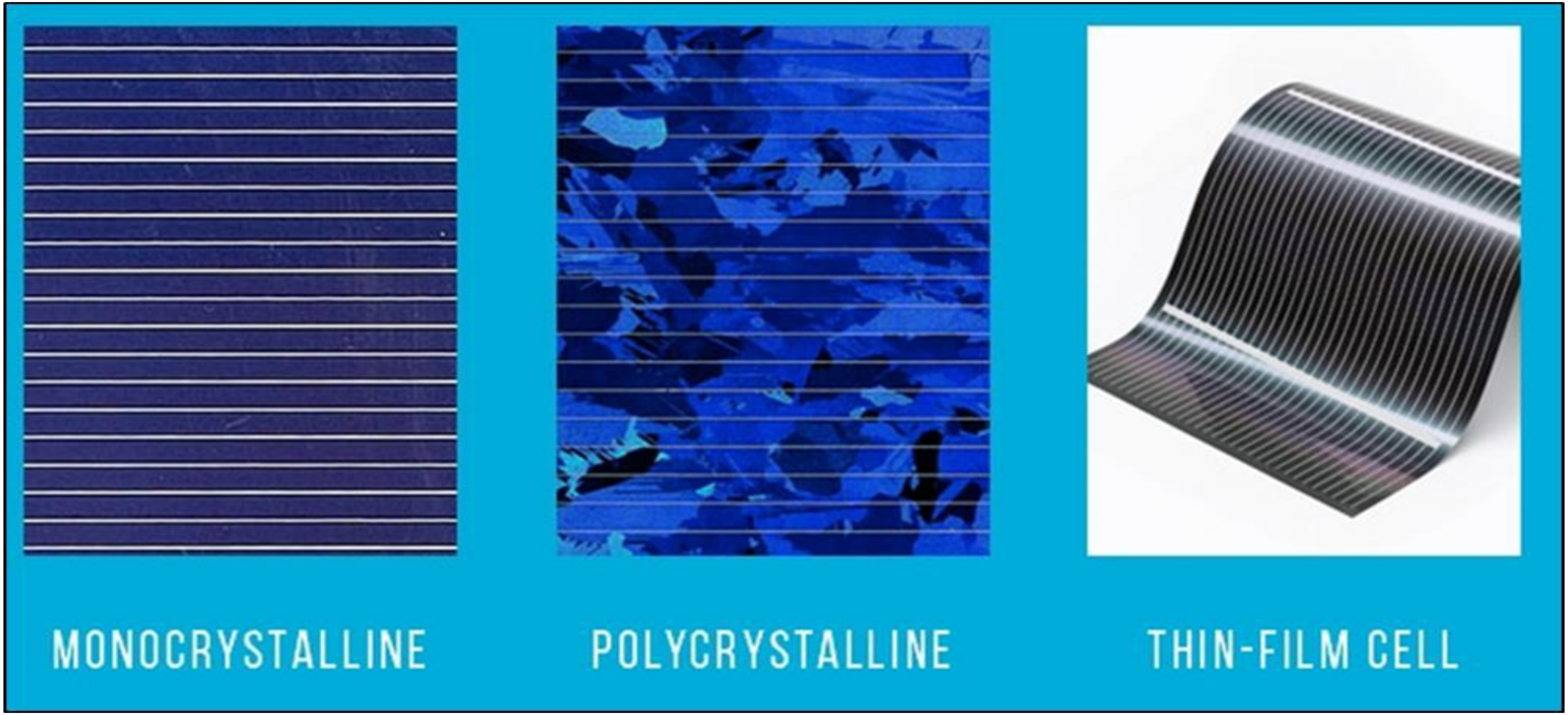
Solar Cells Different Types



Solar Cells Different Types



Solar Cells Different Types



Solar Cells Different Types

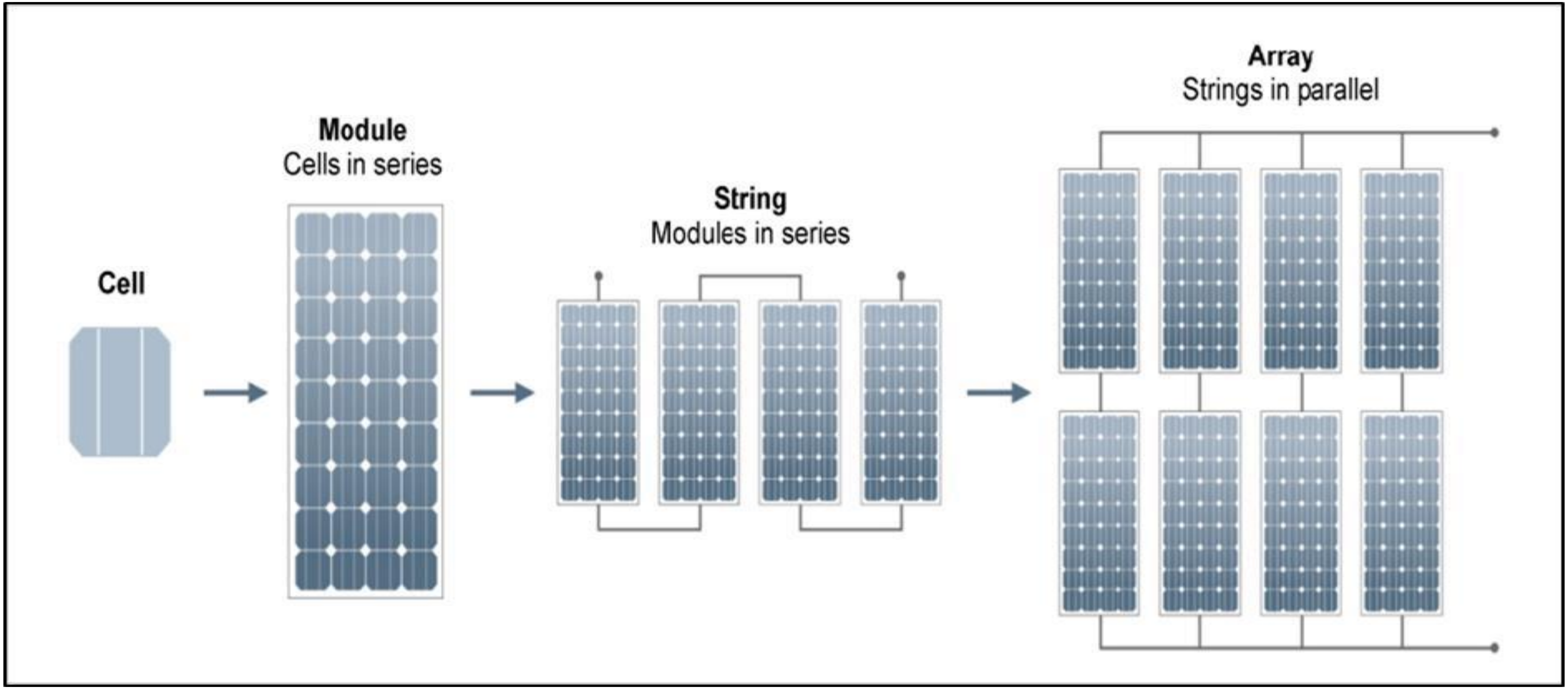
Crystalline	Thin Films
	
Types of Crystalline panels ◆ Single Crystalline (15%) ◆ Multi-Crystalline (14%) (% of sunlight converted to electricity)	**Types of Thin Film panels** ◆ Amorphous Silicon (5-7%) ◆ Copper Indium Diselenide (10%) ◆ Cadmium Telluride (7%) (% of sunlight converted to electricity)
Positive factors ◆ Efficient ◆ Requires less space ◆ Long track record	**Positive factors** ◆ Less expensive ◆ Very versatile ◆ More shade tolerant ◆ Less temperature sensitive
Negative factors ◆ Costly ◆ Limited applications ◆ Shade intolerant ◆ Temperature sensitive	**Negative factors** ◆ Shorter track record ◆ Lower efficiency ◆ Requires more space

Solar Cells Different Types

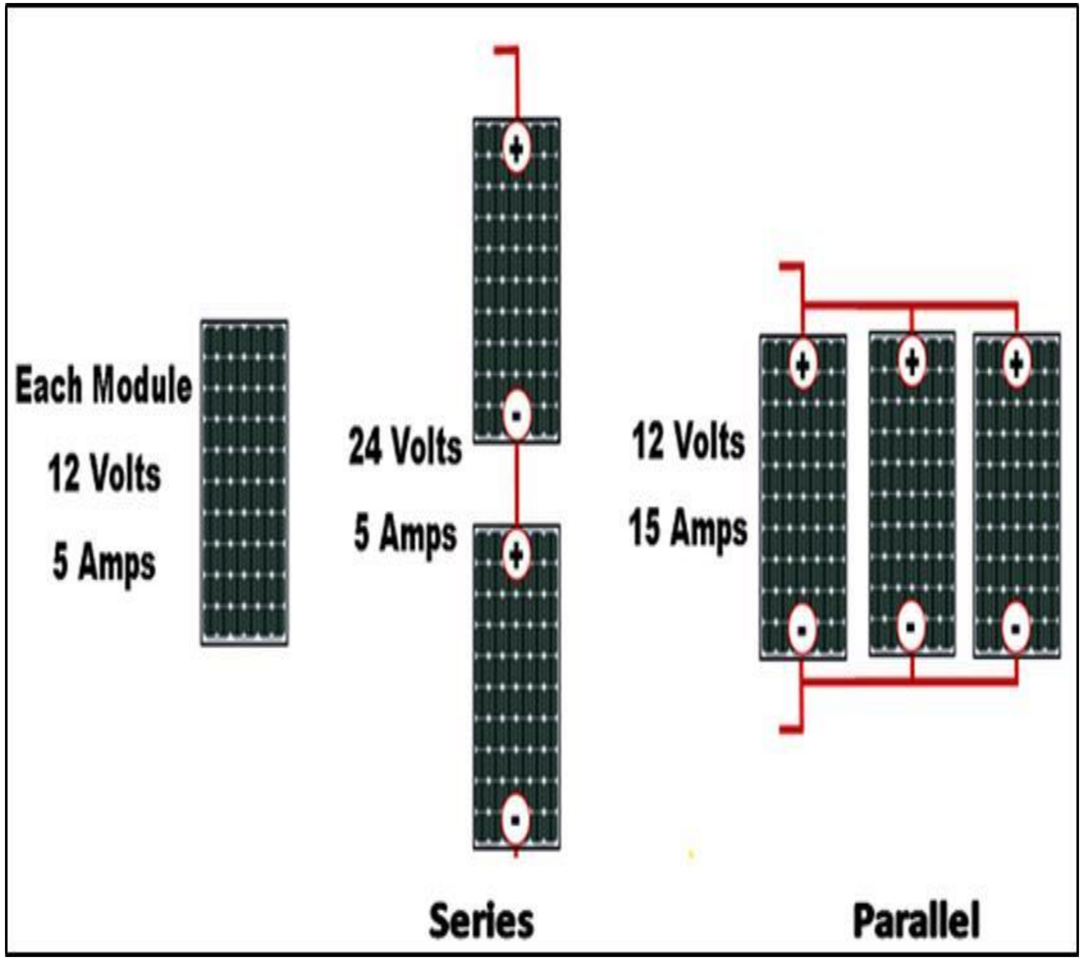
PV Panel Technology Summary

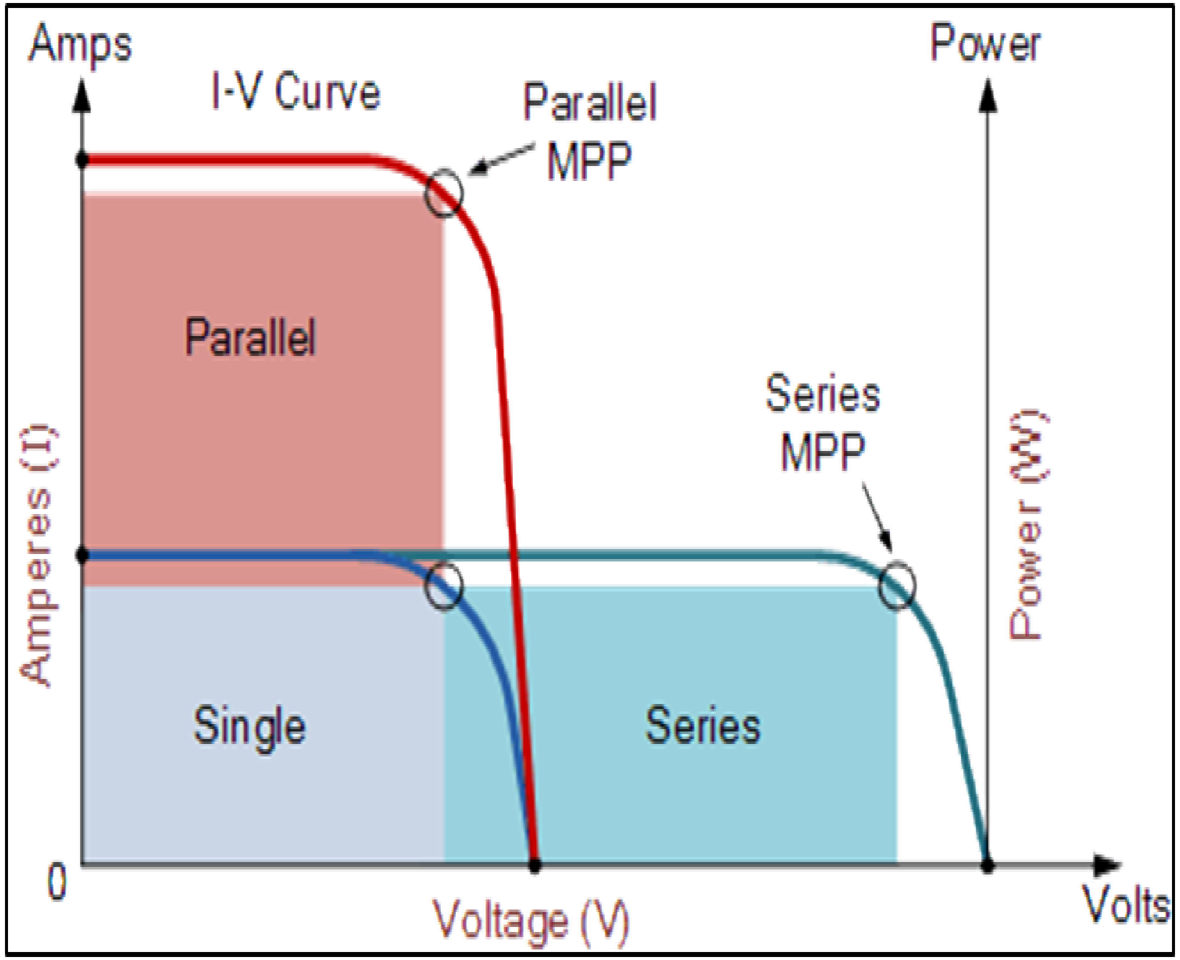
Technology	Description	Module Efficiency (Commercial)	Cell Efficiency (Laboratory)	Sample Companies Employing Technologies
Crystalline Silicon	The orignal approach; grow silicon crystal structures in a variety of ways. Represents almost 90% of total market. Appearance dark blue to black but other colors possible with changes to anti-reflective coatings.			
Single Crystal	Grown in Cylinders and wire- or laser-sliced into circular wafers as thin as 200 microns. Cells are circular and modules are inherently flat black or charcoal.	14 - 15%	25%	BP Solar GE/AstroPower Sanyo Sharp SunWorld
Multi-Crystalline	Cast in blocks or drawn through a die to create a "ribbon" and wire-sliced or cut into rectangular wafers. Cells are typically vibrant blue.	12 - 14%	19%	BP Solar Evergreen Solar Kyocera Solar Schott Solar Sharp SunWorld
Thin-Film Materials	Near single-atom vapor or electro-deposition on low-cost materials (glass, stainless steel, or plastic). Modules can be flexible. Appearance dark charcoal to near black; can also be semi-transparent.			
Amorphous Silicon (a-Si)	Cell and module production part of same process. Widely used in consumer products and on flexible substrates.	5 - 7%	13%	BP Solar Kaneka Solar TerraSolar United Solar Ovonic
Copper Indium Diselenide (CIS)	Alternative semiconductor material under commercialization.	8 - 10%	19%	Global Solar Shell Solar
Cadmium Telluride (CdTe)	Alternative semiconductor material under commercialization.	7 - 9%	17%	BP Solar First Solar

Solar Cells Connections



Solar Cells Connections





Characteristics of Solar Photovoltaic Cells

Standard Test Conditions (STC) against Nominal Operating Cell Temperature (NOCT):

Standard Test Conditions are the laboratory conditions under which all PV modules are tested. STC means:

1An irradiance of 1000 watts per square meter (W/m2), which simulates peak sunshine on a surface.

2 Temperature of the cell 25°C.

However, these are idealized conditions which don't reflect the real site conditions under which a PV module will operate.

Characteristics of Solar Photovoltaic Cells

Standard Test Conditions (STC) against Nominal Operating Cell Temperature (NOCT):

The conditions at Nominal Operating Cell Temperature aim to simulate reality more closely:

1The irradiance is 800 watts per square meter (W/m2), which takes into account the fact that PV modules don't always face the sun.

2 Solar panels heat up considerably during operation, so the temperature considered is 45 (+/- 3) °C.

3 Temperature of ambient air of 20°C is considered.

This means that solar panels will always have higher ratings at STC compared with NOTC.

Characteristics of Solar Photovoltaic Cells

MECHANICAL DATA	
Solar cells	Multicrystalline 156 × 156 mm (6 inches)
Cell orientation	60 cells (6 × 10)
Module dimensions	1650 × 992 × 35 mm(65.0 x 39.1 x 1.4 inches)
Weight	18.6 kg (41 lb)
Glass	3.2 mm(0.13 inches),High Transmission, AR Coated Tempered Glass
Backsheet	White(PD05.08); Black(PD05.05)
Frame	Black Anodized Aluminium Alloy
J-Box	IP 65 or IP 67 rated
Cables	Photovoltaic Technology cable 4.0mm² (0.006 inches²), 1000mm(39.4inches)
Connector	UTX Amphenol
Fire Type	Type 1 or 2

Characteristics of Solar Photovoltaic Cells

ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)	250	255	260	265
Power Output Tolerance-P_{MAX} (W)	0 ~ +5			
Maximum Power Voltage-V_{MPP} (V)	30.3	30.5	30.6	30.8
Maximum Power Current-I_{MPP} (A)	8.27	8.37	8.50	8.61
Open Circuit Voltage-V_{OC} (V)	38.0	38.1	38.2	38.3
Short Circuit Current-I_{SC} (A)	8.79	8.88	9.00	9.10
Module Efficiency η_m (%)	15.3	15.6	15.9	16.2

STC: Irradiance 1000 W/m², Cell Temperature 25°C, Air Mass AM1.5.

Characteristics of Solar Photovoltaic Cells

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	186	189	193	197
Maximum Power Voltage-V_{MPP} (V)	28.1	28.2	28.4	28.6
Maximum Power Current-I_{MPP} (A)	6.63	6.71	6.81	6.89
Open Circuit Voltage-V_{OC} (V)	35.3	35.3	35.4	35.5
Short Circuit Current-I_{SC} (A)	7.10	7.17	7.27	7.35

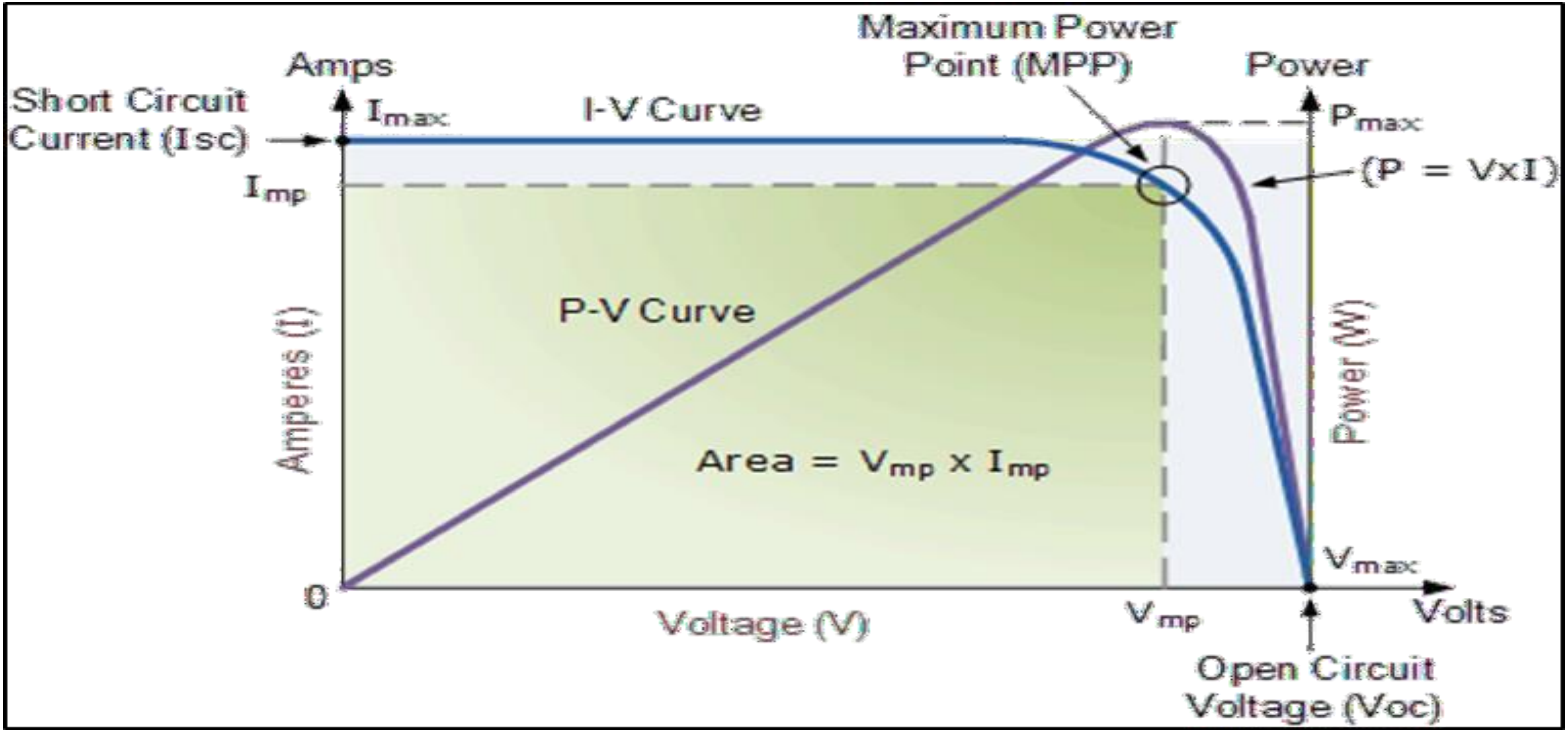
NOCT: Irradiance at 800 W/m², Ambient Temperature 20°C, Wind Speed 1 m/s.

Characteristics of Solar Photovoltaic Cells

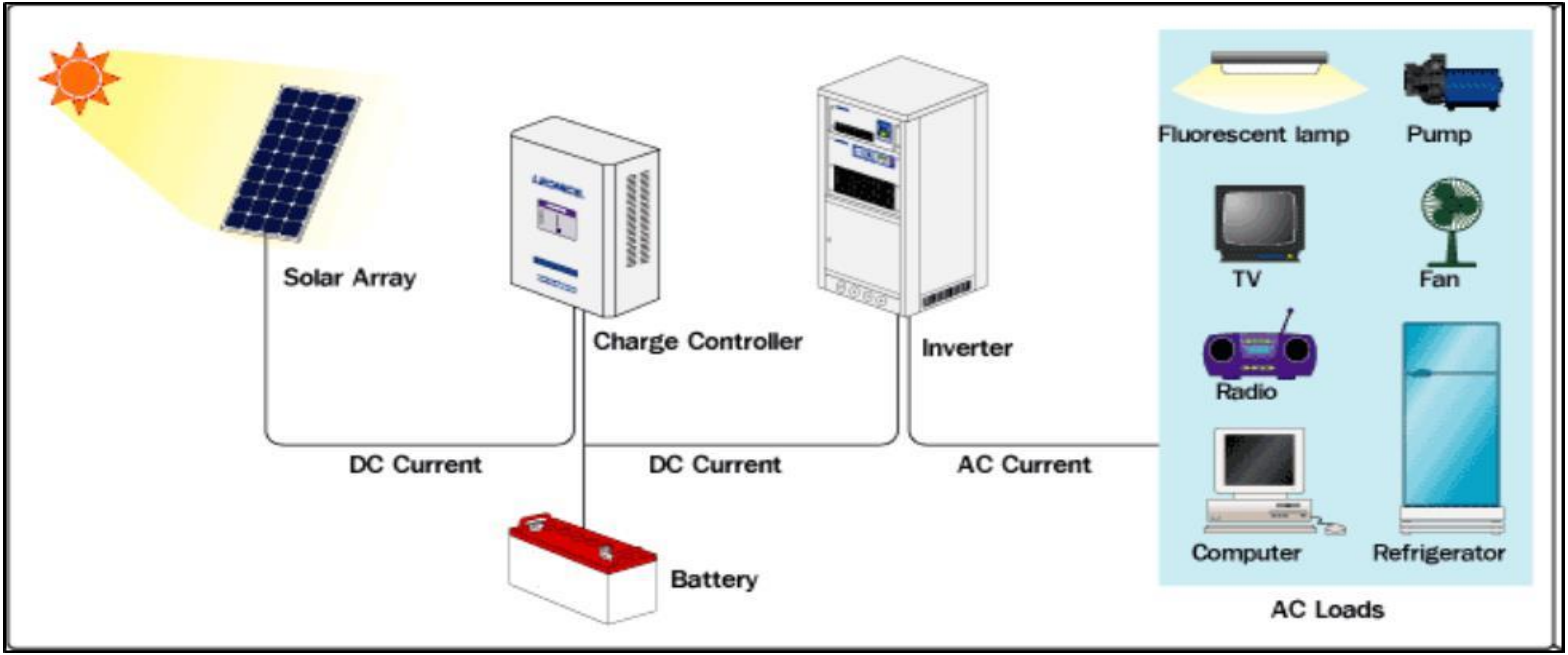
TEMPERATURE RATINGS	
Nominal Operating Cell Temperature (NOCT)	44°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.41%/°C
Temperature Coefficient of V_{OC}	- 0.32%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS	
Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC(IEC) 1000V DC (UL)
Max Series Fuse Rating	15A

Solar Cell I-V Characteristic Curves

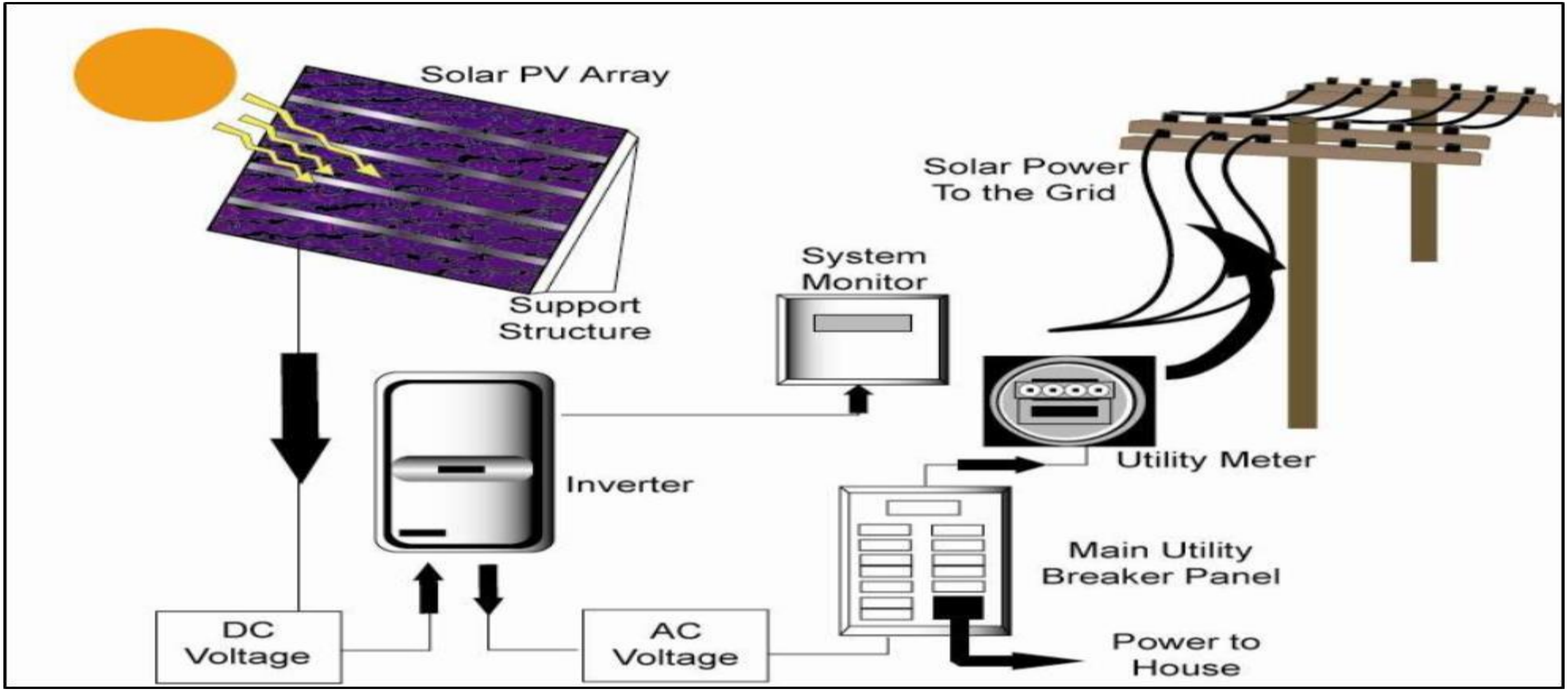


Solar Photovoltaic Systems



Stand Alone PV System (OFF-Grid)

Solar Photovoltaic Systems



Grid-Tied PV System (ON-GRID)

Contents

Day 3

- Batteries
  - ✓ Theory of Operation
  - ✓ Different Types of Batteries (Lead Acid, Ni-Cd, Ni-MH and Li-ion)
  - ✓ Batteries Connection
  - ✓ Battery Ratings & Temperature Effect.
- Charge Controller
  - ✓ Functions
  - ✓ Types & Theory of Operation (Fixed Voltage (Shunt, Series and PWM) and MPPT)
  - ✓ Technical Specification
- Inverter
  - ✓ Function
  - ✓ Theory of Operation
  - ✓ Different Types of Solar Inverter (Off-grid and Grid-Tie)
  - ✓ Technical Specification

Batteries

- A battery is a device that is able to store electrical energy in the form of chemical energy, and convert that energy into electricity.

- **Advantages:**

– Backup for night and cloudy days.

- **Disadvantages:**

– Decreases the efficiency of PV system.
– Only 80% of energy stored retainable.
– Adds to the expense of the system.
– Finite Lifetime ~ 5 – 10 years.
– Added floor space, maintenance and safety concerns.

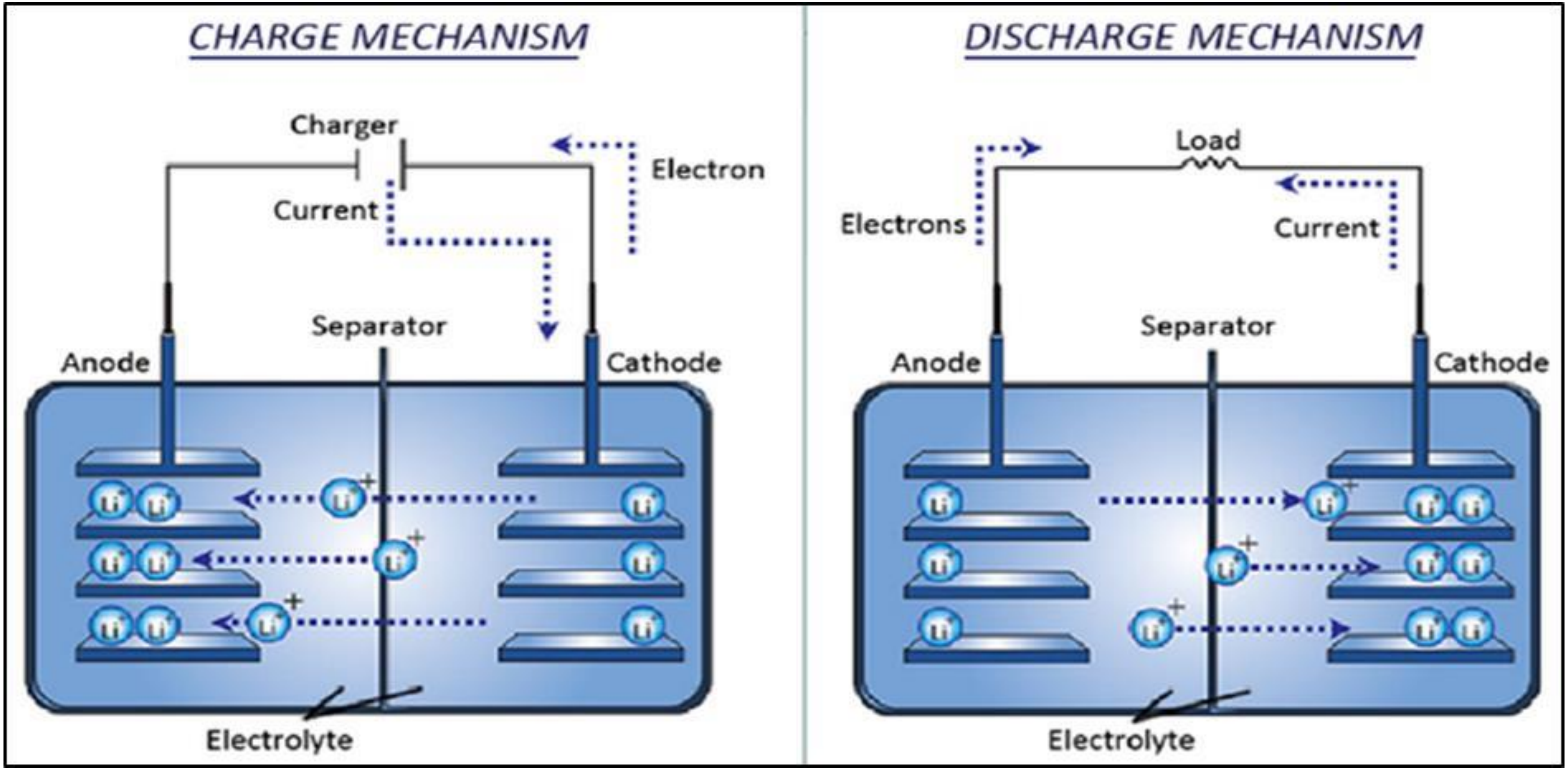
Batteries

Batteries

Primary batteries; if the battery is disposable, it will produce electricity until it runs out of reactants. These batteries only work in one direction, transforming chemical energy to electrical energy.

Rechargeable batteries (secondary batteries); are designed so that electrical energy from an outside source can be applied to the chemical system, and reverse its operation, restoring the battery's charge.

Theory of Operation



Stages of Charging

- There are four stages to your battery charging:

- **Bulk** – occurs when the batteries are at a lower state-of-charge, generally anything less than 80% full. The Bulk stage basically allows the solar panel to put as much amperage into the batteries as possible.

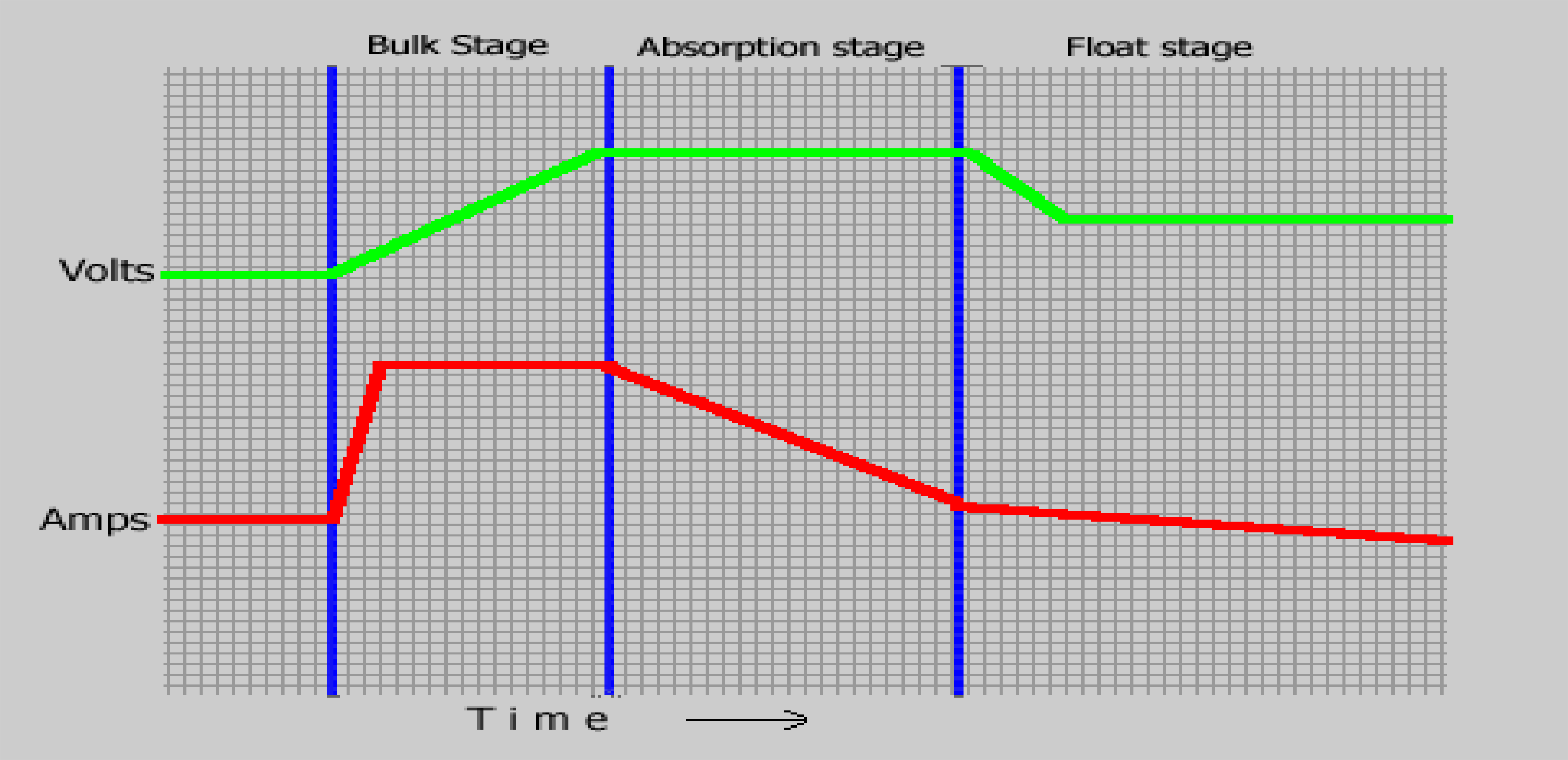
- **Absorb** – once the batteries reach the programmed "Absorb Voltage", usually somewhere between 14.4 – 14.8 Volts for lead-acid batteries, the batteries will go into the Absorb stage. During this stage, the batteries are kept at the programmed voltage, and the amperage going into the batteries reduces as the batteries become more full.

Stages of Charging

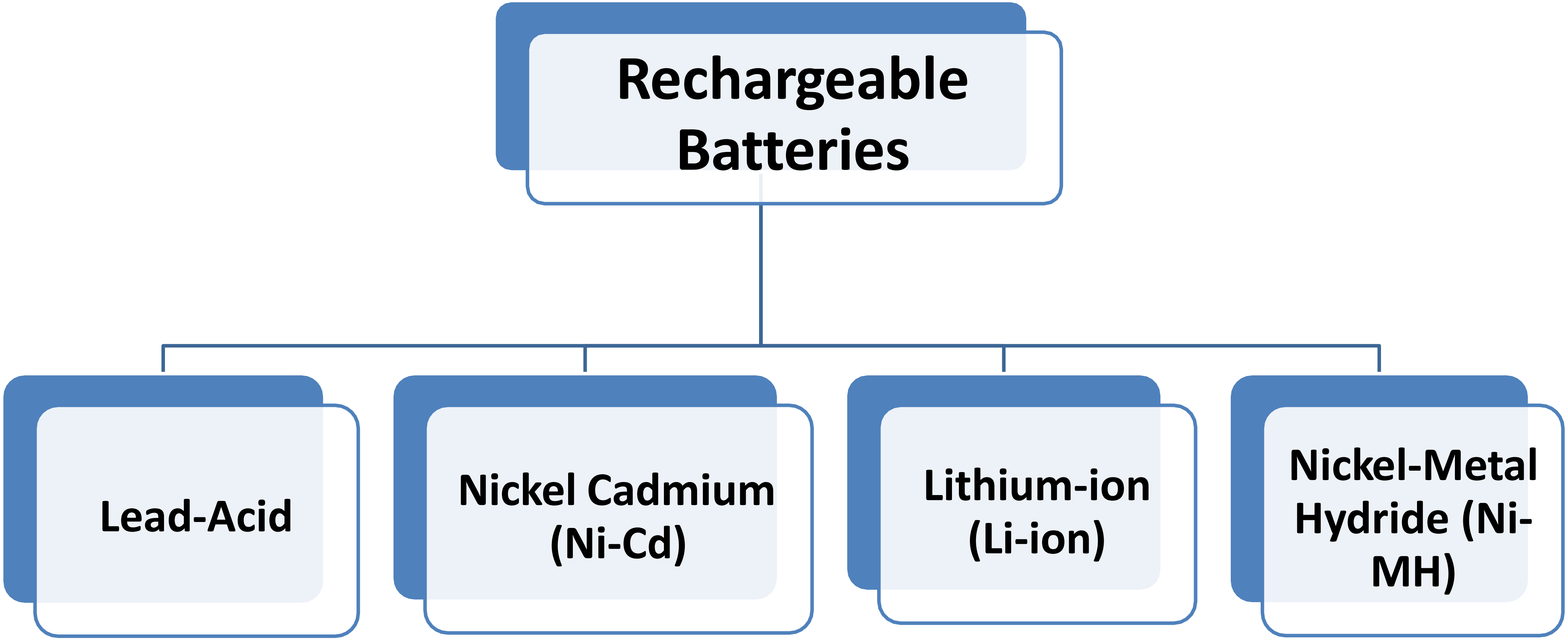
- **Float** –batteries achieve float stage where the charge voltage is reduced to between 13.0 VDC and 13.8 VDC and held constant, while the current is reduced to less than 1% of battery capacity. This mode can be used to maintain a fully charged battery indefinitely.

- **Equalization** – is a controlled overcharge stage. The electrolyte in a wet battery can stratify over time. In equalization, the voltage is brought up above peak charging voltage (15-16 volts in a 12 volt) well into the gassing stage, and held for a fixed (but limited) period. This stirs up the chemistry in the entire battery, "equalizing" the strength of the electrolyte.

Stages of Charging



Different Types of Batteries



Lead Acid Batteries

- Lead acid batteries are a low-cost reliable power workhorse used in heavy duty applications.

- They are usually very large and because of their weight, they’re always used in non-portable applications such as solar-panel energy storage, vehicle ignition and lights, backup power and load leveling in power generation/distribution.

- The lead-acid is the oldest type of rechargeable battery and still very relevant and important into today’s world.

Lead Acid Batteries

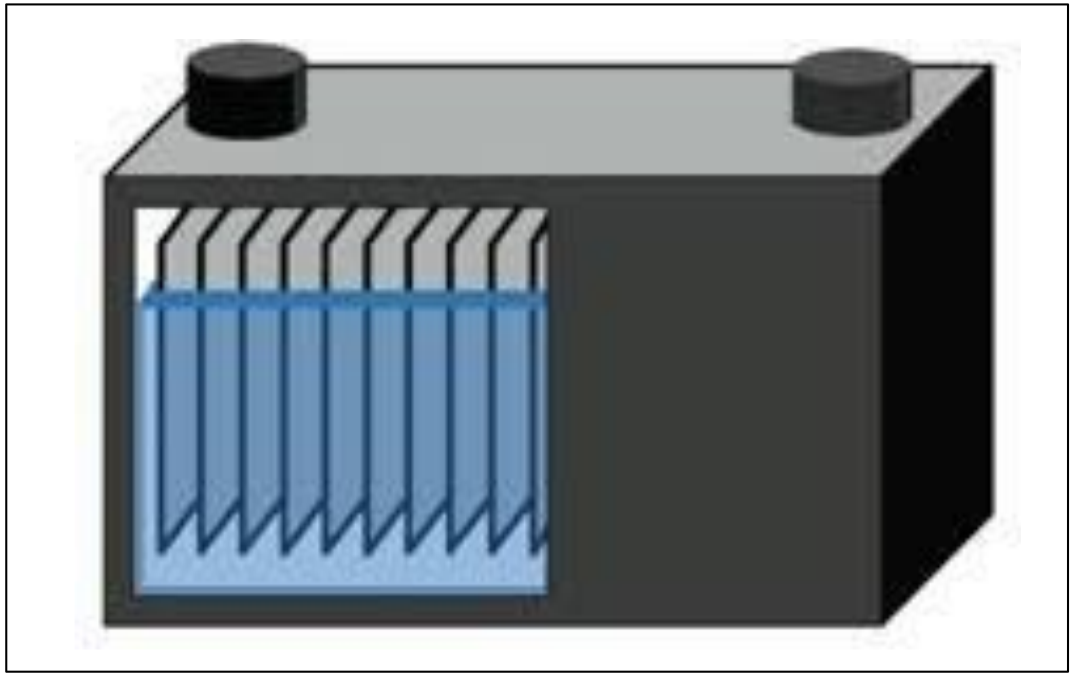
- Difference between a normal lead-acid car battery and a deep cycle battery;

- **A car's battery** is designed to provide a very large amount of current for a short period of time. This surge of current is needed to turn the engine over during starting.

- **A deep cycle battery** is designed to provide a steady amount of current over a long period of time. A deep cycle battery is also designed to be deeply discharged over and over again (something that would ruin a car battery very quickly).

Deep Cycle Lead Acid Batteries

Flooded: This is the traditional engine start and traction style battery. The liquid electrolyte is free to move in the cell compartment. The user has access to the individual cells and can add distilled water as the battery dries out.



Deep Cycle Lead Acid Batteries

Sealed: The only difference is that the manufacturer has ensured that a sufficient amount of acid in the battery to sustain the chemical reaction under normal use throughout the battery warranty period.

VRLA: This stands for Valve Regulated Lead Acid battery. This is also a sealed battery. The valve regulating mechanism allows for a safe escape of hydrogen and oxygen gasses during charging.

Deep Cycle Lead Acid Batteries

AGM: Absorbed Glass Matte construction allows the electrolyte to be suspended in close proximity with the plate's active material. In theory, this enhances both the discharge and recharge efficiency.

Deep Cycle Lead Acid Batteries

GEL: The gel cell is similar to the AGM style because the electrolyte is suspended, but different because technically the AGM battery is still considered to be a wet cell. The electrolyte in a GEL cell has a silica additive that causes it to set up or stiffen, like Jell-O.

Nickel Cadmium Batteries

Specific Power: 150W/kg

Charge/discharge efficiency: 70-90%

Self-discharge rate: 10%/month

Cycle durability/life: 2000cycles

Nickel-Metal Hydride Batteries

Specific Power: 250-1000 W/kg

Charge/discharge efficiency: 66% - 92%

Self-discharge rate: 1.3-2.9%/month at 20°C

Cycle Durability/life: 180 - 2000

Lithium-ion Batteries

Specific Power: 250: 340 W/kg

Charge/discharge percentage: 80-90%

Cycle Durability: 400: 1200 cycles

Nominal cell voltage: NMC 3.6/3.85V

Other Batteries Types

Comparison of Rechargeable Batteries

Battery	Memory	Self-Discharge Rate	Capacity (mA-hrs)	Toxic	High-Drain Device Performance	Available Recharge Cycles	Cost	Notes
Nickel Metal Hydride (NiMH)	No	Moderate	Moderate to High	No	Good	Moderate	Mod	**Best for:** All high-current draw devices. Use only LSD (low self discharge) variety for low-use devices like emergency flashlights and smoke detectors
Nickel Cadmium (NiCad)	Maybe	High to Moderate	Moderate	Yes	Moderate	Moderate to High	Mod	**Best for:** All high-current draw devices. **Not for use** in low-drain, low-use devices like emergency flashlights and smoke detectors Being replaced by NiMH
Alkaline	Yes	Moderate to Low	Low	No	Poor	Low	Low	**Best for:** LED flashlights (provide brighter light), other infrequently-used devices, items that require extra voltage (i.e., more than 2 batteries)
Lithium Ion	No	Low	High	Yes	Good	Moderate	High	**Best for:** Digital cameras, laptops, cell phones

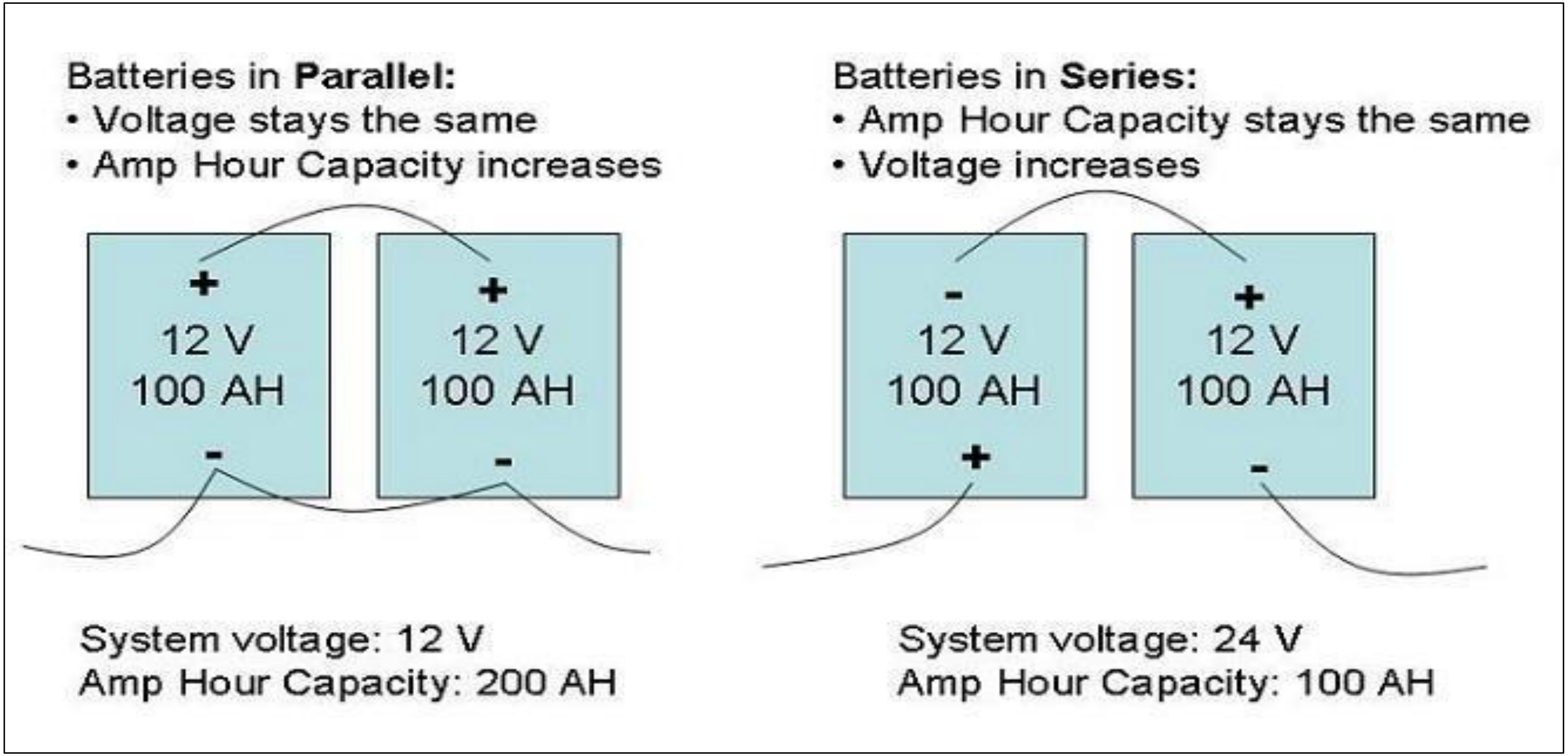
Memory: Batteries that are susceptible to developing a memory suffer from degraded battery performance over time and multiple charges
Self-Discharge Rate: How quickly the batteries lose their charge sitting in a drawer
Available Recharge Cycles: The number of times a battery can be recharged
Toxic: Toxic batteries have special disposal requirements and must be turned in to special recycling centers

Len Penzo dot Com (www.LenPenzo.com)

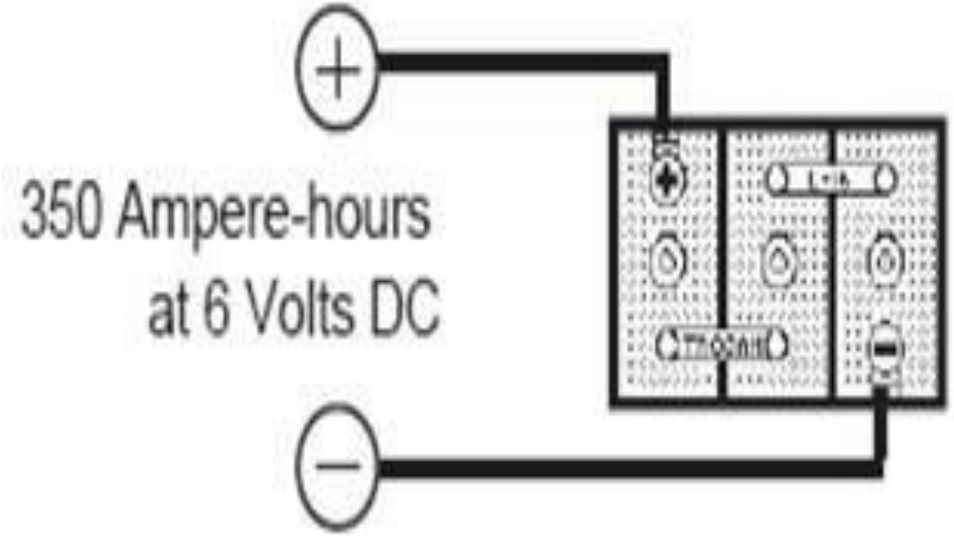
Batteries

- Below are some factors to consider when selecting the right type of battery for your project:
- **1. Energy Density:** The energy density is the total amount of energy that can be stored per unit mass or volume. This determines how long your device stays on before it needs a recharge.
- **2. Power Density:** Maximum rate of energy discharge per unit mass or volume.
- **3. Safety:** It is important to consider the temperature at which the device you are building will work. High temperatures generally reduce the performance of most batteries.
- **4. Life cycle durability:** The stability of energy density and power density of a battery with repeated cycling (charging and discharging) is needed for the long battery life required by most applications.
- **5. Cost:** It is important that the cost of your battery choice is commensurate with its performance and will not increase the overall cost of the project abnormally.

Batteries Connection

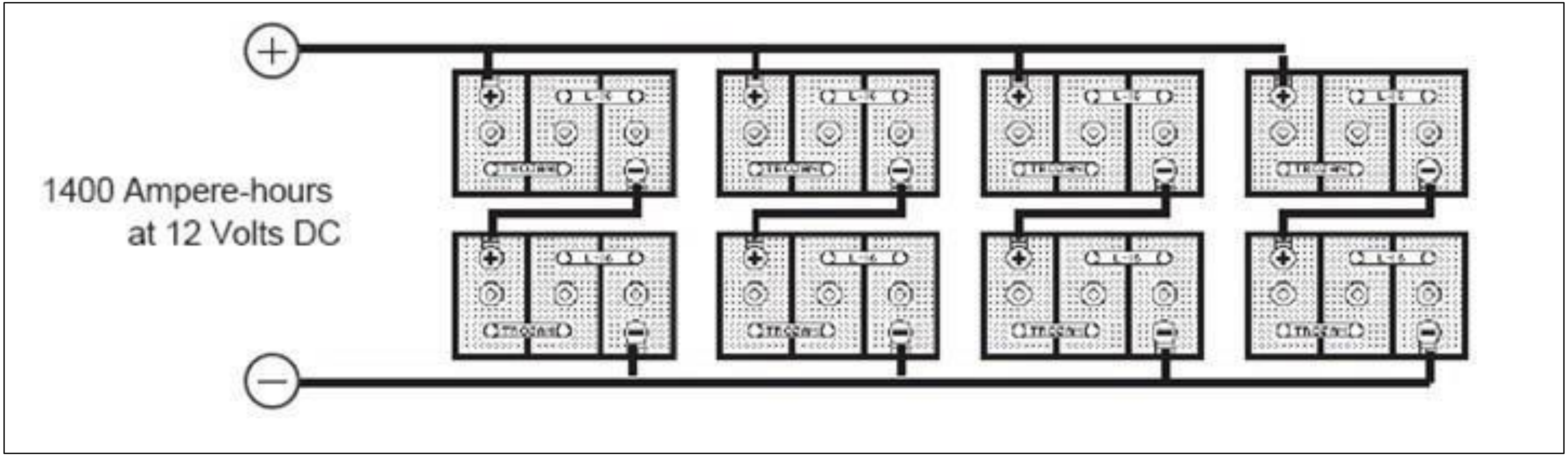


Batteries Connection

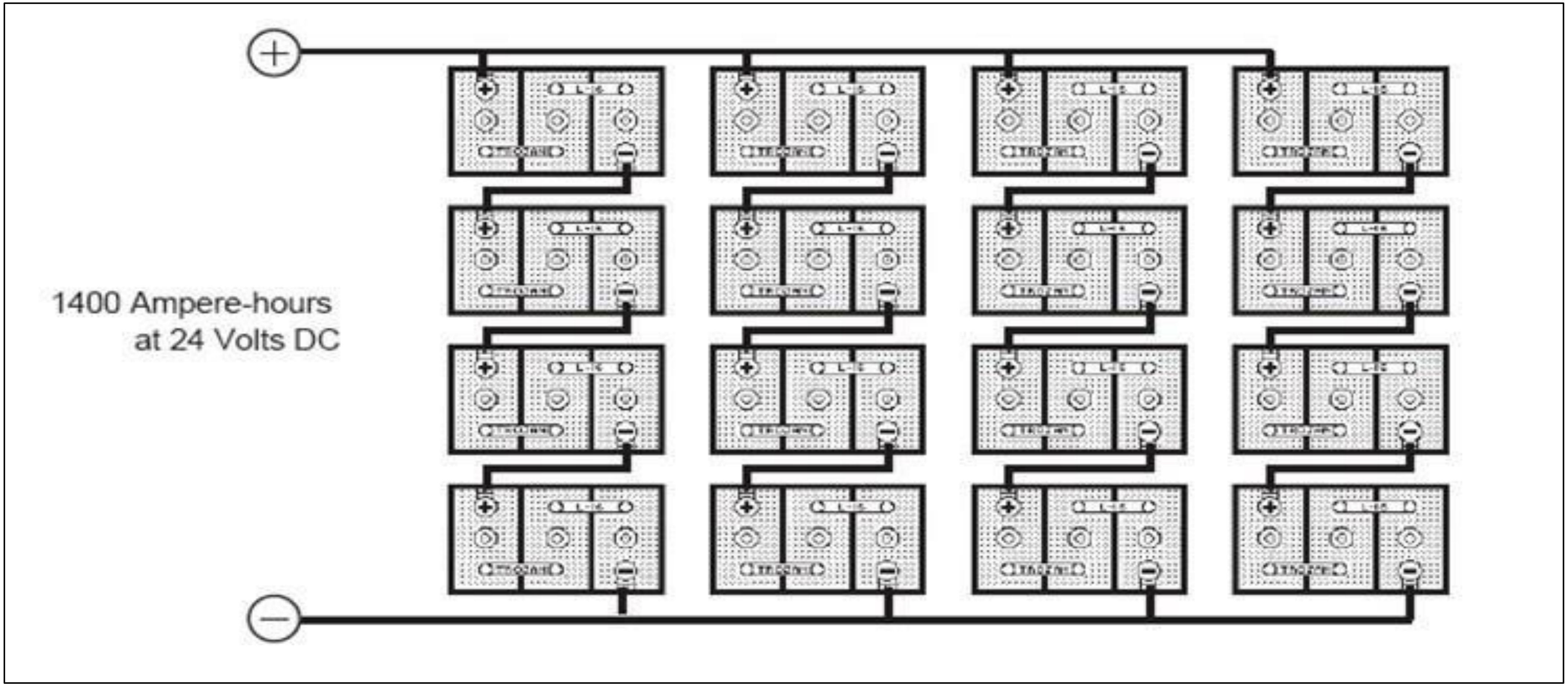


A single L-16 lead-acid battery composed of three series connected 350 Amp-hr cells yielding a battery of 350 Amp-hrs at 6 VDC.

Batteries Connection



Batteries Connection



Batteries Ampere-hour Storage

- The amp-hour is a unit of battery energy capacity, equal to the amount of continuous current multiplied by the discharge time, that a battery can supply before exhausting its internal store of chemical energy.

$$\text{Continuous current (in Amps)} = \frac{\text{Amp-hour rating}}{\text{Charge/dischrge time (in Hours)}}$$

$$\text{Charge/discharge time (in Hours)} = \frac{\text{Amp-hour rating}}{\text{Continuous current (in Amps)}}$$

State of Charge (SOC)

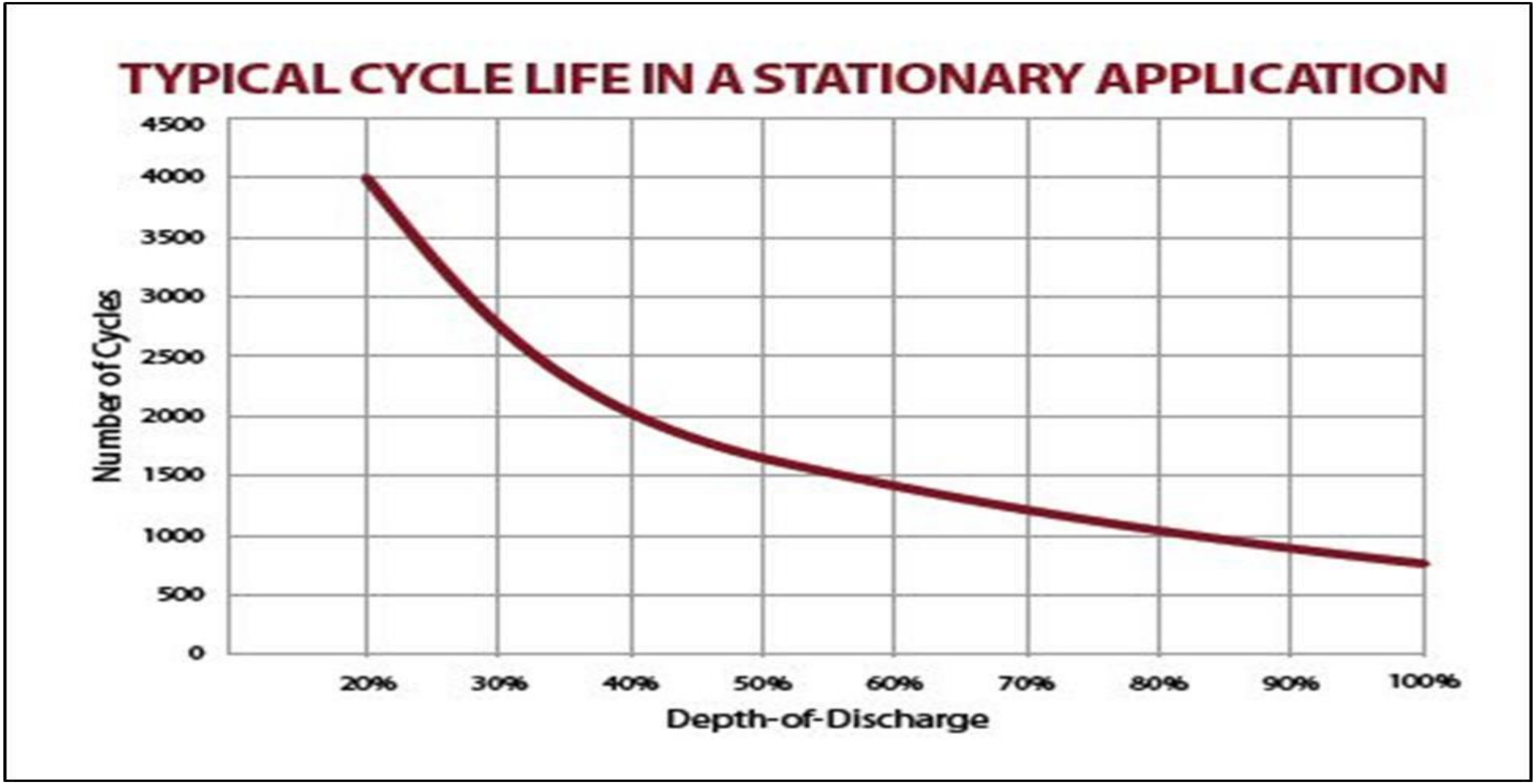
	STATE OF CHARGE			
	V open circuit	V open circuit	V open circuit	V open circuit
charge	6-V battery	12-V battery	24-V bank	48-V bank
100%	6.37	12.73	25.46	50.92
90%	6.31	12.62	25.24	50.48
80%	6.25	12.50	25.00	50.00
70%	6.19	12.37	24.74	49.48
60%	6.12	12.24	24.48	48.96
50%	6.05	12.10	24.20	48.40
40%	5.98	11.96	23.92	47.84
30%	5.91	11.81	23.62	47.24
20%	5.83	11.66	23.32	46.64
10%	5.75	11.51	23.02	46.04

Depth of Discharge

- The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80 % DOD is referred to as a deep discharge.

- Your battery's "cyclic life," or the number of charge/discharge cycles in its useful life, depends on how much of the battery's capacity you normally use. If you regularly discharge the batteries at a lower percentage amount, it will have more useful cycles than if you frequently drain the battery to its maximum DoD. For example, a battery may have 15,000 cycles at a DoD of 10 percent, but only 3,000 cycles at 80 percent DoD.

DOD vs. # of Cycles



Temperature

- **Batteries get sluggish at cold temperatures.**
- **Usable capacity drops radically below 40^{o}F.**
- **Self Discharge happens rapidly above 120^{o}F ~ 50^{o}C.**
  - ✓ Temperature greater than 120^{o} F results in total discharge in 4 weeks.
  - ✓ At room temperatures loss is 6% and will discharge in 16 weeks.
  - ✓ Storage (Fully-Charged) between 35^{o} F - 40^{o} F
- **Keep them at room temperature between 55^{o}F and 100^{o}F ~ 15^{o}C and 35^{o}C**

Battery Temperature Compensation

- Battery charging voltages should be corrected based on battery temperature, which is referred to as temperature compensation, a charging feature that helps ensure that a battery is neither undercharged nor overcharged regardless of battery temperature.

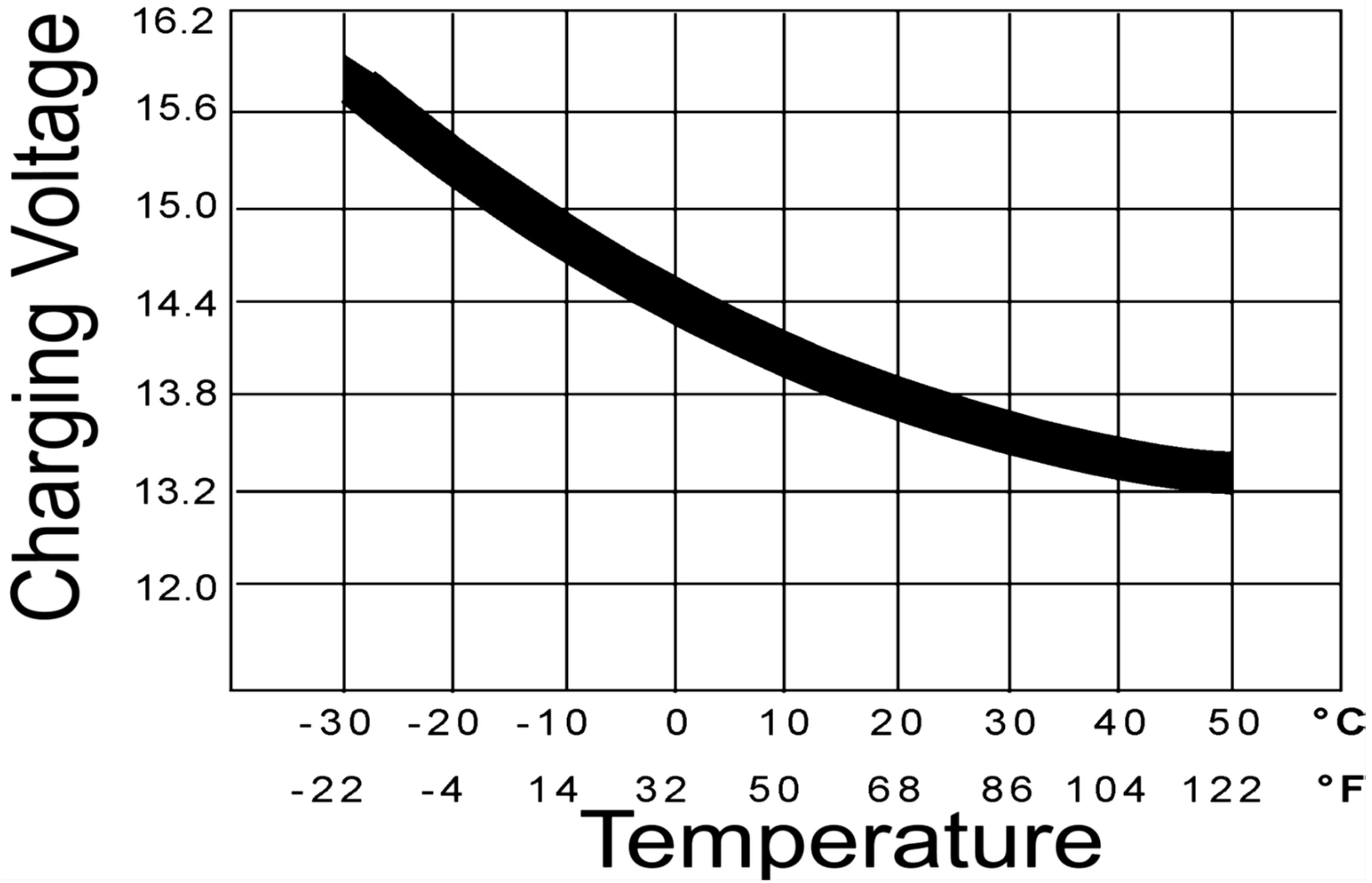
- The most widely used temperature compensation formula is:

  -0.005 V per ºC per 2 V cell.

- In order to find your new temperature corrected charge voltage you need to know 4 things:

- 1. Nominal system voltage. 2. Charge Voltage at 25°C [77°F].
- 3. Temperature compensation value. 4. The temperature.

Battery Temperature Compensation



Battery Temperature Compensation

- **Example 1:** let’s use a 24V system, with a charge voltage of 28.6V, a temperature compensation value of -5mV/°C/cell, and a battery temperature of 40°C.

From the system voltage, there are 12 battery cells (24V / 2V per cell).

-0.005V/°C/cell x 12 cells = -0.06V/°C. The temperature compensation value is from 25°C, so 40°C-25°C = 15°C x -0.06V/°C = -0.9V + 28.6V = 27.7V. So the battery charge voltage at 40°C would be 27.7V.

Battery Temperature Compensation

- **Example 2:** let's use a 12V system, with a charge voltage of 14.1V, a temperature compensation value of -3mV/°C/cell, and a battery temperature of 5°C.

From the system voltage, there are 6 battery cells (12V / 2V per cell).

-0.003V/°C/cell x 6 cells = -0.018V/°C. The temperature compensation value is from 25°C, so 5°C-25°C = -20°C x -0.018V/°C = 0.36V + 14.1V = 14.46V. So the battery charge voltage at 5°C would be ~14.4V.

Battery Temperature Multiplier

While sizing the battery, the winter ambient temperature should be considered in order to take care of the battery capacity in winter season.

Temperature Multiplier

Temp ºF	Temp ºC	Multiplier
80 F	26.7 C	1.00
70 F	21.2 C	1.04
60 F	15.6 C	1.11
50 F	10.0 C	1.19
40 F	4.4 C	1.30
30 F	-1.1 C	1.40
20 F	-6.7 C	1.59

Charge Controller

- The control of battery charging is so important that most manufacturers of high quality batteries (with warranties of five years or longer) specify the requirements for voltage regulation, low voltage disconnect and temperature compensation.

- When these limits are not respected, it is common for batteries to fail after less than one quarter of their normal life expectancy, regardless of their quality or their cost.

Charge Controller

- A charge controller is an essential part of nearly all power systems that charge batteries, whether the power source are solar panels, wind, hydro, fuel, or the utility grid. **Its purpose is to keep your deep cycle batteries properly fed and safe for the long term.** The basic functions of a controller are quite simple:

1. Preventing Overcharge:

Preventing overcharge is simply a matter of reducing the flow of energy to the battery when the battery reaches a specific voltage. When the voltage drops due to lower sun intensity or an increase in electrical usage, the controller again allows the maximum possible charge. This is called "voltage regulating." It is the most essential function of all charge controllers. The controller "looks at" the voltage, and regulates the battery charging in response.

Charge Controller

2. Low Voltage Disconnect (LVD):

A low voltage disconnect circuit will disconnect loads (appliances, lights, etc.), when over-discharge is approaching, a 12 volt battery drops below 11 volts and a 24 V battery drops below 22 V. It will reconnect the loads only when the battery voltage has substantially recovered due to some substantial charging. A typical LVD reset point is 13 volts for a 12 volt system and 26 V for a 24 V system.

3. Blocking Reverse Current:

Solar panels work by pumping current through your battery in one direction. At night, the panels may pass a bit of current in the reverse direction, causing a slight discharge from the battery.

4. Control Set Points vs. Temperature:

The ideal voltage set points for charge control vary with a battery's temperature. Some controllers have a feature called "temperature compensation." When the controller senses a low battery temperature, it will raise the set points. Otherwise when the battery is hot, it will reduce the charge too soon. If your batteries are exposed to temperature swings greater than about 30° F (17° C), compensation is essential.

Charge Controller

5. Electrical Overload Protection:

Overload can be caused by a fault (short circuit) in the wiring, or by a faulty appliance. Some charge controllers have overload protection built in, usually with a push-button reset.

6. Displays and Metering:

A display system can indicate the flow of power into and out of the system, the approximate state of charge of your battery, and when various limits are reached.

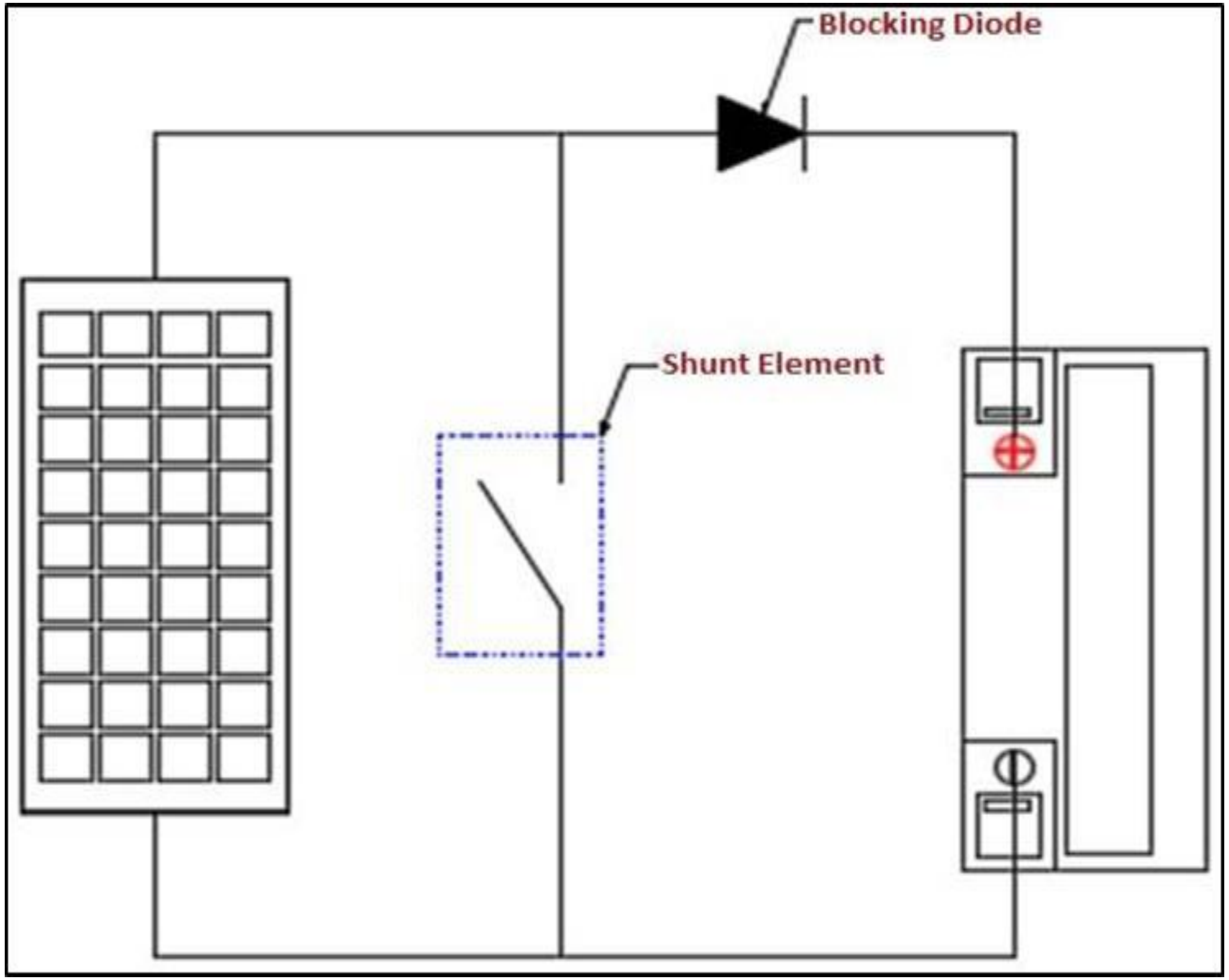
7. Control Set Points vs. Battery Type:

The ideal set points for charge controlling depend on the design of the battery. Some controllers have a means to select the type of battery.

Charge Controller Types

1. Shunt Regulator:

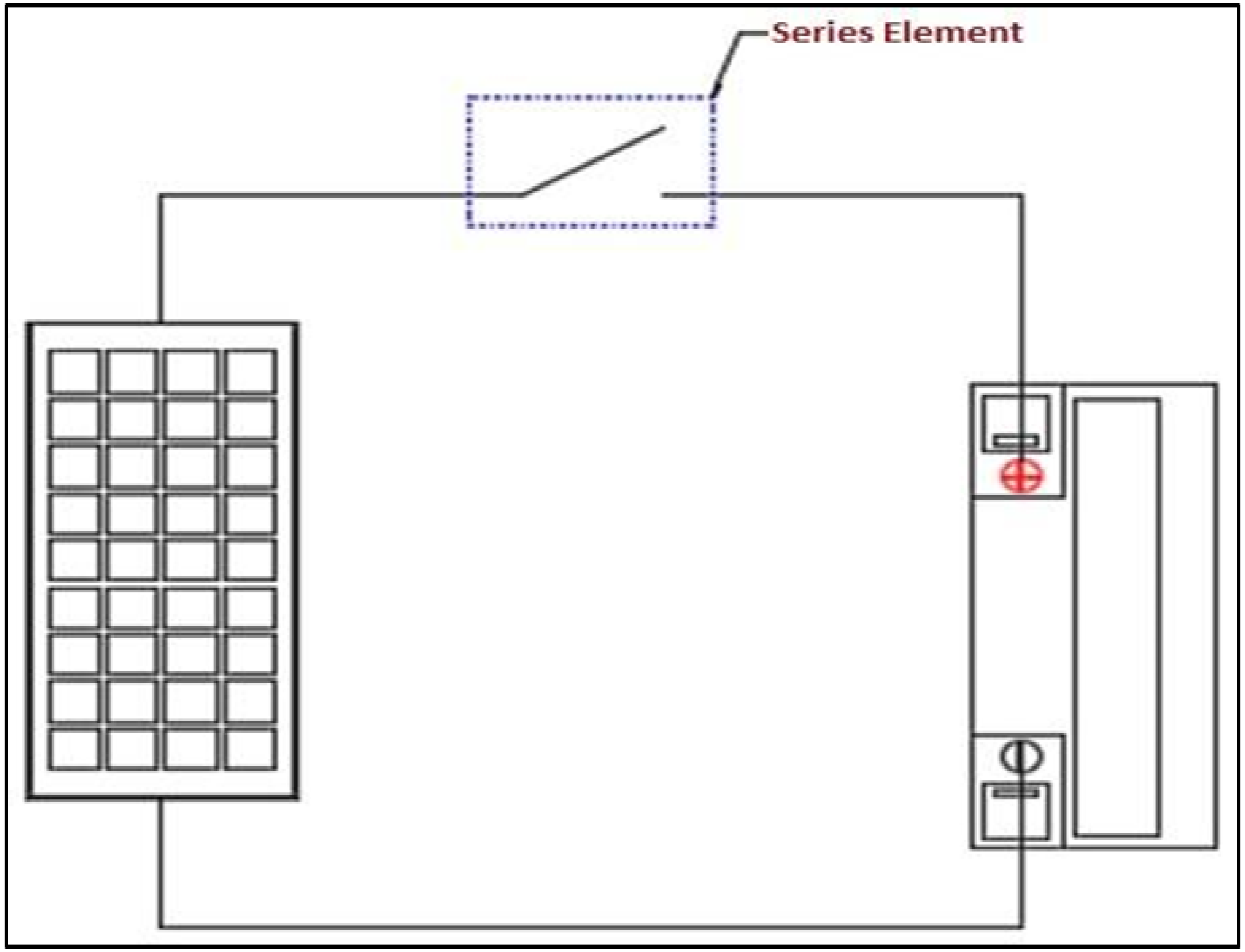
Shunt regulators function by short circuiting the solar array when the battery reaches a set voltage.



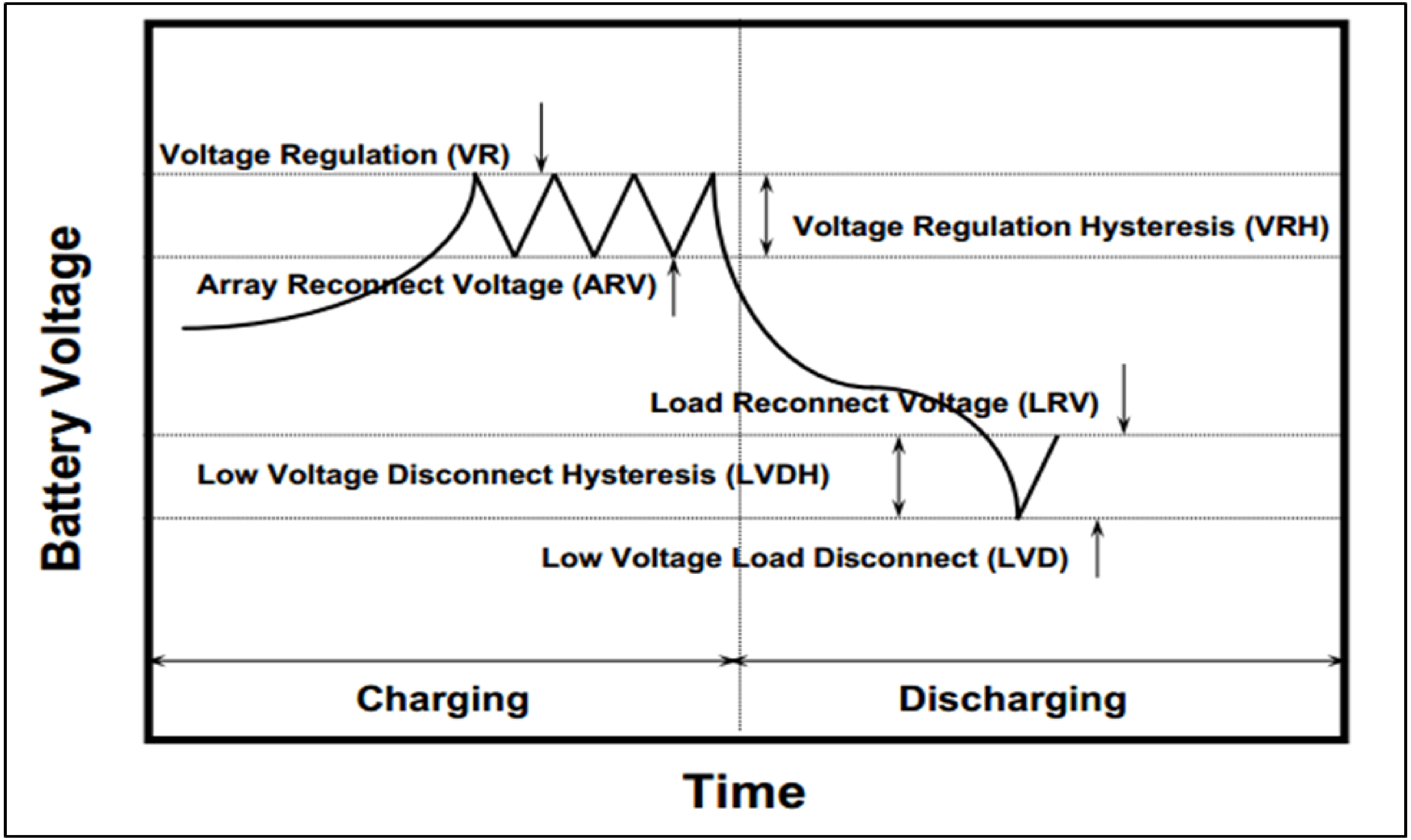
Charge Controller Types

2. Series Regulator:

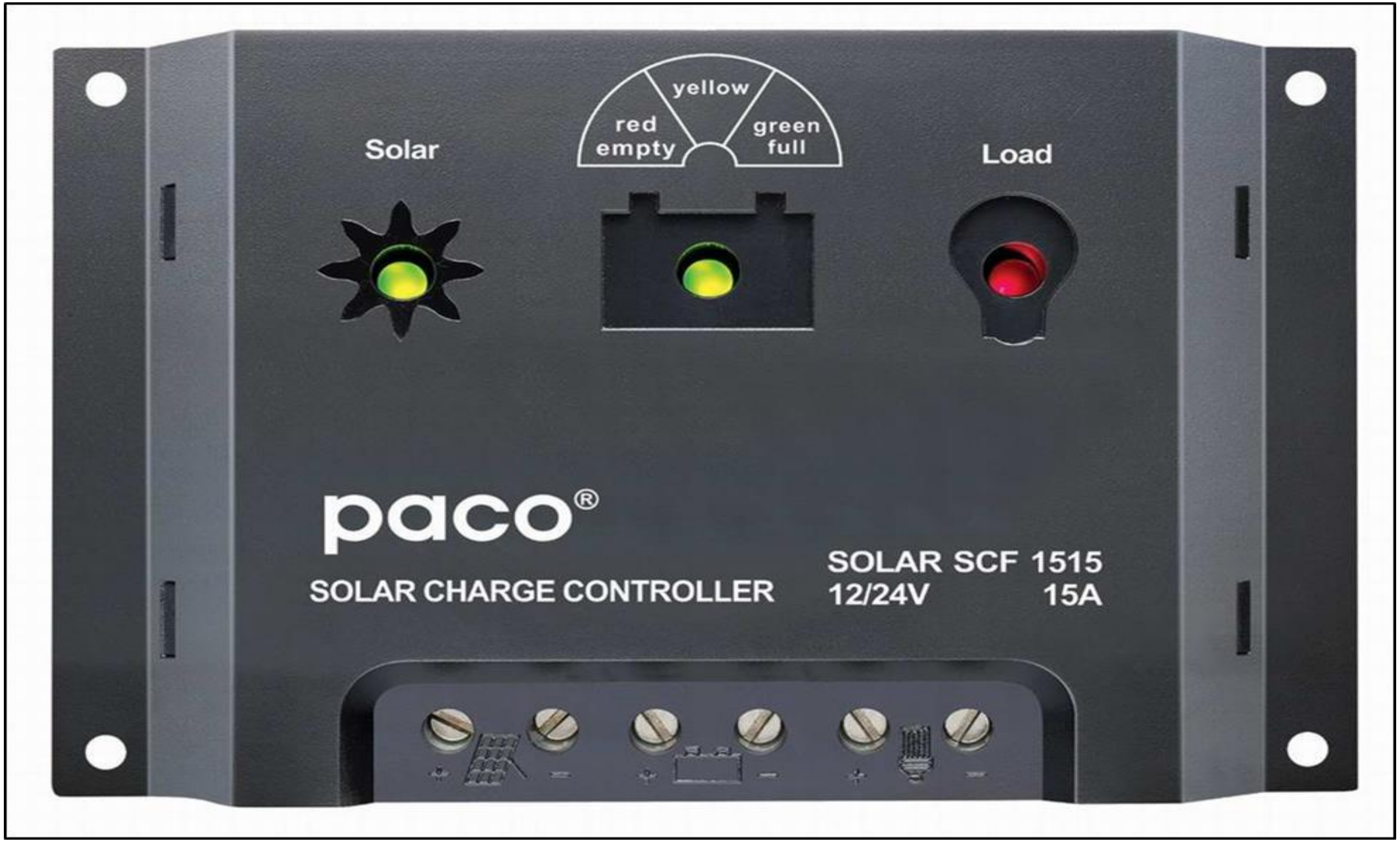
Series regulators function by open circuiting the solar array when the battery reaches a set voltage.



Charge Controller Types



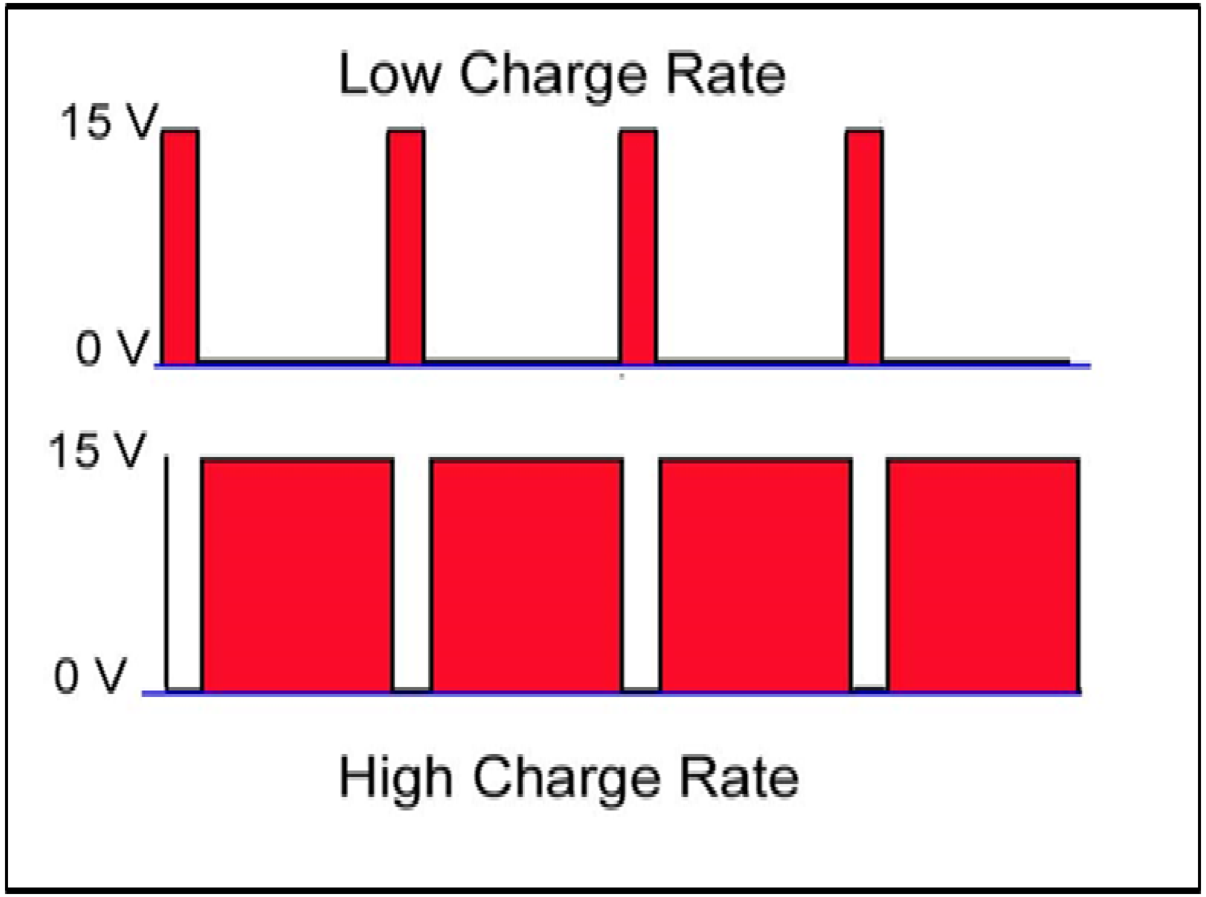
Charge Controller Types



Charge Controller Types

3. Pulse Width Modulation (PWM) Regulator:

PWM regulators are similar to series regulators, but they use a transistor instead of a relay to open the array. By switching the transistor at high frequency with various modulated widths, a constant voltage can be maintained.



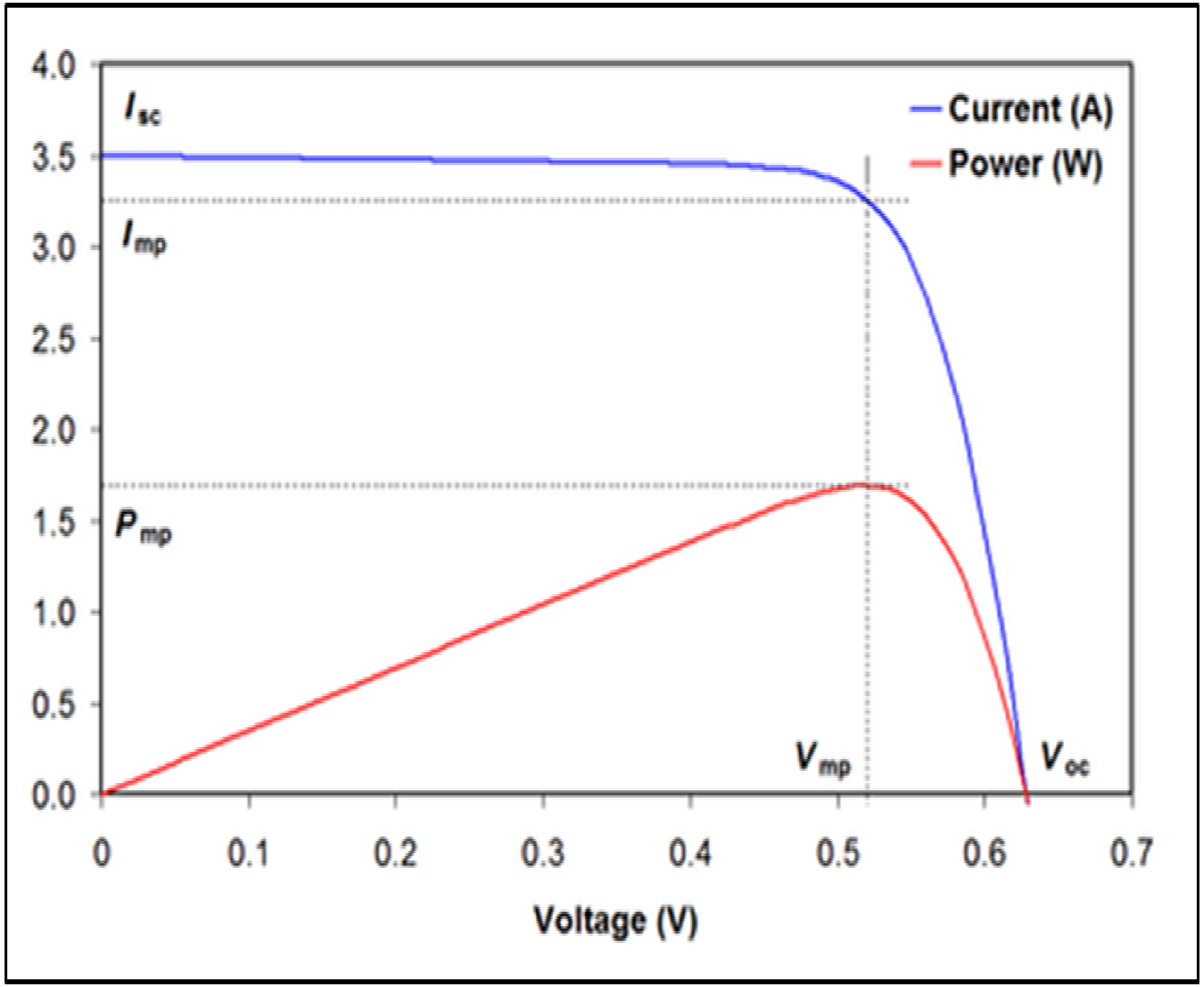
Charge Controller Types

Charge Controller Types

4. Maximum Power Point Tracking (MPPT) controller:

MPPT charge controller takes the PWM to the next level, by allowing the array voltage to vary from the battery voltage.

Imagine having a battery that is low, at 12 V. A MPPT takes a voltage of 17.6 volts at 7.4 amps and converts it down, so that what the battery gets is now 10.8 amps at 12 volts.



Charge Controller Types

Fixed Voltage vs. MPPT

- With a regular fixed voltage or PWM charge controller, if your batteries are low at say 12.4 volts, then your 100 watt solar panel rated at 6 amps at 16.5 volts (6 amps times 16.5 volts = 100 watts) will only charge at 6 amps times 12.4 volts or just 75 watts. You just lost 25% of your capacity!

- The MPPT controller compensates for the lower battery voltage by delivering closer to 8 amps into the 12.4 volt battery maintaining the full power of the 100 watt solar panel! 100 watts = 12.4 volts times 8 amps.

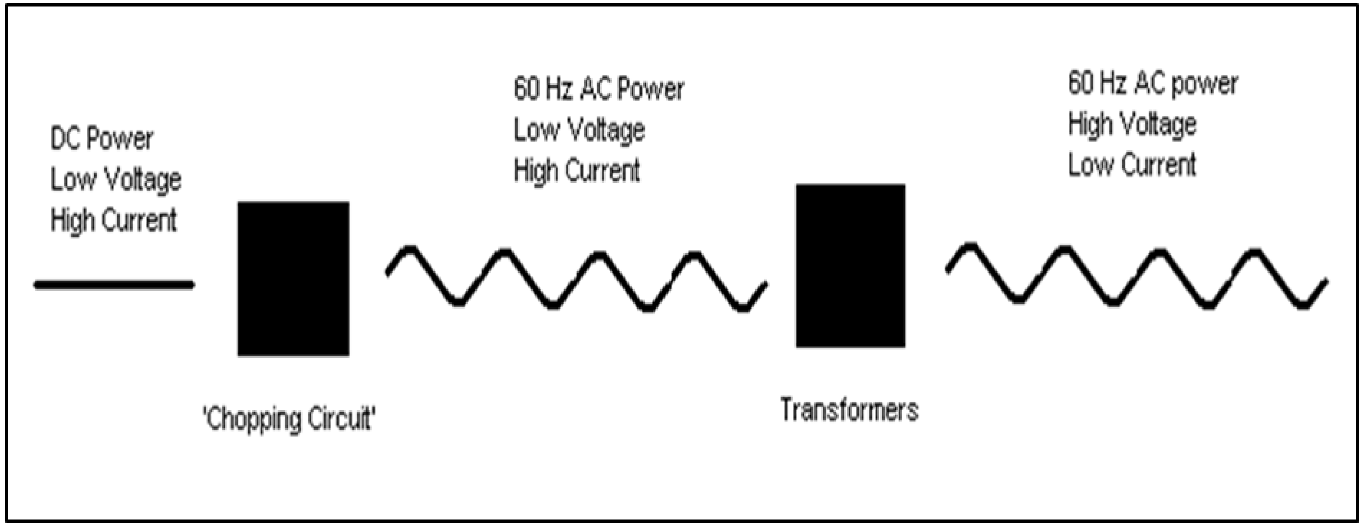
Inverter

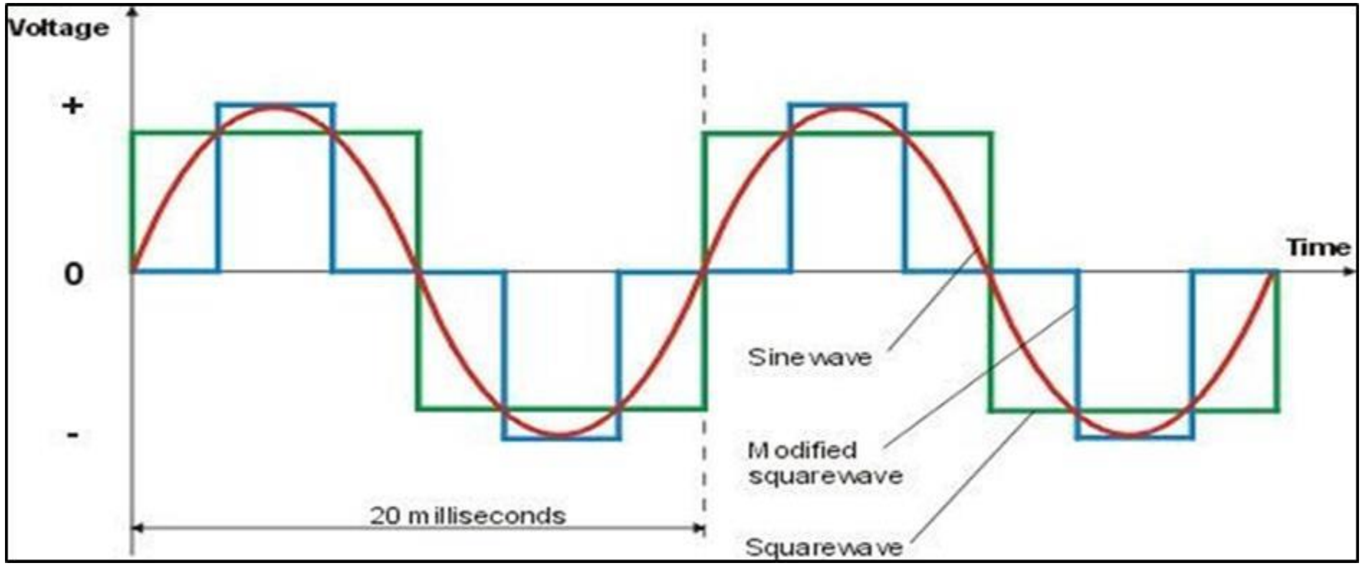
- The Solar Inverter is an essential device in any solar power system. Its basic function of the inverter is to change the variable Direct Current output of the solar panels into Alternating Current.

- The converted Alternating Current power is used for running your appliances like the TV, Refrigerator, Microwave, etc.

Inverter

- **Inverter takes low voltage high current DC power from a PV panel or battery and sends it through a 'chopping' circuit which changes it to low voltage high current AC power at 60Hz. The power then goes through a series of large transformers which output 220V AC power at 60Hz.**

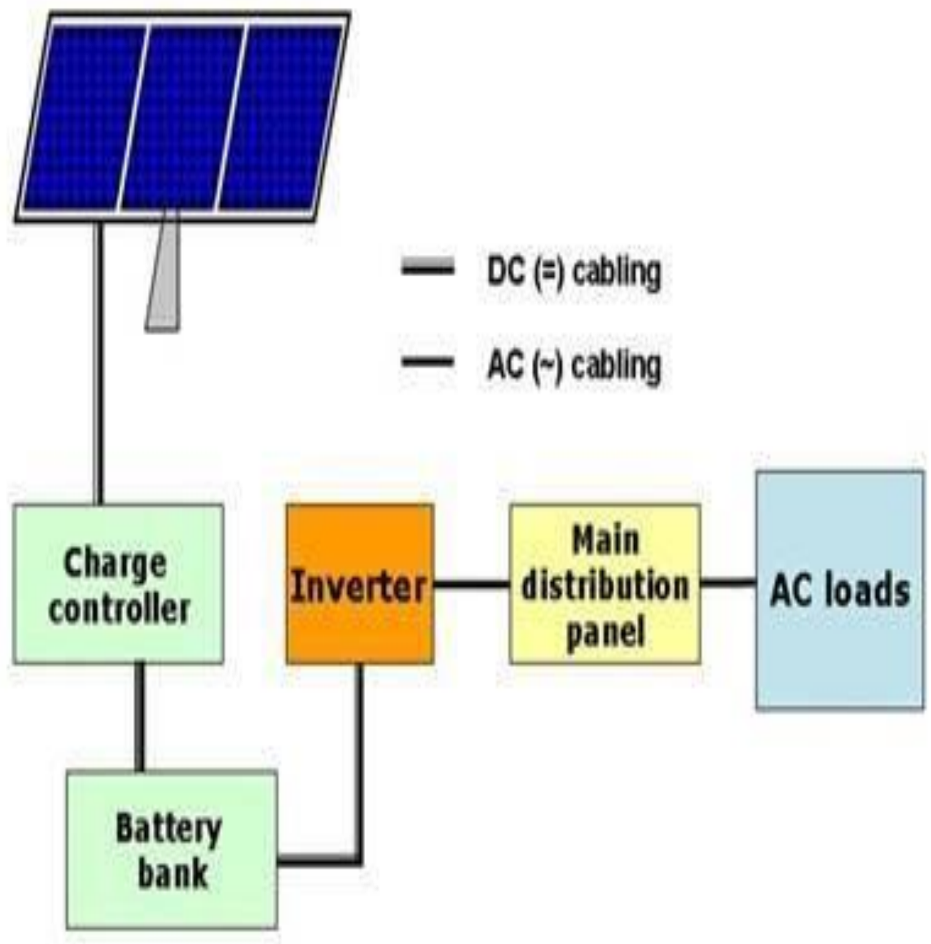




Different Types of Inverter

- **1. Off-Grid Inverters:**

Off grid inverters are used in remote systems where the solar inverter is fed DC power from a battery panel. This battery panel is charged by solar panels. The main function of an off-grid inverter is converting the output voltage of either the battery bank or the solar array to AC voltage.



Off-Grid Inverter

- There are three different types of stand-alone inverters currently available on the market, with regards to the produced type of voltage wave – sine-wave, quasi (modified) sine-wave and square-wave ones.

- **Square Wave**; Very few but the very cheapest inverters any more are square wave. A square wave inverter will run simple things like tools with universal motors with no problem – but not much else. These are seldom seen any more except in the very cheap or very old ones.

Off-Grid Inverter

- **Modified Sine Wave (quasi-sine);** A modified sine wave inverter actually has a waveform more like a square wave, but with an extra step.

  - ✓ Motors, such as refrigerator motor, pumps, fans etc. will use about 20% more power. This is because a fair percentage of a modified sine wave is higher frequencies – that is, not 60 Hz – so the motors cannot use it.

  - ✓ Some fluorescent lights will not operate quite as bright, and some may buzz or make annoying humming noises.

  - ✓ Appliances with electronic timers and/or digital clocks will often not operate correctly. Because the modified sine wave is noisier and rougher than a pure sine wave, clocks and timers may run faster or not work at all.

  - ✓ Items such as bread makers and light dimmers may not work at all – in many cases appliances that use electronic temperature controls will not control.

  - ✓ Most equipment will operate without any noticeable difference, and because the lower cost, makes this the most common inverter sold and generally the only type found at your local retailer.

Off-Grid Inverter

Off-Grid Inverter

- **Pure Sine Wave;** A pure sine wave is what you get from your local utility grid.

  - ✓ Major advantage of a pure sine wave inverter is that all of the equipment which is sold on the market is designed for a pure sine wave. This guarantees that the equipment will work to its full specifications.

  - ✓ Some appliances, such as motors and microwave ovens will only produce full output with pure sine wave power.

  - ✓ A few appliances, such as bread makers, light dimmers, and some battery chargers require a pure sine wave to work at all.

  - ✓ Audio equipment, satellite systems, and video equipment, will run properly using pure sine wave inverters.

  - ✓ These are the most expensive of the inverter designs and outperform all other types of inverters, regardless of use.

Off-Grid Inverter

Off-Grid Inverter

- **Off-grid inverter specifications:**

❑ Rated input power – usually selected to be of 10% more than the PV array peak power

❑ Rated output power – should be enough, so that the inverter should be able to handle all the loads that are to be working simultaneously.

❑ DC input voltage accepted from the battery bank – the most typical voltages are 12V, 24V, and 48V.

❑ Output voltage – usually 110 VAC or 220 VAC.

❑ Output frequency – 50Hz in Europe, 60 Hz in the USA.

❑ Surge capacity – enables the inverter to supply much more output power than its rated value within a short period to provide high starting current to motors (in refrigerators, water pumps, etc.).

Off-Grid Inverter

SPECIFICATIONS*	GP-175	GP-300	GP-600
Continuous Wattage	175W	300W	600W
Surge Rating	210W	400W	860W
Output Waveform	Modified Sine Wave		
Output Voltage	110 VAC RMS +5% / -10%		
Output Frequency +-1%	60 Hz		
Input Voltage	10.5 -15 VDC		
Efficiency	80-90%		
No Load Current Draw	0.2 A		
Protection	Overload, over-temperature, over-voltage and low voltage		
Low Battery Alarm +-2%	10.5 V		
Low Battery Shut-down +-2%	10.0 V		
Operating Temp.Range	0 – 40 C / 32 – 104 F		
Storage Temp.Range	-30 – 70 C / -22 – 158 F		
Cooling	Passive	Continuous fan	Continuous fan
AC Receptacle	1	2	2
(LxWxH) mm	135 x 53 x 46	165 x 89 x 51	229 x 86 x 51
inches	5.3 x 2.1 x 1.8	6.5 x 3.5 x 2	9 x 3.4 x 2
Weight (kg/lbs)	0.5 / 1.1	0.8 / 1.8	2.1 / 4.6
Warranty	1 year		
Inverter Install Kit	Auto utility adaptor	Auto utility adaptor	Spring clamp

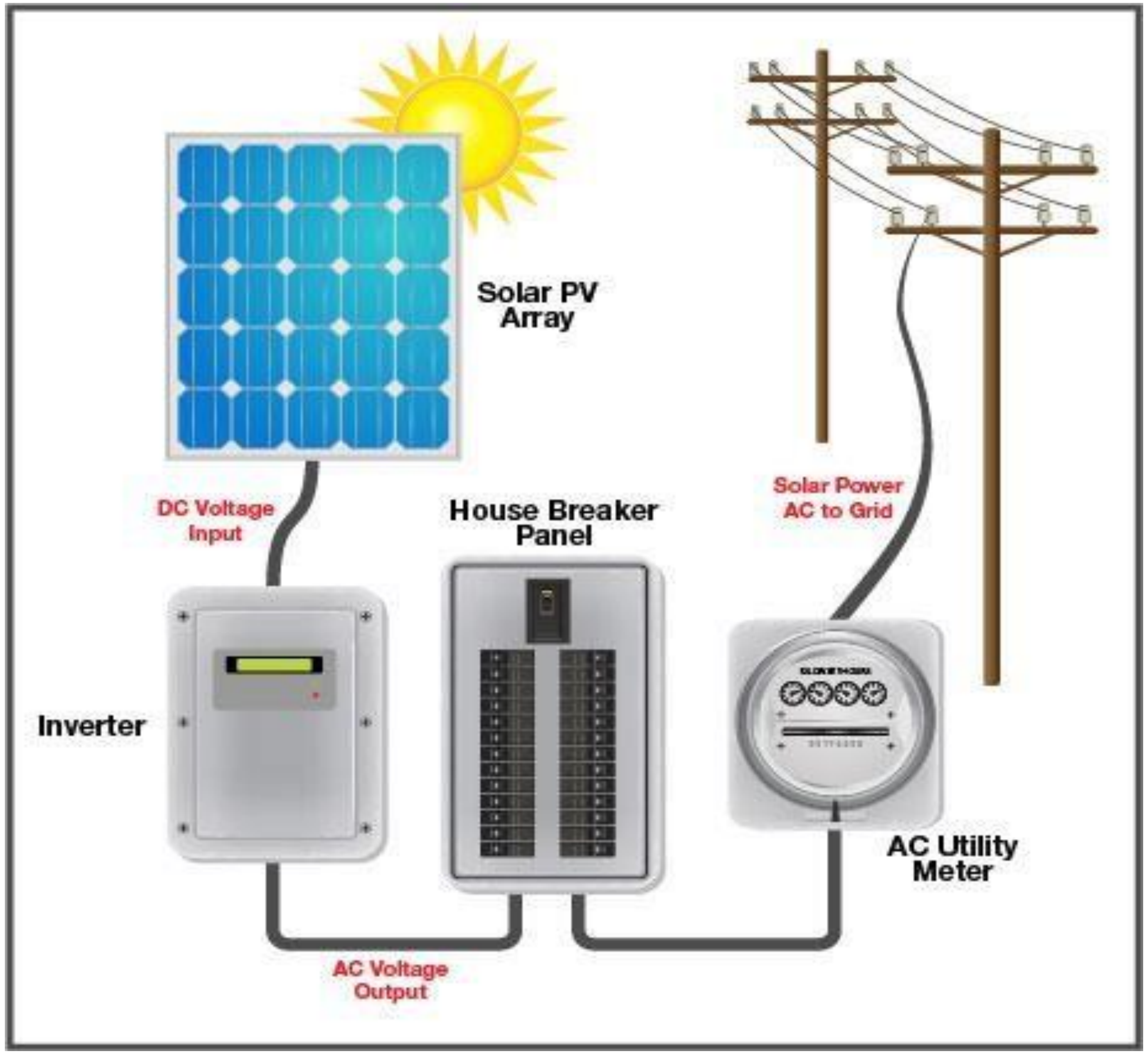
*Specifications subject to change without notice

Different Types of Inverter

- **2. Grid Tie Inverter:**

A grid-tie inverter has a different function than the off-grid inverter. It not only converts DC current into an alternating current suitable for injecting into an electrical power grid.

To inject electrical power efficiently and safely into the grid, grid-tie inverters must accurately match the voltage sampling and synchronization and phase of the grid sine wave AC waveform.



Gird-Tie Inverter

- Most grid-tied inverters are based on Maximum Power Point Tracking (MPPT) – a feature 'squeezing' maximum possible amount of power from the PV array.

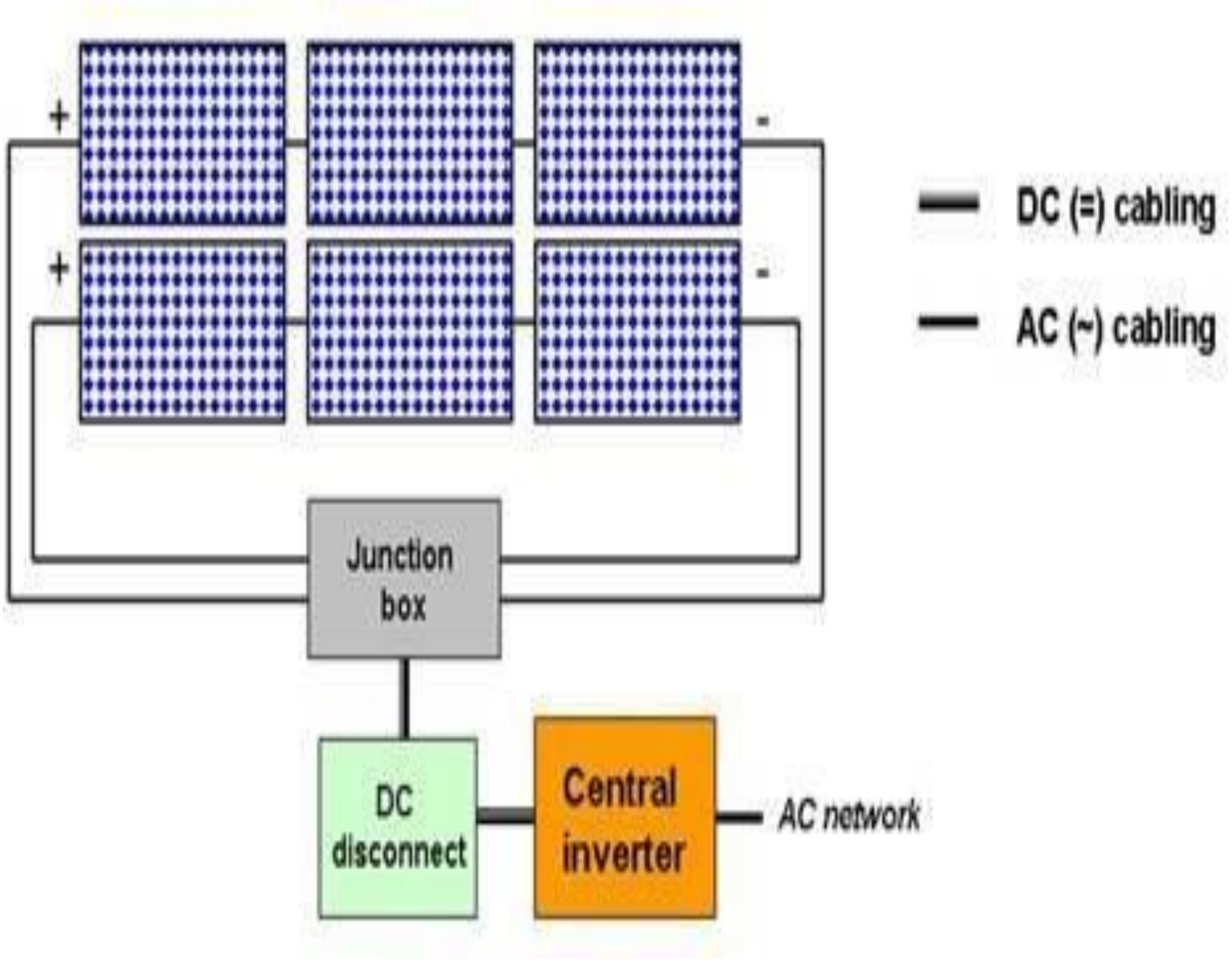
- One of the main features of a grid-tied inverter is that it stops operating in case of a grid failure. Thus technicians doing any repair works on utility network are prevented from getting an electric shock.

- There are generally two types of inverters for grid-tied systems without battery backup – **string inverters** and **micro inverters**.

Gird-Tie Inverter

- In small home PV systems the solar array is usually connected to a single (central) inverter.
- Their main advantage is cost-effectiveness and simplicity to install.
- String inverters, however, suffer from a notable drawback – if one solar panel of the array gets shaded or otherwise degrades in performance, the performance of the whole solar array deteriorates, which in turn results in a reduced inverter's DC input power and hence – in a reduced inverter's AC output power.

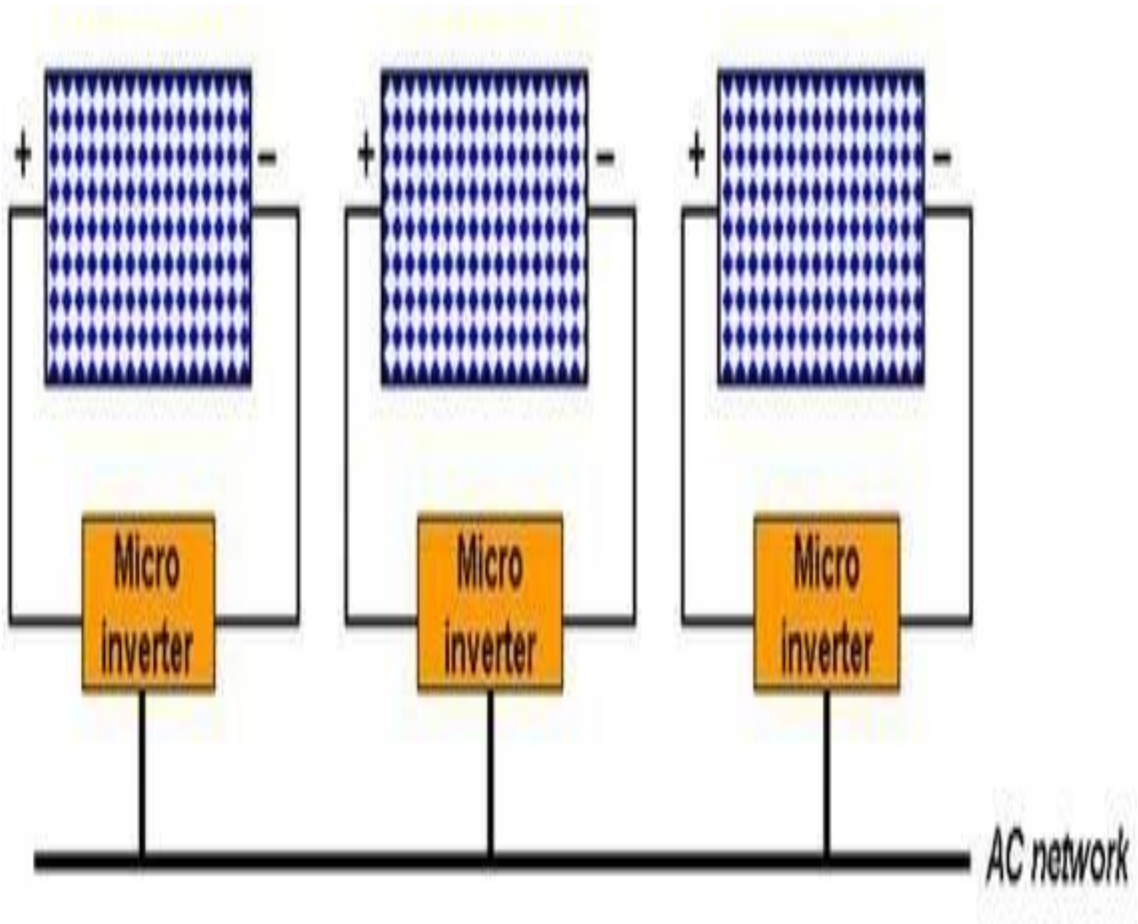
Gird-Tie Inverter



Gird-Tie Inverter

- Micro inverters (also known as ‘module inverters’) have a relatively low output power of less than 250 W.
- A micro inverter is a part of a PV module and operates as a central inverter, but only for the solar panel it is connected to.
- Micro inverters are installed on each panel of the solar array, thus both the installation cost and the overall system cost tends to increase.
- Micro inverters, however, overcome the drawbacks of string (central) inverters. If one solar panel gets shaded or otherwise degrades by performance or even fails, this in no way can affect the performance of the other panels of the solar array.

Gird-Tie Inverter



Gird-Tie Inverter

- Typically, a solar system based on micro inverters is reported to generate 16% more solar power compared to string(central) inverters.
- Furthermore, the inverter efficiency of a system with micro inverters can reach 96.5% compared to the maximum 92% efficiency of a string (central) inverter.
- It has also been proved that, when connected to a central (string) inverter, shading of 9% of the solar array results in about 54% decrease in its power output!
- Micro inverters are noted for their much longer durability than central inverters due to the fact that they are not exposed to such a high power and heat like central inverters. For this reason, micro inverters come with a more extended warranty – 20-25 years – compared to the typical 10 years guarantee of their string counterparts.

Gird-Tie Inverter

The advantages of micro inverters as opposed to central inverters:

- Safer, both to install and maintain, since avoiding wiring lots of panels in series (when DC voltage can increase up to hundreds of volts) eliminates the need of high voltage DC wiring.
- Allow mounting PV modules on different surfaces and facing different directions.
- Much lower heat dissipation and hence, no need for active cooling which, in turn, means that each inverter operates silently.
- Expanding your solar panel system is easier – you don't have to worry about buying and installing a second central inverter and redesigning the whole system.

Gird-Tie Inverter

Micro parallel inverters are a relatively recent achievement that combines the benefits of string inverters and micro inverters.

A micro parallel inverter is a smart device containing four individual channels that can be connected to four separate solar panels. Each channel acts as a single micro inverter and can track the performance of its solar panel by using MPPT.

Also, a micro parallel inverter acts as a string inverter for all the four solar panels, with the exception that if one panel fails, the performance of the other channel panels remains unaffected. Indeed, this is also valid if three of the four solar panels fail.

Furthermore, one micro parallel inverter is easier to install than four micro inverters, concerning both labor cost and wiring cost.

Gird-Tie Inverter

Delta RPI-Home Series Product Specs

	RPI H3	RPI H5
Input (DC)		
Operating voltage range	125-550Vdc	200-1000Vdc
MPP voltage range	320-500Vdc	310-850Vdc
Max. input voltage	630Vdc	1000Vdc
Start up voltage	150Vdc	250Vdc
Max. input current	10Adc	17.5Adc
Number of MPPT	1	1
MC4 Connectors	2 pairs	2 pairs
Output (AC)		
Max. output power	3000VA	5000VA (4600VA)
Max. output current	14.3A	24.5A
AC voltage range	184-265Vac	184-276Vac
Frequency range	50/60Hz +/-5Hz	50/60Hz +/-5Hz
Total harmonic distortion	<3%	<3%
Reactive Power	0.8 ind ~ 0.8 cap	0.8 ind ~ 0.8 cap
Efficiency		
Peak efficiency	97.00%	97.50%
Euro efficiency	96.20%	97.00%
System Safety & Communication		
Communication port	RS485 / WiFi Optional	RS485 / WiFi Optional
Display	LCD 16 characters x 2	LCD 16 characters x 2
Operating temperature range	-20°C to 60°C	-20°C to 60°C
Night time power consumption	<2W	<2W
Protection Level	IP65	IP65
Certification Safety	VDE AR-N 4105,	VDE AR-N 4105, CEI-021 RD1699
Mechanical information		
Physical size (DxWxH)	367 x 420 x 157 mm	470 x 531 x 167mm
Net weight	15 kg	24 kg

All specifications are subject to change without prior notice.

Contents

Day 4

- Auxiliary Components
  - ✓ Balance of System
  - ✓ Wiring System
  - ✓ Monitoring System
  - ✓ Grid Charger (Inverter/Charger)
  - ✓ Racking & Mounting System
- Off-Grid System Design
  - ✓ Load Estimation
  - ✓ Solar Panels Sizing
  - ✓ Battery Sizing
  - ✓ Charge Controller Sizing
  - ✓ Off-Grid Inverter Sizing
- Grid-Tie System Design
  - ✓ Solar Panels Sizing
  - ✓ Grid-Tied Inverter Sizing

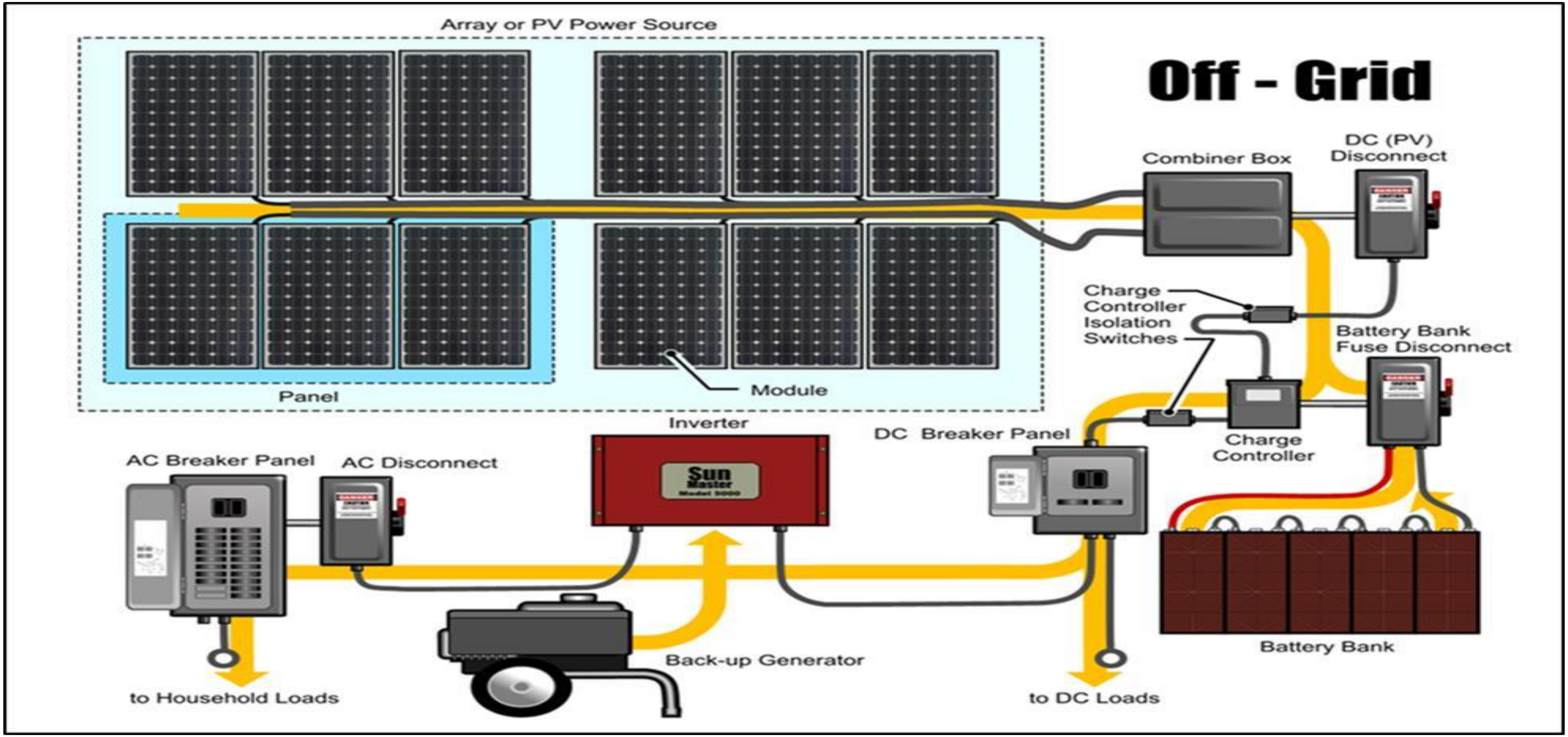
Auxiliary Components

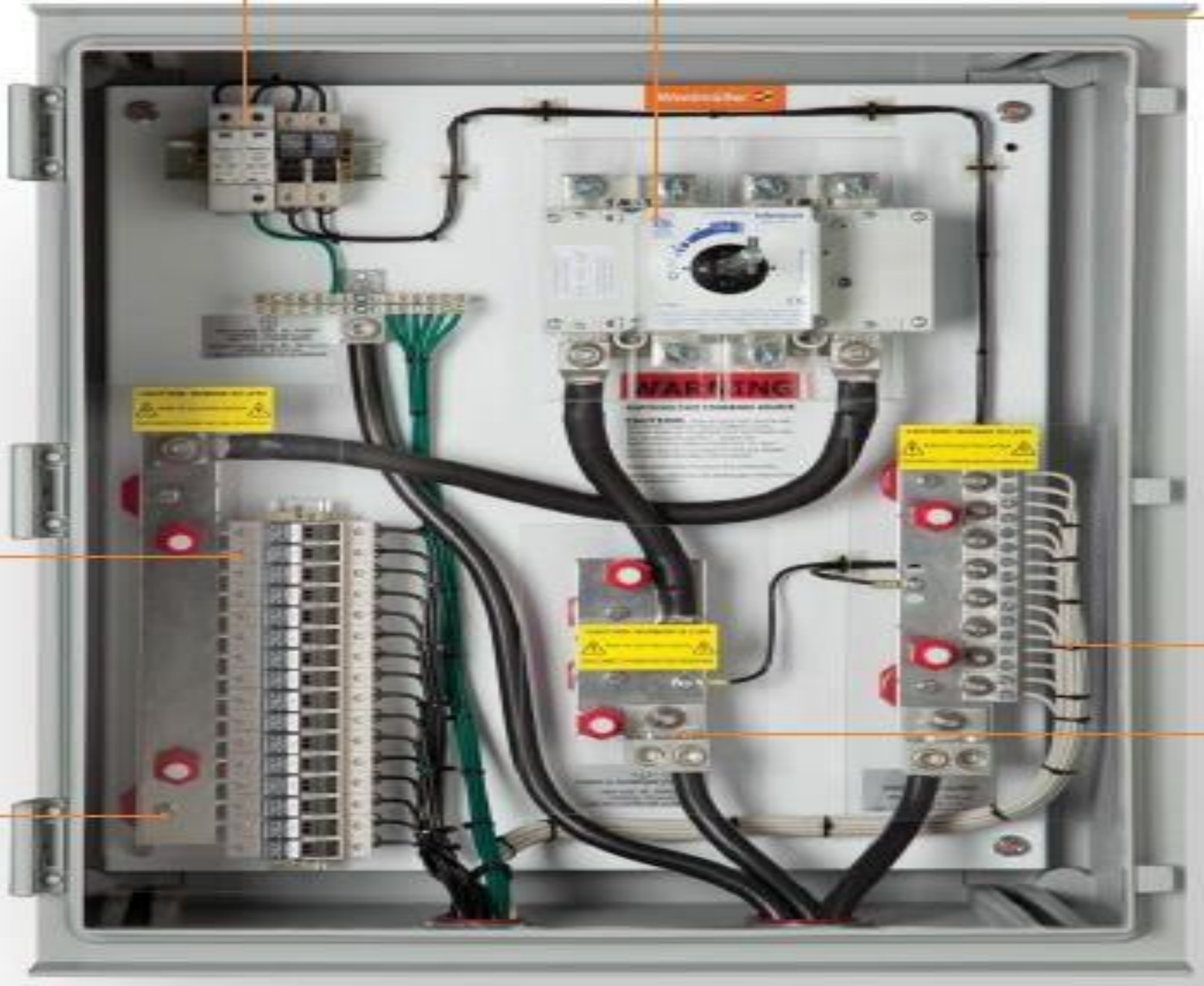
- **Balance of Systems:**

Balance of System components work to combine other electrical products within the system, then combining and delivering a series of power control and distribution options for any PV array.

Commonly, most items that make up Balance of Systems products include: Combiner Boxes, DC/AC Disconnects, Circuit Breakers, Fuses, Bus bars, Surge Devices, among other components that may vary from system to system.

Auxiliary Components




Surge protection
- for photovoltaic systems
- for data and communication devices
Local disconnect switch
NEMA 4X/IP66 enclosure
Fuse holders
Bussing system with safety shields
Pre-wired combiner boxes
Rugged high-power output lugs
Other options:
- Wireless communications
- Current monitoring
- Power supplies
- Cable glands
WARNING

Balance of System

- **Combiner Box:**

Combiner Box is critical for securely housing and protecting the internal components. Most combiner boxes are rated to IP65 and include breather drains making them suitable for tropical and sub-tropical environments.

The primary function of the combiner box is to group together incoming PV strings to achieve higher output currents. Depending on the scale and topology of the PV installation, differing numbers of PV input strings will be needed.

Balance of System

Balance of System

- **DC/AC Disconnectors:**

In electrical engineering, a disconnector is used to ensure that an electrical circuit is completely de-energized for service or maintenance, and thery are often found in electrical distribution and industrial applications.

A solar PV system typically has two safety disconnects. The first is the PV disconnect (or Array DC Disconnect). The PV disconnect allows the DC current between the modules (source) to be interrupted before reaching the combiner box.

The second disconnect is the AC Disconnect. The AC Disconnect is used to separate the inverter from the electrical grid or AC breaker panel.

Balance of System

Balance of System

- **Fuses & Circuit Breakers:**

A fuse and circuit breaker both of them protect an overloaded circuit by disrupting the current continuity. The way they disrupt the current flow is dissimilar.

A fuse is a simple piece of metal that melts down when overheated because of excessive flow of current whereas a circuit breaker has switching mechanism that is activated when unsafe current flows through the circuit.

Fuses are faster to disrupt the current flow but they must be replaced after a piece of metal melts down, whereas circuit breakers can be reset and used multiple times.

Balance of System

Wiring Sizing

- **Wiring System:**

Solar cables and wires are seen as the arteries and veins of any solar PV system. Mostly, the electricity generated by PV solar panels is used at another place. Solar cables and wires are required to transport this electricity.

Wire size selection based on two criteria:

- ✓ Ampacity
- ✓ Voltage drop

Wiring Sizing

- **Ampacity: current carrying ability of a wire without degrading**

  The larger the wire, the greater its capacity to carry current

  Wire size given in terms of American Wire Gauge (AWG)

  The higher the gauge number, the smaller the wire

- **Voltage drop: the loss of voltage due to a wire's resistance and length**

  Function of wire gauge, length of wire, and current flow in the wire.

Wiring Sizing

- **Must comply with National Electrical Code NEC**
- **Ampacity:**
  - ✓ NEC Table 310.15(B)(16)
  - ✓ Isc X 1.25 (over irradiance) X 1.25 (3 hours continuous use)
- **Physical Size:**
  - ✓ Will it fit in the breaker
  - ✓ Conduit fill consideration
- **Temperature:**
  - ✓ NEC Table 310.15(B)(2)(b)
  - ✓ Within acceptable operating temperatures of terminals to which it's connected
- **Voltage Drop:**
  - ✓ Long distance runs requires larger cable to reduce losing voltage.

Wiring Types

- **Wire Types Used in PV**
- **USE-2:**
  - ✓ UV (sunlight) resistant; used in wet or dry location.
  - ✓ Can not be used in conduit UNLESS also marked RHW-2 and/or XHHW-2.
  - ✓ Typically used from modules to combiner box in grounded systems.
- **PV Wire:**
  - ✓ Similar to USE-2, but with thicker insulation; available up to 2KV.
  - ✓ Required for ungrounded systems.
- **THWN-2 or XHHW-2:**
  - ✓ Used in wet or dry locations; Not sunlight resistant, must be in conduit.
  - ✓ Typically used from combiner box to DC load center or disconnect.
- **THW:**
  - ✓ Dry location only.
  - ✓ Typically used for battery cables.

Maximum Allowable Ampacity

Copper

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C through 90°C (140°F through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

Conductor Size (AWG or KCMIL)	60°C/140°F TW & UF	75°C/167°F RHW, THHW, THW, THWN, XHHW, USE, ZW	90°C/194°F TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, XHH, XHHW, XHHW-2, USE-2 & ZW
18	–	–	14
16	–	–	18
14*	15	20	25
12*	20	25	30
10*	30	35	40
8	40	50	55
6	55	65	75
4	70	85	95
3	85	100	115
2	95	115	130
1	110	130	145
1/0	125	150	170
2/0	145	175	195
3/0	165	200	225
4/0	195	230	260
250	215	255	290
300	240	285	320
350	260	310	350
400	280	335	380
500	320	380	430
600	350	420	475
700	385	460	520
750	400	475	535
800	410	490	555
900	435	520	585
1000	455	545	615

American Wire Gauge (AWG)

American Wire Gauge (AWG) to mm^2

AWG	mm^2	AWG	mm^2
30	0.05	2	35
28	0.08	1	50
26	0.14	1/0	50
24	0.25	2/0	70
22	0.34	3/0	95
20	0.50	4/0	120
19	0.75	250	150
18	1.0	300	150
16	1.5	350	185
14	2.5	400	185
12	4	450	240
10	6	500	240
8	10	600	300
6	16	750	400
4	25		

Ambient Temperature Correction

TABLE 310.15(B)(2)(a) Ambient Temperature Correction Factors Based on 30°C (86°F)

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in the ampacity tables by the appropriate correction factor shown below.

Ambient Temperature (°C)	Temperature Rating of Conductor			Ambient Temperature (°F)
	60°C	75°C	90°C	
10 or less	1.29	1.20	1.15	50 or less
11–15	1.22	1.15	1.12	51–59
16–20	1.15	1.11	1.08	60–68
21–25	1.08	1.05	1.04	69–77
26–30	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	132–140
61–65	—	0.47	0.65	141–149
66–70	—	0.33	0.58	150–158
71–75	—	—	0.50	159–167
76–80	—	—	0.41	168–176
81–85	—	—	0.29	177–185

Heat Adjustment

Table 310.15(B)(3)(c) Ambient Temperature Adjustment for Circular Raceways Exposed to Sunlight on or Above Rooftops

Distance Above Roof to Bottom of Conduit	Temperature adder °C	Temperature adder °F
0–13 mm (½ in.)	33	60
Above 13 mm (½ in.)–90 mm (3½ in.)	22	40
Above 90 mm (3½ in.)–300 mm (12 in.)	17	30
Above 300 mm (12 in.)–900 mm (36 in.)	14	25

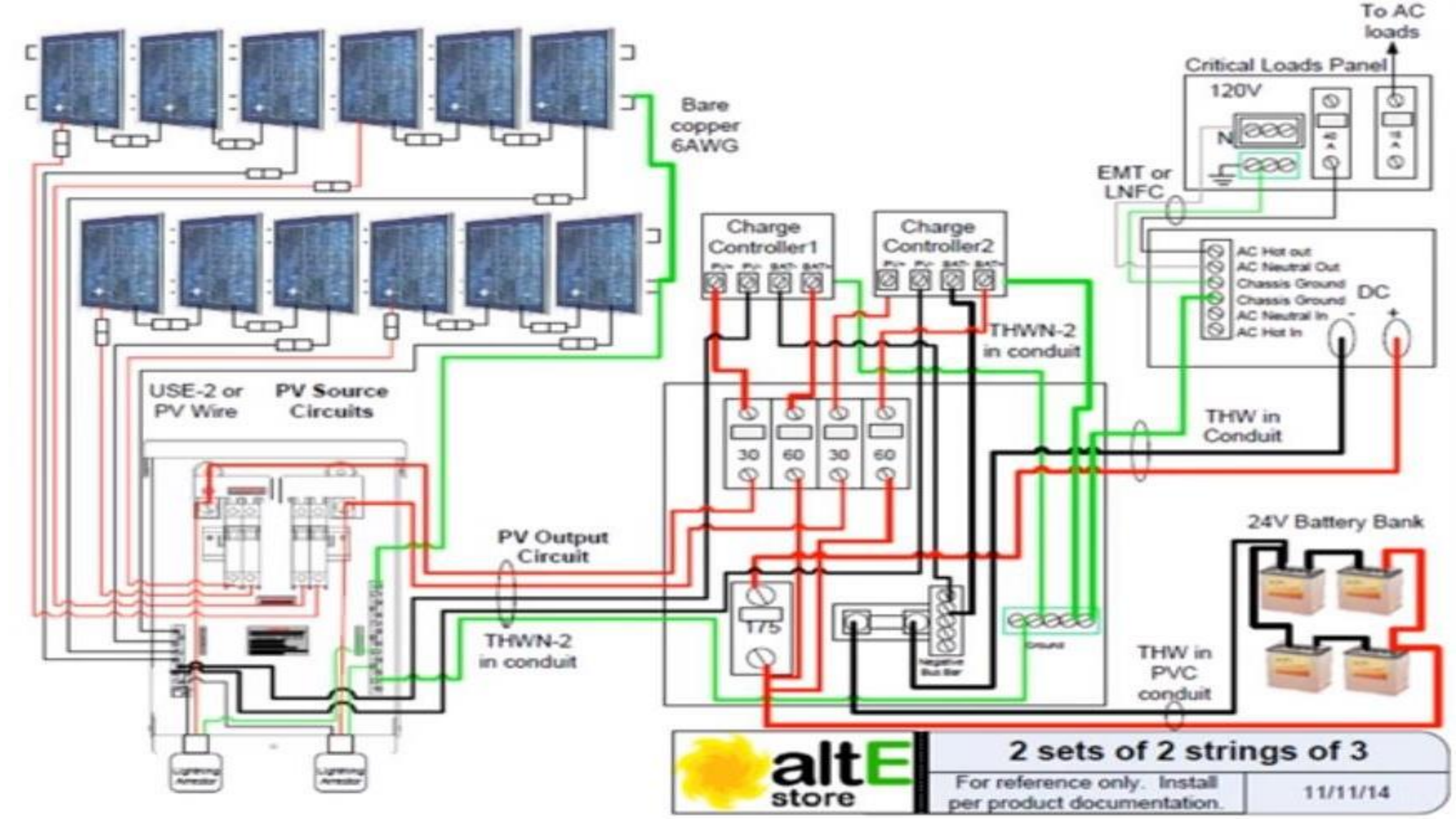
Table 310.15(B)(3)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Number of Conductors[1]	Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

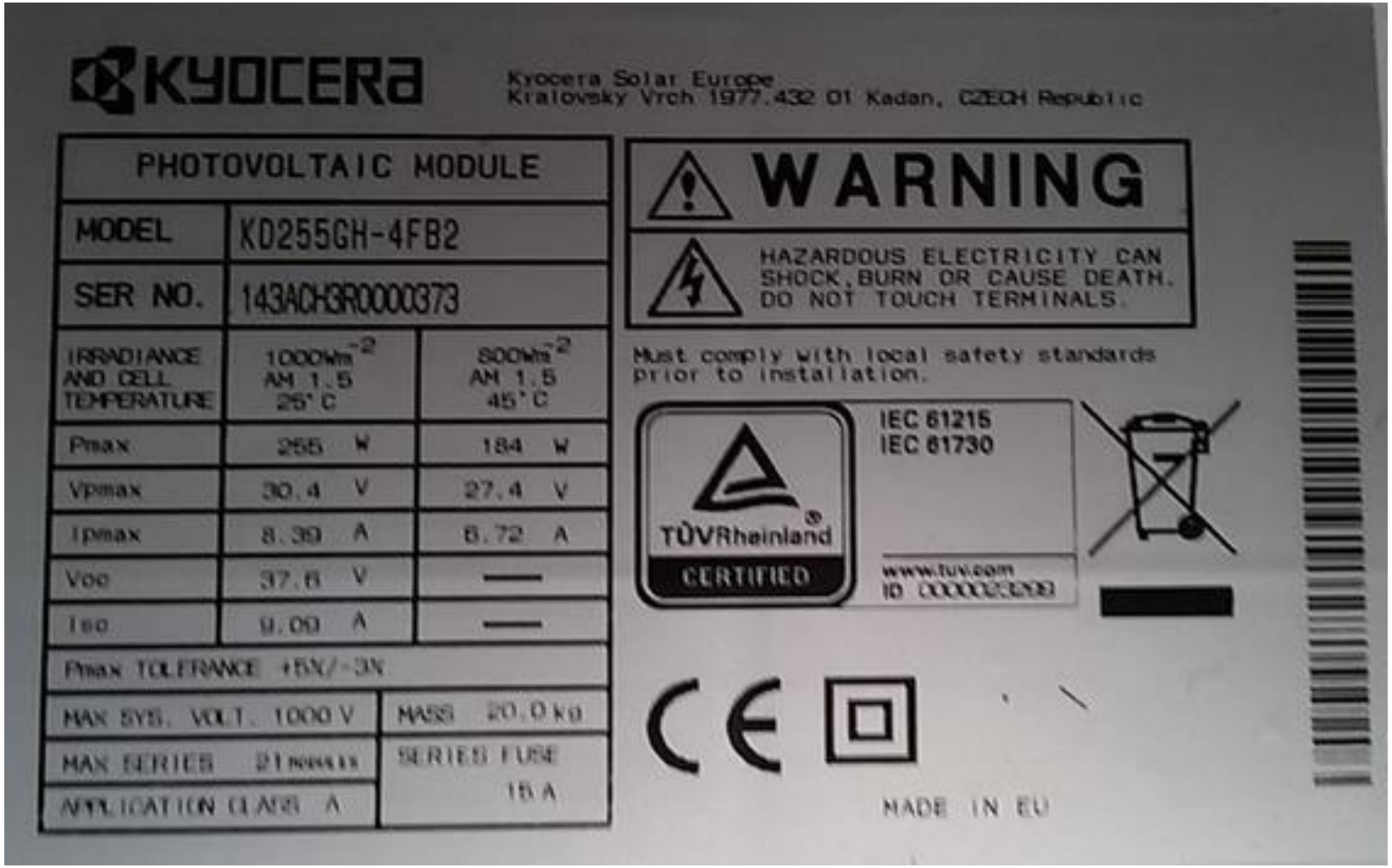
[1]Number of conductors is the total number of conductors in the raceway or cable adjusted in accordance with 310.15(B)(5) and (6).

Auxiliary Components

- **Example:**
- Two sets of two parallel strings of three kyocera KD255 in series going into 2 charge controllers with 3500 24V inverter at 38°C outside ambient, 15 m from battery bank in a 22°C room.
- Determine wire sizes for PV source circuit (from string to combiner box)
- Determine wire size for PV output circuit (from combiner box to DC load center)
- Determine wire size for battery to inverter cable
- Determine wire size for inverter output (AC)


To AC loads
Critical Loads Panel
120V
N
Bare copper 6AWG
EMT or LNFC
Charge Controller1
Charge Controller2
AC Hot out
AC Neutral Out
Chassis Ground
Chassis Ground
AC Neutral In
AC Hot In
DC
THWN-2 in conduit
USE-2 or PV Wire
PV Source Circuits
THW in Conduit
30
60
30
60
PV Output Circuit
24V Battery Bank
THWN-2 in conduit
175
Negative Bus Bar
Ground
THW in PVC conduit
altE store
2 sets of 2 strings of 3
For reference only. Install per product documentation.
11/11/14

Auxiliary Components



Wiring Sizing

- **PV Source Wire (Module to Combiner Box)**
- **Maximum Panel Current:**

  9.09A Isc X 1.25 (over-irradiance) = 11.36A
- **Continuous Current:**

  11.36A X 1.25 (3 hour continuous) = 14.2A
- **Using USE-2 Wire from PV module to combiner box**
- **Terminal Temperature Rate:**

  Breaker rater for 75°C

  Must use 75°C rating, even though wire is rated for 90°C

  Breaker accepts 18-6AWG
- **Temperature Compensation:**

  Ambient temperature of 38°C

Auxiliary Components

Wiring Sizing

- **PV Output Wire (Combiner Box to DC Load Center)**
- **Combined Current:**

  9.09 X 1.56= 14.2A X 2 strings = 28.4A
- **Using THWN-2 Wire from combiner box to DC Load Center in conduit**

  4 current carrying wires and ground
- **Temperature Compensation:**

  Ambient temperature of 38°C
- **Terminal Temperature Range:**

  Breaker rater for 75°C

  Must use 75°C rating, even though wire is rated for 90°C

  Breaker accepts 18-6AWG

Voltage Drop

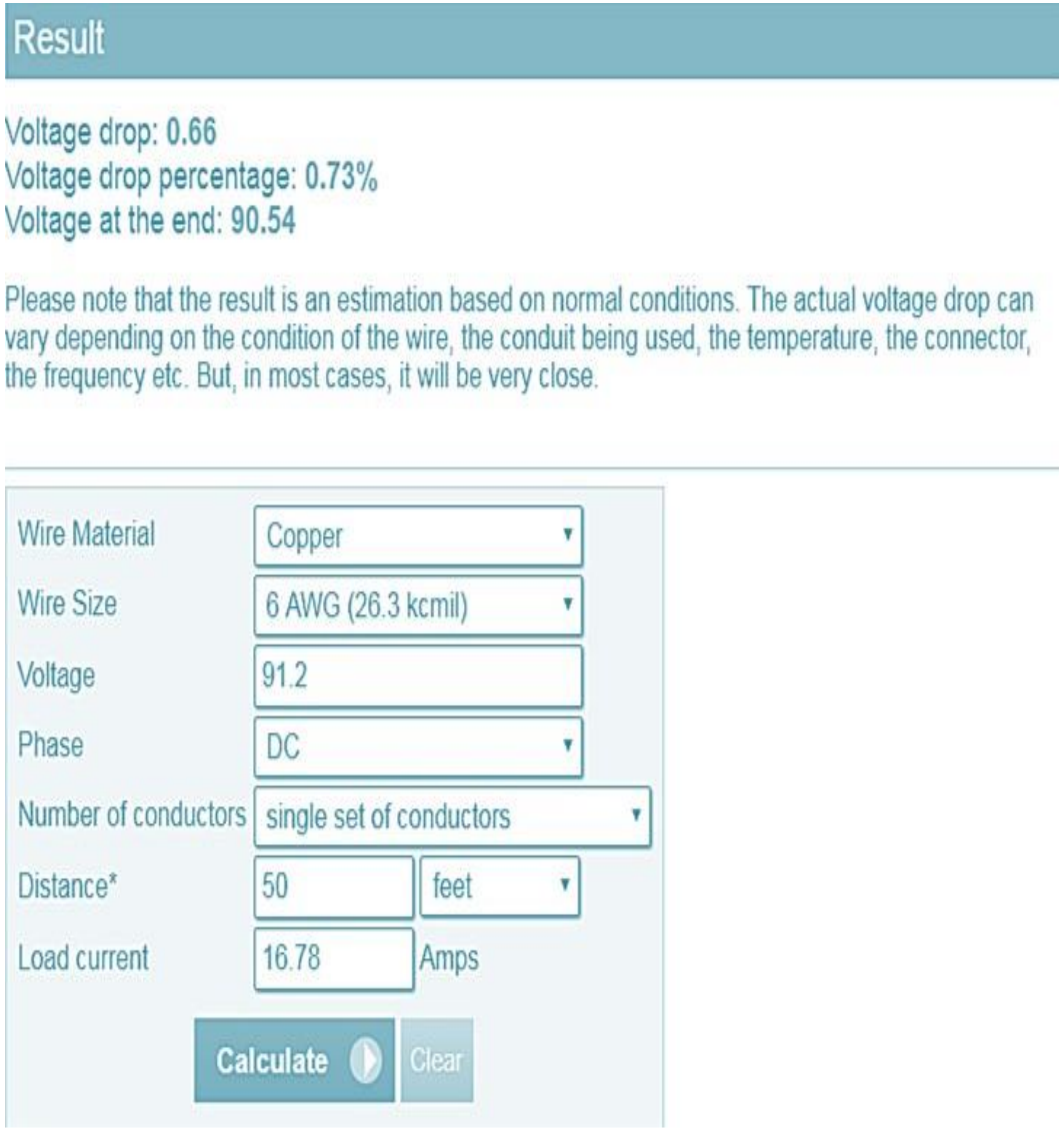
- **Calculate Voltage Drop from Combiner Box to DC Load Center**

  8.39 Imp X 2 strings = 16.78A

  30.4 Vmp X 3 in series = 91.2V

  ≤ 2% voltage drop recommended

- **Use Voltage Drop Calculator:**
  https://www.calculator.net/voltage-drop-calculator.html



Wiring Sizing

- **Battery to Inverter Cables**
- **Calculate the highest current possible:**

  Inverter Wattage ÷ Battery Bank Lowest Voltage

  3500W ÷ 20V = 175A

- **Using THW Wire for Dry Location**

  2 wires in conduit

- **Temperature Compensation:**

  Cool equipment room temperature of 22°C

Voltage Drop

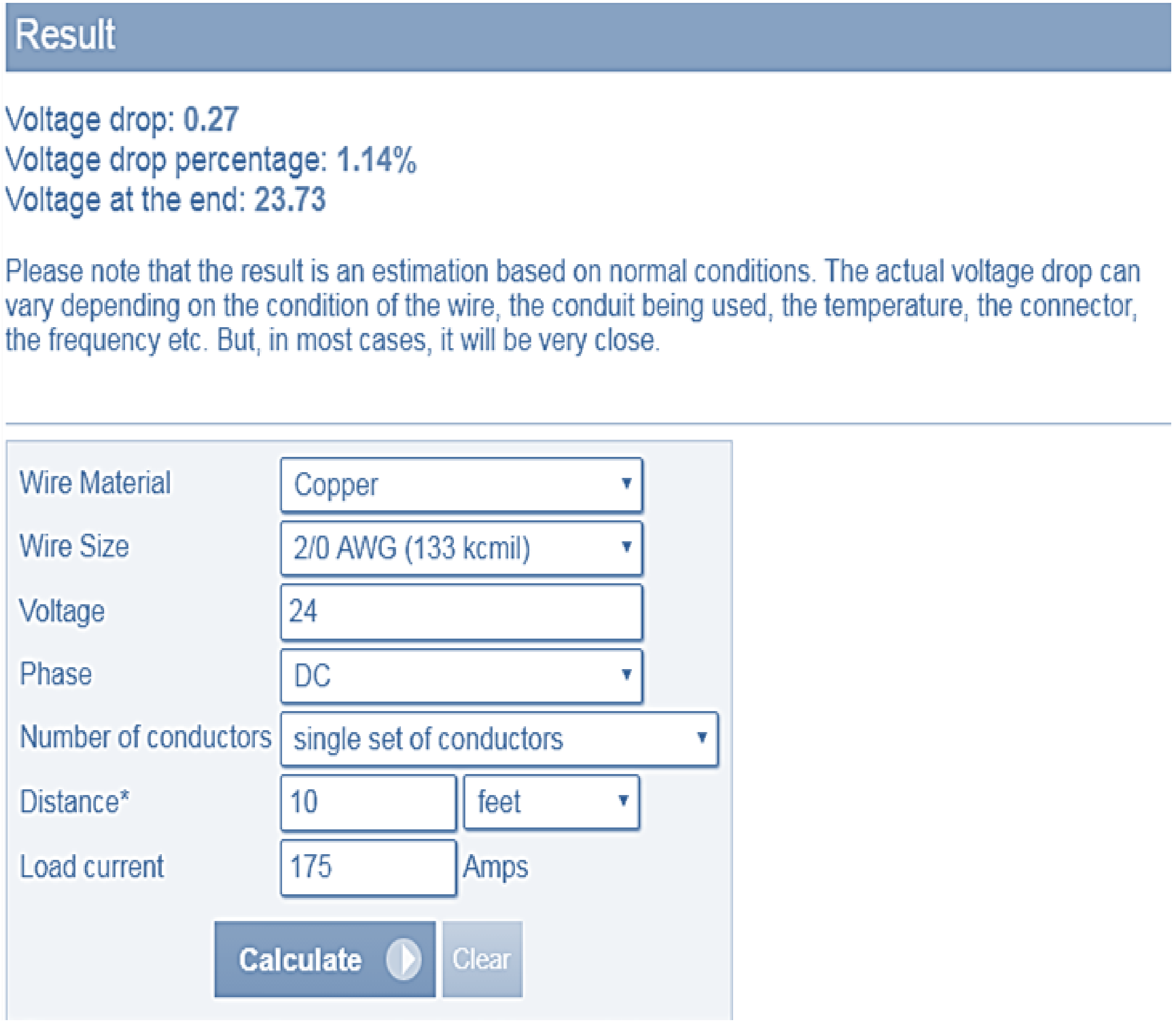
- **Calculate Voltage Drop from Battery to Inverter**

  175A

  24V system

  ≤ 2% voltage drop recommended

- **Use Voltage Drop Calculator:** https://www.calculator.net/voltage-drop-calculator.html



Wiring Sizing

- **Inverter Output Wires**
- **Calculate the Continuous current:**

  Inverter Wattage ÷ VAC

  3500W ÷ 120V = 29.2A

- **Check NEC Tables**

  2 current carrying wires in conduit

- **Temperature Compensation:**

  Cool equipment room temperature of 22°C

Wiring Sizing

- **Summary**
- **PV Source Wires:**

  Minimum required USE-2 of 14 AWG
- **PV Output Wires:**

  Minimum required THWN-2 of 6 AWG
- **Battery to Inverter Cables:**

  Minimum required THW of 2/0 AWG
- **Inverter Output Wires:**

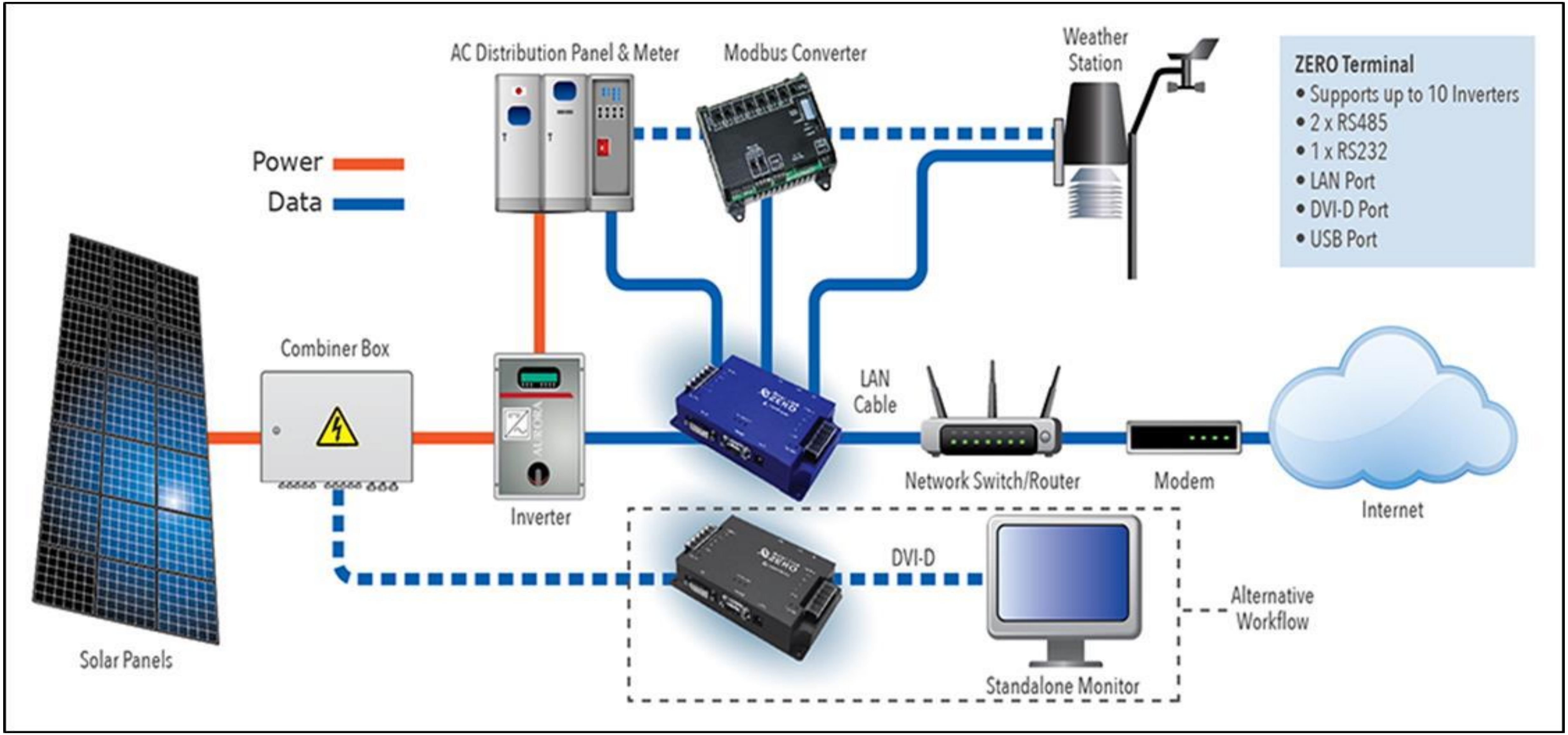
  Minimum required wire of 10 AWG

Auxiliary Components

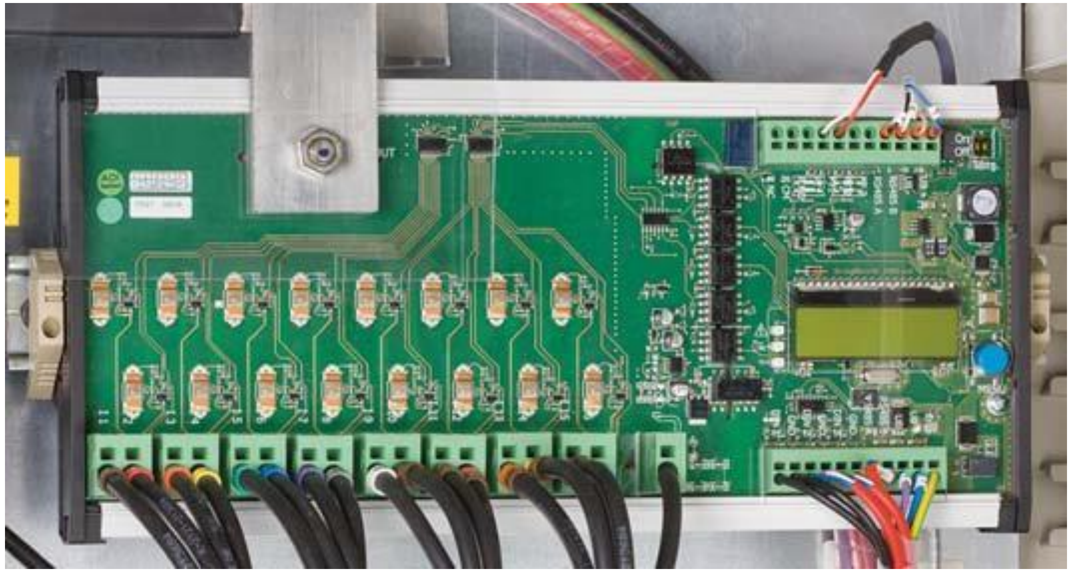
- **Monitoring:**

Monitoring Equipment components are usually connected to a concurrent Inverter manufacturer, and they view and relay system energy information analytics to an in-product console or web connected device through their proprietary software. Monitoring Equipment components may be integrated into an Inverter, or in some instances – be connected to another component of a photovoltaic array.

Monitoring System



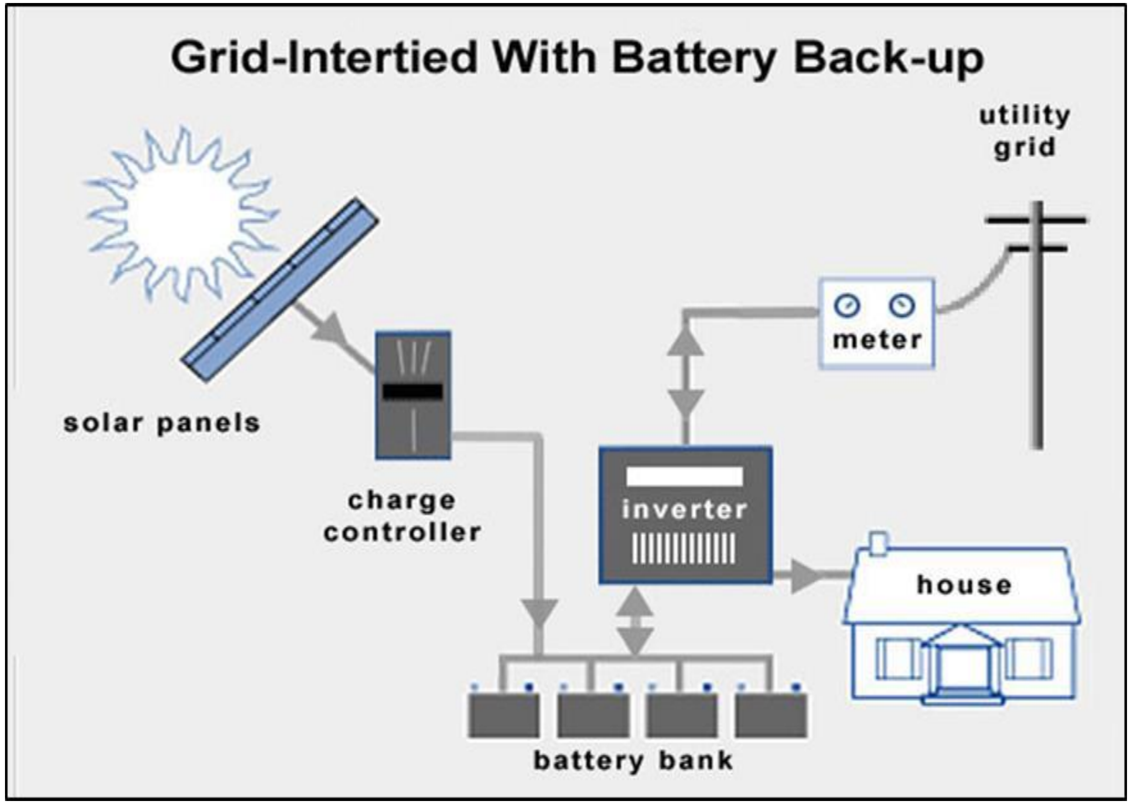
Monitoring System



Auxiliary Components

- **Grid Charger (Inverter/Charger):**

Used in grid interactive solar PV systems with batteries. A grid charger can provide charging of the batteries taking AC power from the grid in case solar power is not sufficient to charge the battery or battery voltage is too low. This may happen during the continuous cloudy days.



Grid Charger (Inverter/Charger)

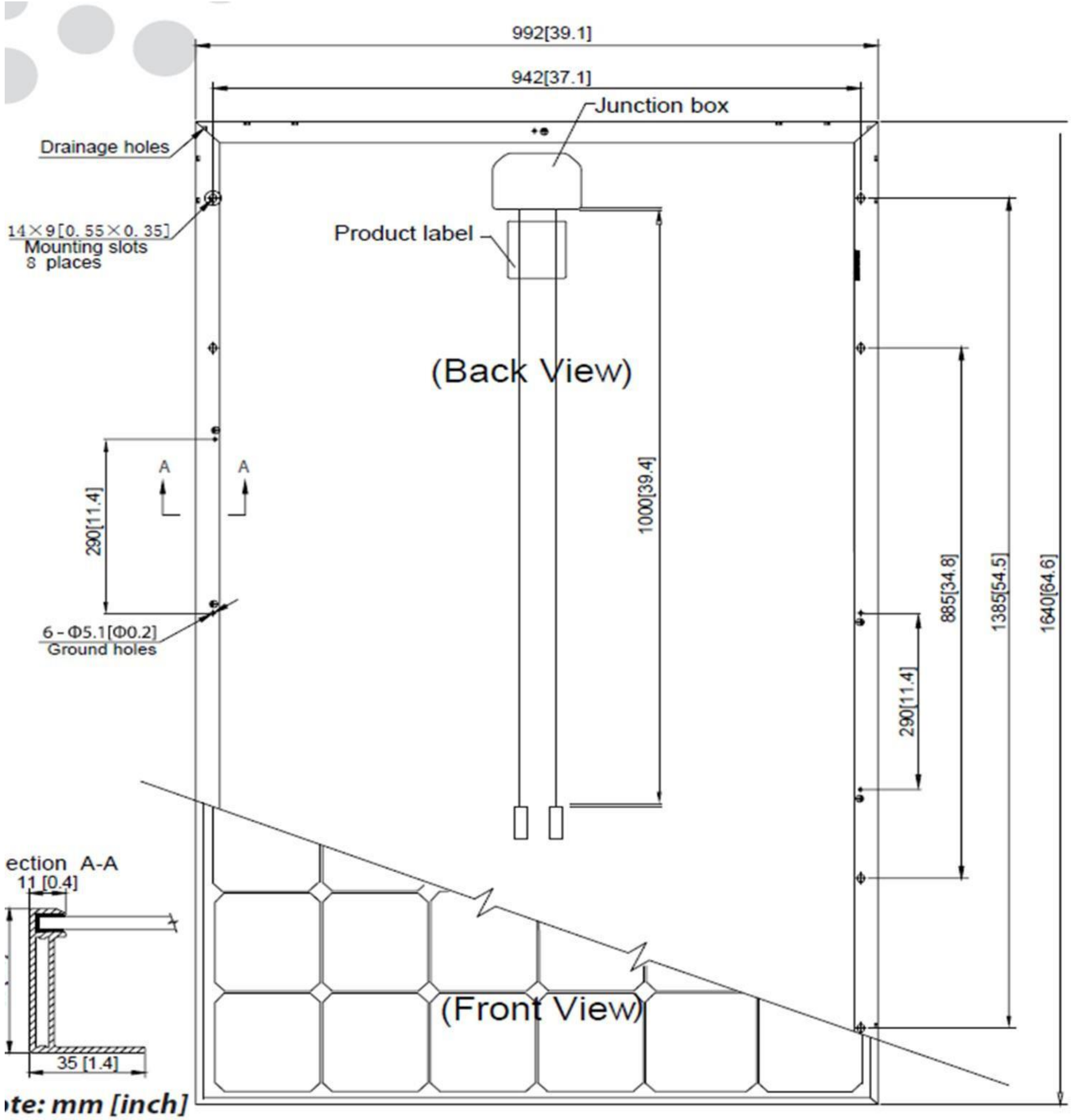
MultiPlus 12 Volt / 24 Volt / 48 Volt	C 12/800/35 C 24/ 800/16	C 12/1200/50 C 24/1200/25	C 12/1600/70 C 24/1600/40	C 12/2000/80 C 24/2000/50	12/3000/120 24/3000/70 48/3000/35	24/5000/120 48/5000/70
PowerControl	Yes	Yes	Yes	Yes	Yes	Yes
PowerAssist	Yes	Yes	Yes	Yes	Yes	Yes
Transfer switch (A)	16	16	16	30	16 or 50	100
INVERTER						
Input voltage range (V DC)	9,5 – 17 V 19 – 33 V 38 – 66 V					
Output	Output voltage: 230 VAC ± 2% Frequency: 50 Hz ± 0,1% (1)					
Cont. output power at 25°C (VA) (3)	800	1200	1600	2000	3000	5000
Cont. output power at 25°C (W)	700	1000	1300	1600	2400	4000
Cont. output power at 40°C (W)	650	900	1200	1400	2200	3700
Cont. output power at 65°C (W)	400	600	800	1000	1700	3000
Peak power (W)	1600	2400	3000	4000	6000	10.000
Maximum efficiency (%)	92 / 94	93 / 94	93 / 94	93 / 94	93 / 94 / 95	94 / 95
Zero load power (W)	8 / 10	8 / 10	8 / 10	9 / 11	20 / 20 / 25	30 / 35
Zero load power in AES mode (W)	5 / 8	5 / 8	5 / 8	7 / 9	15 / 15 / 20	25 / 30
Zero load power in Search mode (W)	2 / 3	2 / 3	2 / 3	3 / 4	8 / 10 / 12	10 / 15
CHARGER						
AC Input	Input voltage range: 187-265 VAC Input frequency: 45 – 65 Hz Power factor: 1					
Charge voltage 'absorption' (V DC)	14,4 / 28,8 / 57,6					
Charge voltage 'float' (V DC)	13,8 / 27,6 / 55,2					
Storage mode (V DC)	13,2 / 26,4 / 52,8					
Charge current house battery (A) (4)	35 / 16	50 / 25	70 / 40	80 / 50	120 / 70 / 35	120 / 70
Charge current starter battery (A)	4 (12 V and 24 V models only)					
Battery temperature sensor	yes					
GENERAL						

Auxiliary Components

- **Racking & Mounting System:**

Racking and Mounting components work to ensure a PV array is connected to either the ground or a roof.

Racking and Mounting is an essential part of any solar energy system. Both roof-top and ground mount arrays need to be set atop a sound and reliable structure to ensure the system can maintain integrity and operate for an extended period of time



Racking & Mounting System

- **Fixed Ground Mounting:**

Ground mounting is nicely suited to sites where unobstructed sun exposure is available without needing to place panels on a roof top.

Racking & Mounting System

- **Fixed Roof Mounting:**

Fixed roof mounting has all the advantages of fixed ground mounting but with reduced ease of maintenance traded off against immunity to tampering and/or vandalism. One additional issue is the possible need for roof penetrations to accommodate mounting hardware.

Racking & Mounting System

- **Wall Mounting:**

South facing building walls can be taken advantage of as module mounting surfaces. Modules arrays can be parallel to the wall, tilted away from the wall, or configured as an overhanging canopy.

Racking & Mounting System

- **Top of Pole Mounting:**

Top of pole mounting is another fixed array mounting method. Arrays remain stationary even through the arrangement looks similar to a tracker. Top of pole mounts often allow for seasonal tilt adjustments which may help to optimize harvests particularly during winter conditions.

Racking & Mounting System

- **Tracking Mounting:**

Using a tracker can increase array energy harvest 25% – 40% over fixed mounting. Trackers can be ground or roof mounted. When ground mounted, the tracking hardware can add 15% – 20% to the cost of a project over fixed mounting hardware. Since roof top installations require more engineering and labor to complete, the system cost differential between tracked and fixed related to mounting method alone will be smaller still.