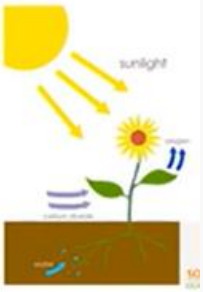
# Types of Solar Energy

- **Passive Solar Energy**
- **Solar Thermal Energy**
- **Solar Photovoltaic Energy**

## Passive Solar Energy

- **Utilizes Solar Energy without any Mechanical System.**
- **Direct from Sun**

e.g. Drying Clothes , Natural Lighting. Disinfect Water, Photosynthesis.

## Solar Thermal Energy

- **Utilizes Heat from Sunlight**

e.g. Solar water Heater, Solar Cooker, Solar Thermal Power Plant.

## Solar Photovoltaic Energy

- **Sunlight into Electricity using Solar Cell**

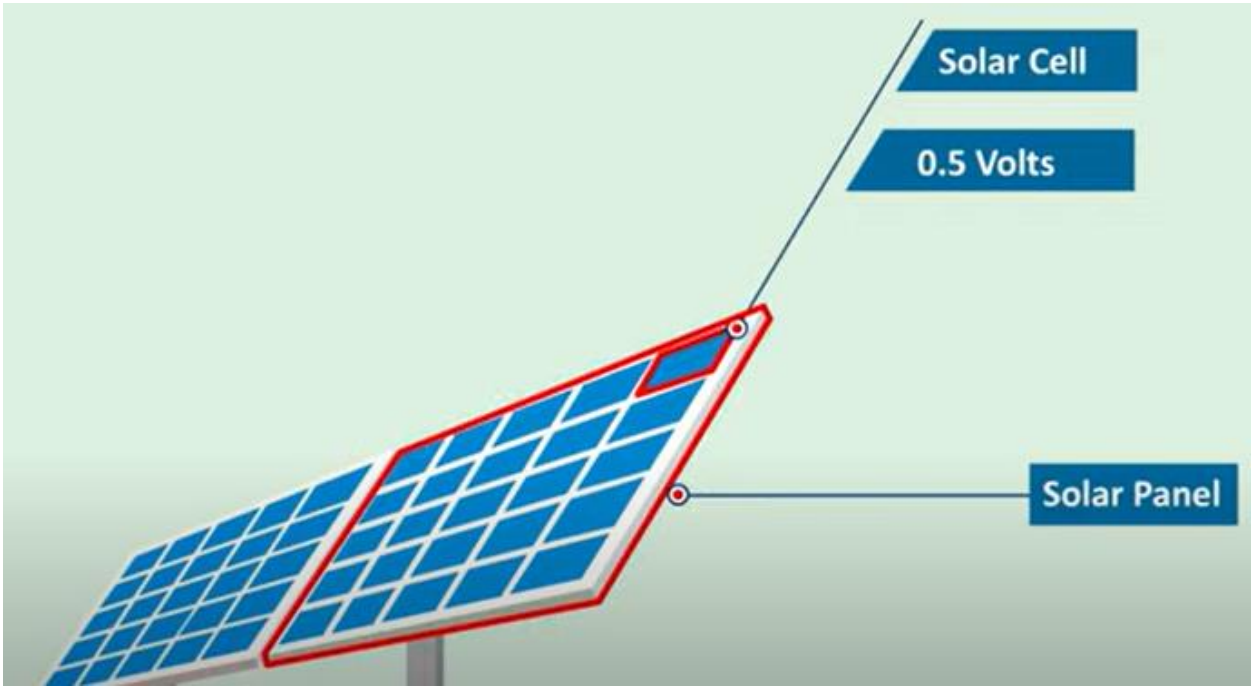
e.g. Solar Rooftop System, Solar Power Plant, Solar Home lighting System, Solar Lanterns, Solar Street lights, Solar Charging Station etc.

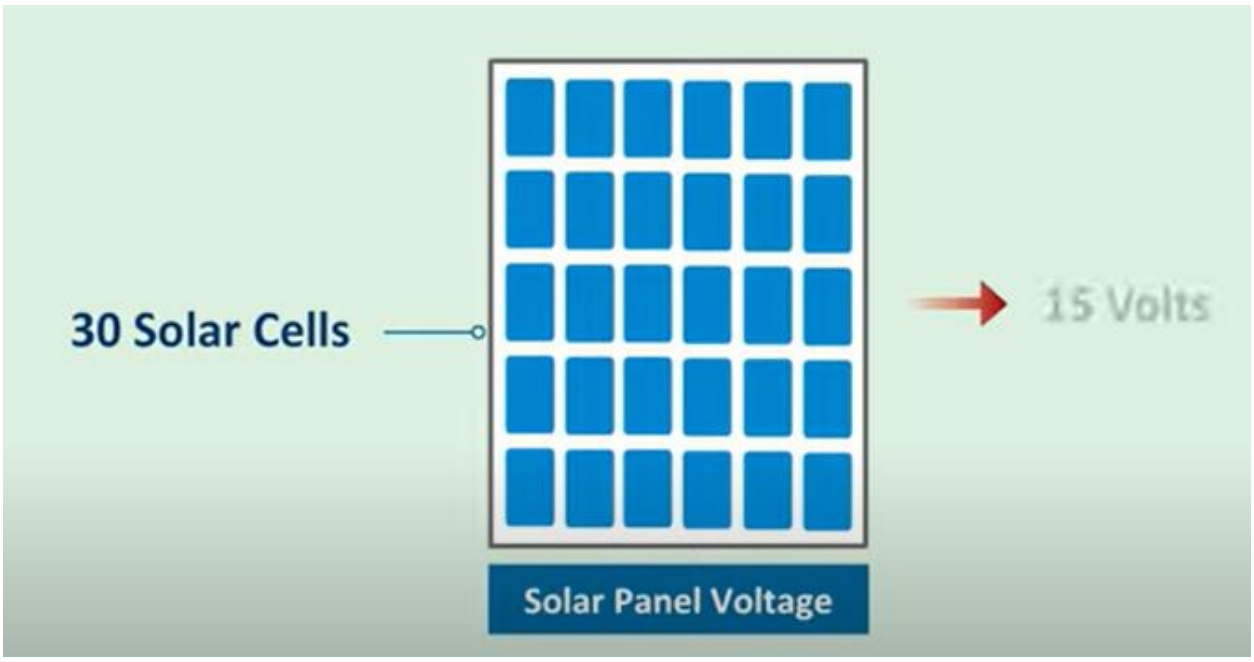
# Fundamentals of Solar Photovoltaic Systems

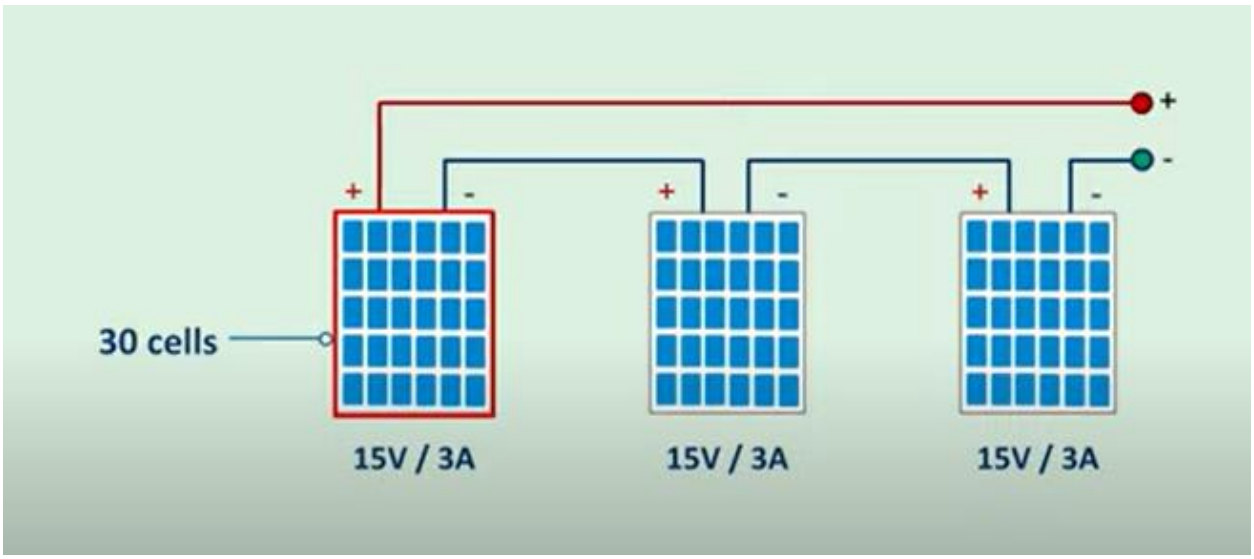
# A Single Solar Cell

**A typical solar cell can produce about 0.5V**

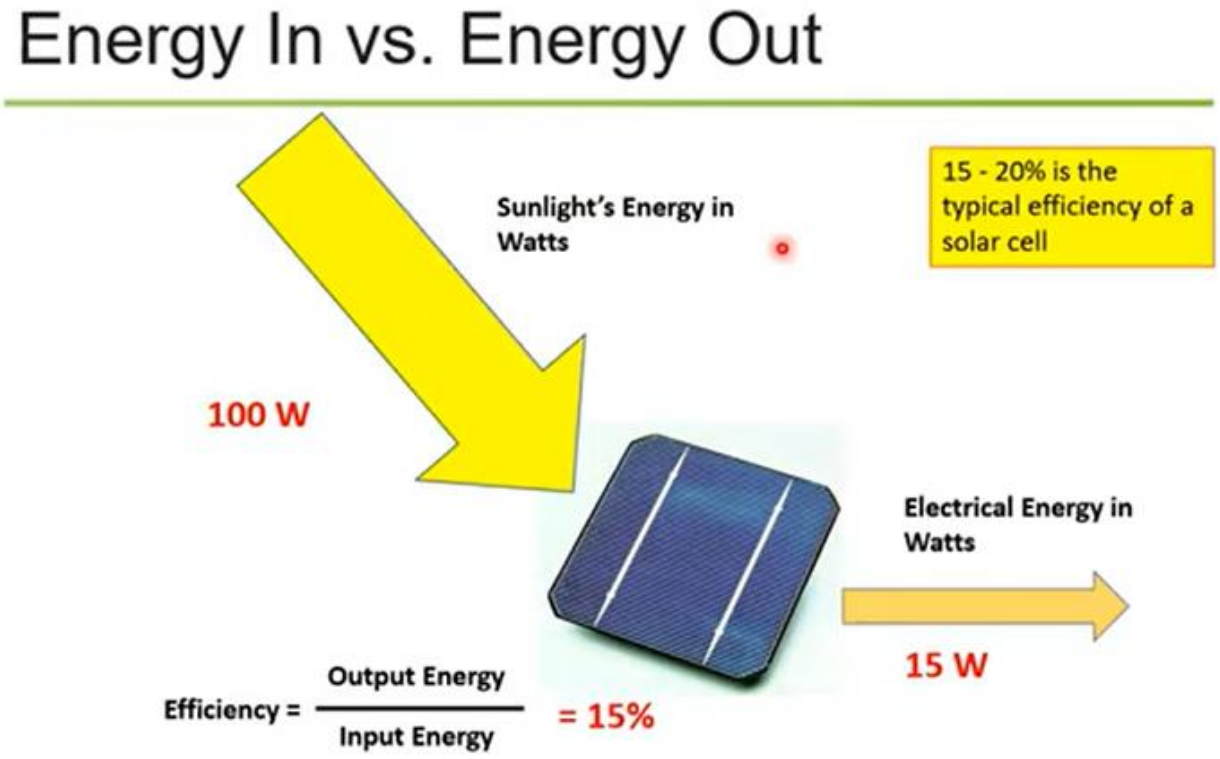
**How do we get a system with 120V?**

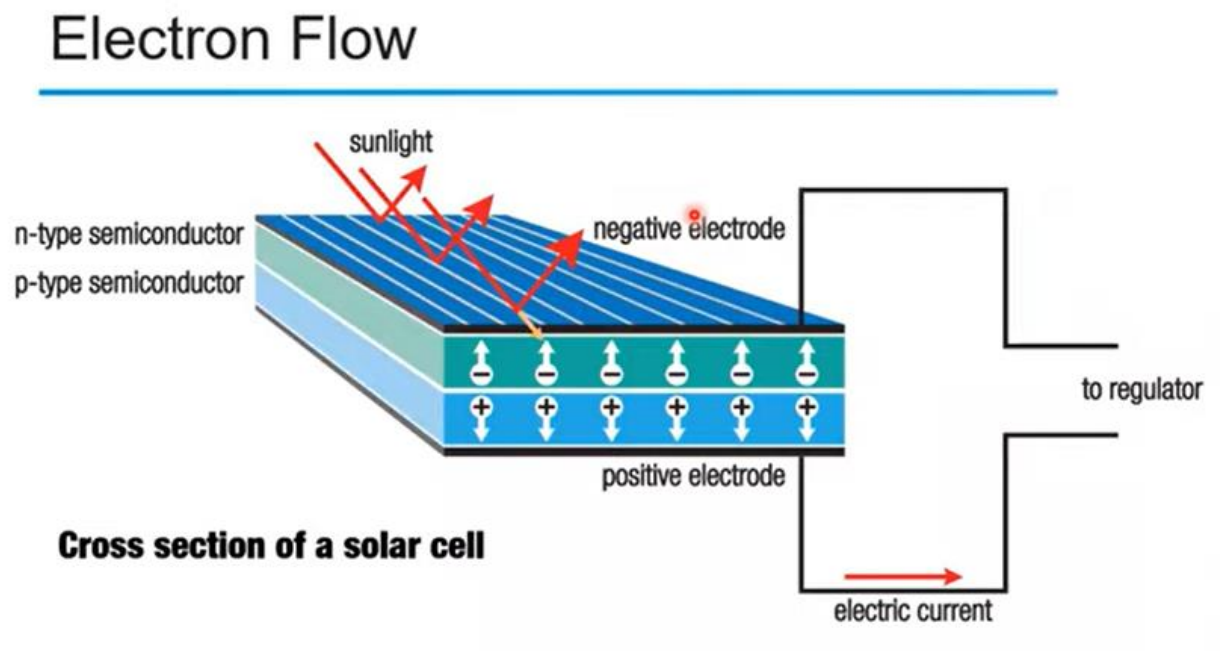



30 Solar Cells
15 Volts
Solar Panel Voltage


+
-
+
-
+
-
+
-
30 cells
15V / 3A
15V / 3A
15V / 3A

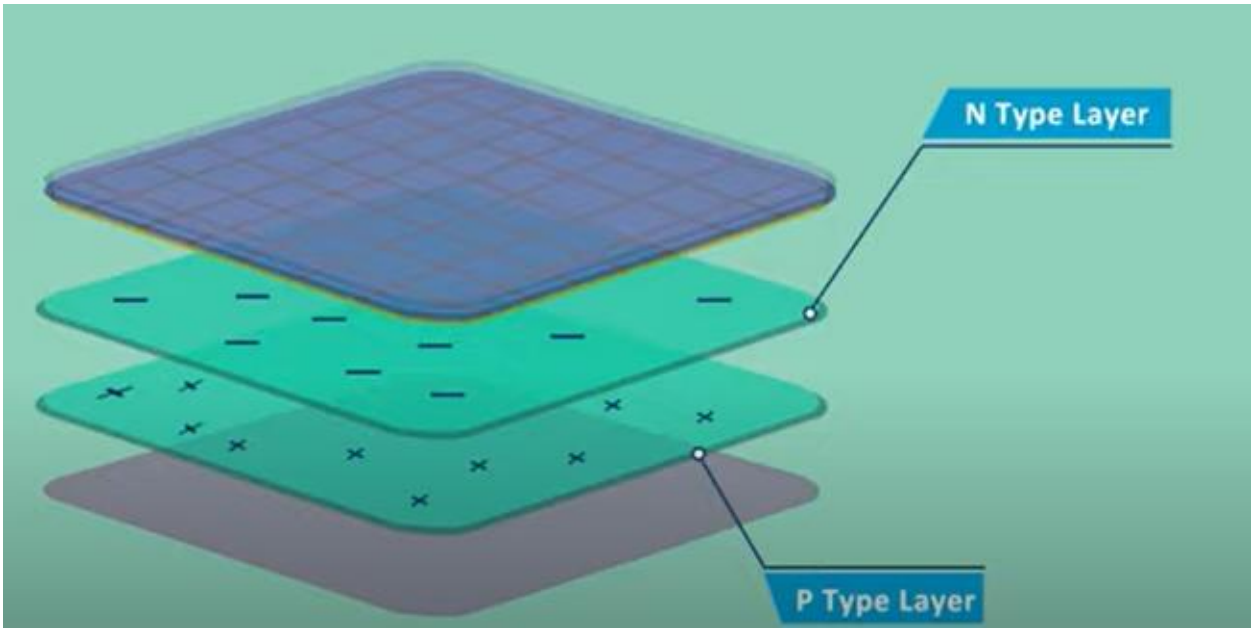
Solar array

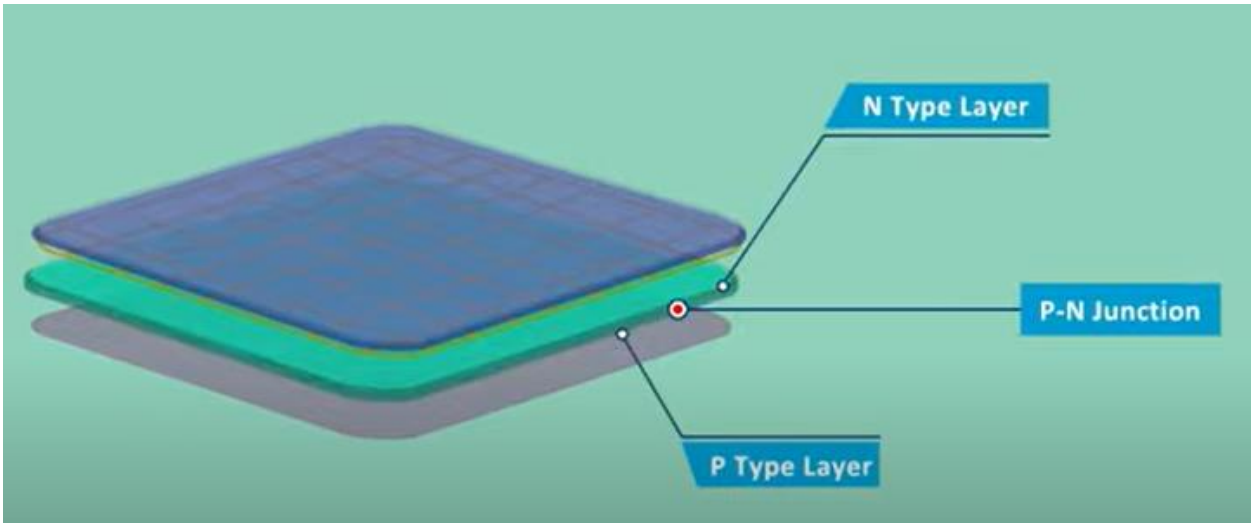


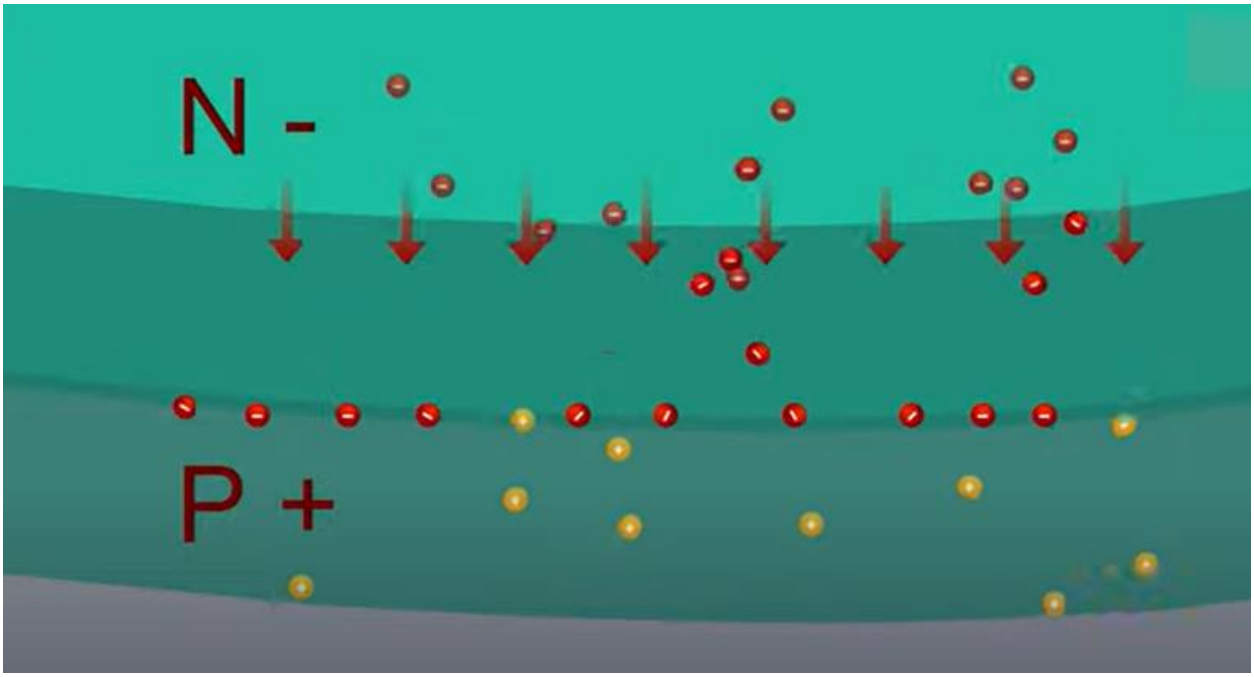

N type semi Boron (thin high concentration of e )

P phosphorous



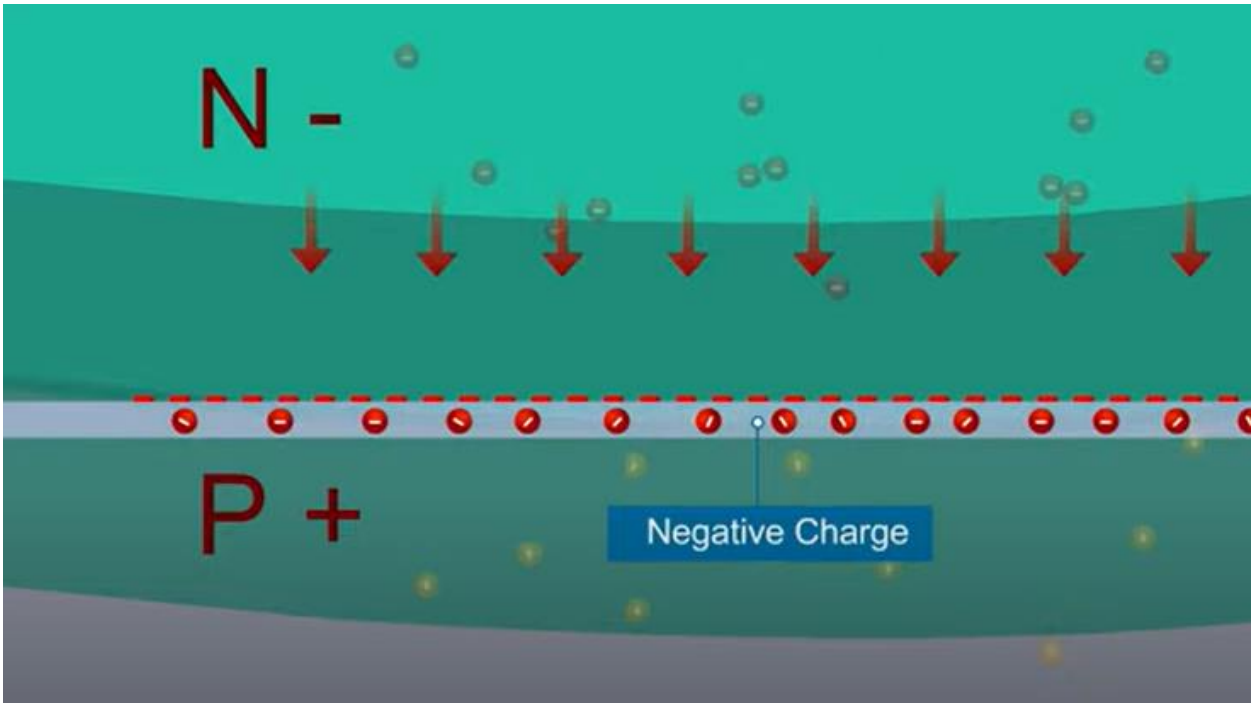



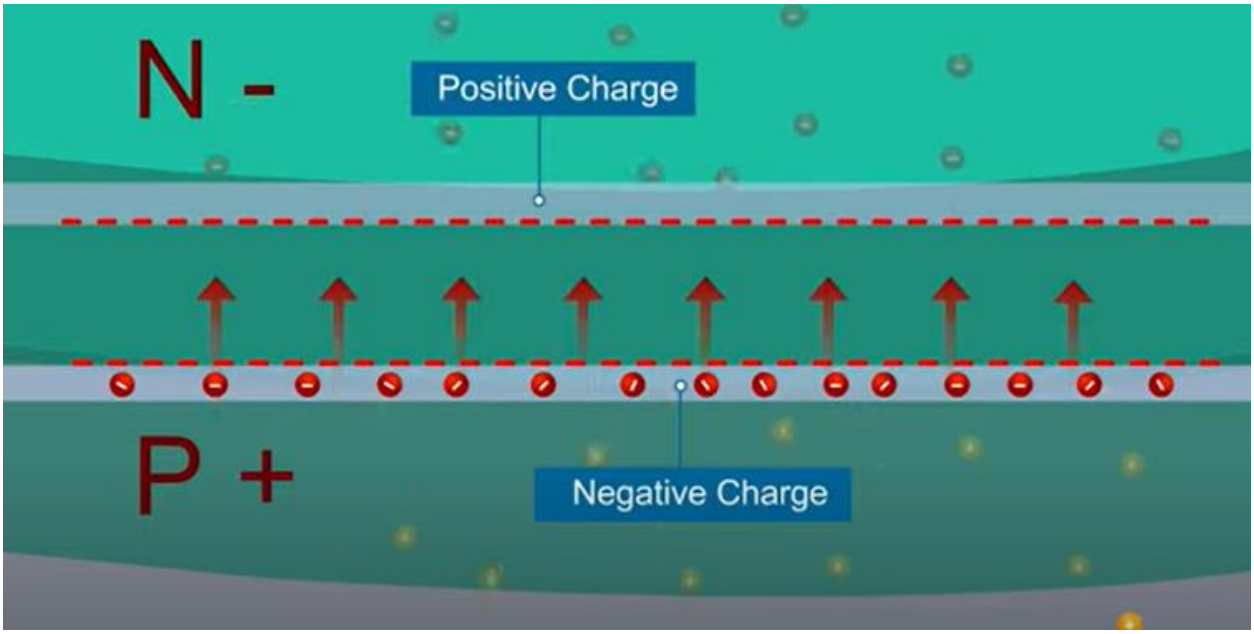

n-p joined as PN junction

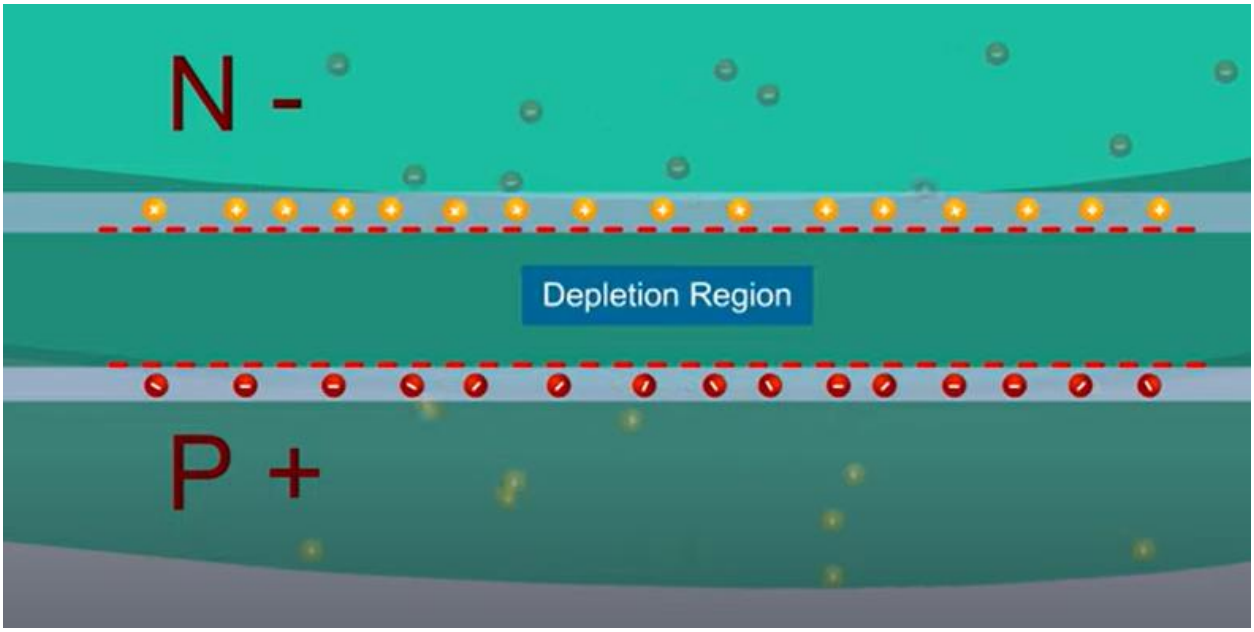



When PN junction, e try to reach P junction creating –ve charge layer

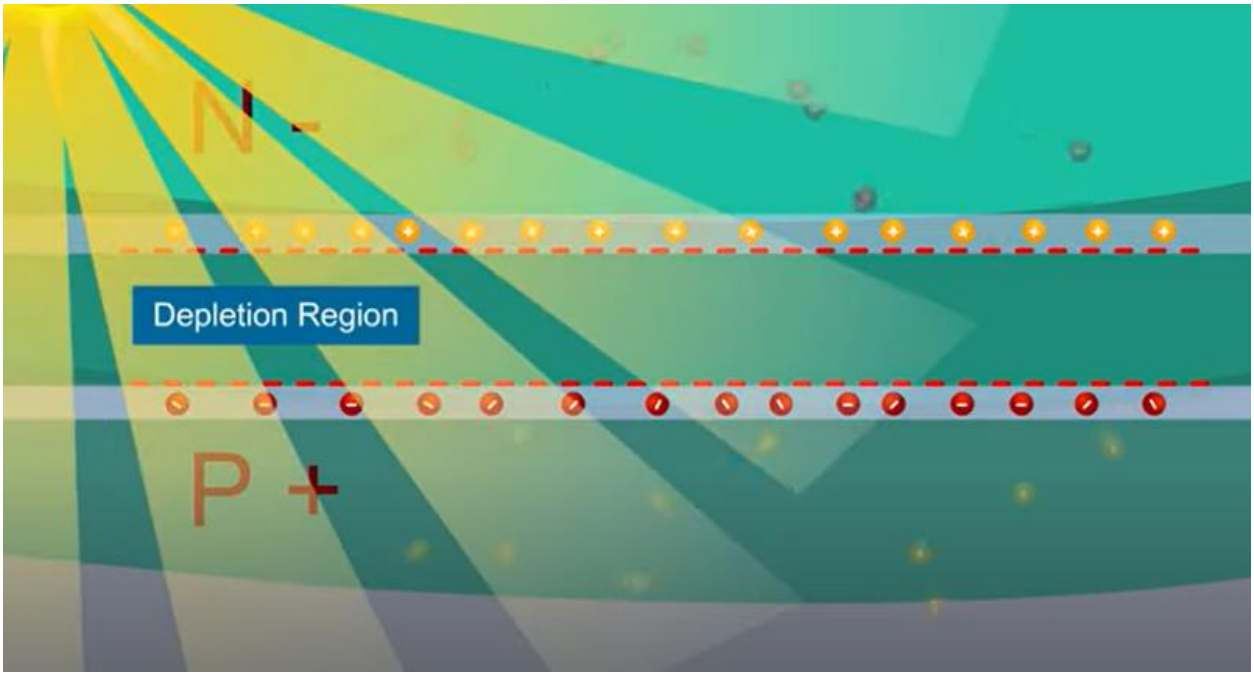
Similarly p try and +ve charge layer



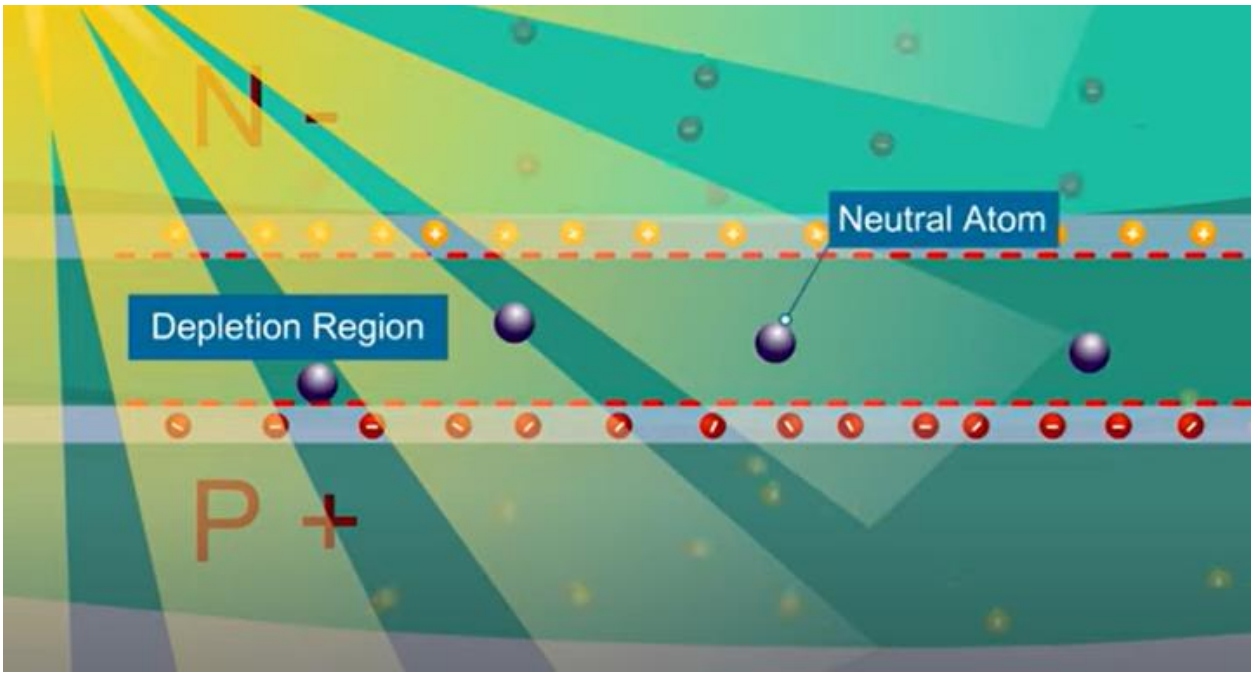


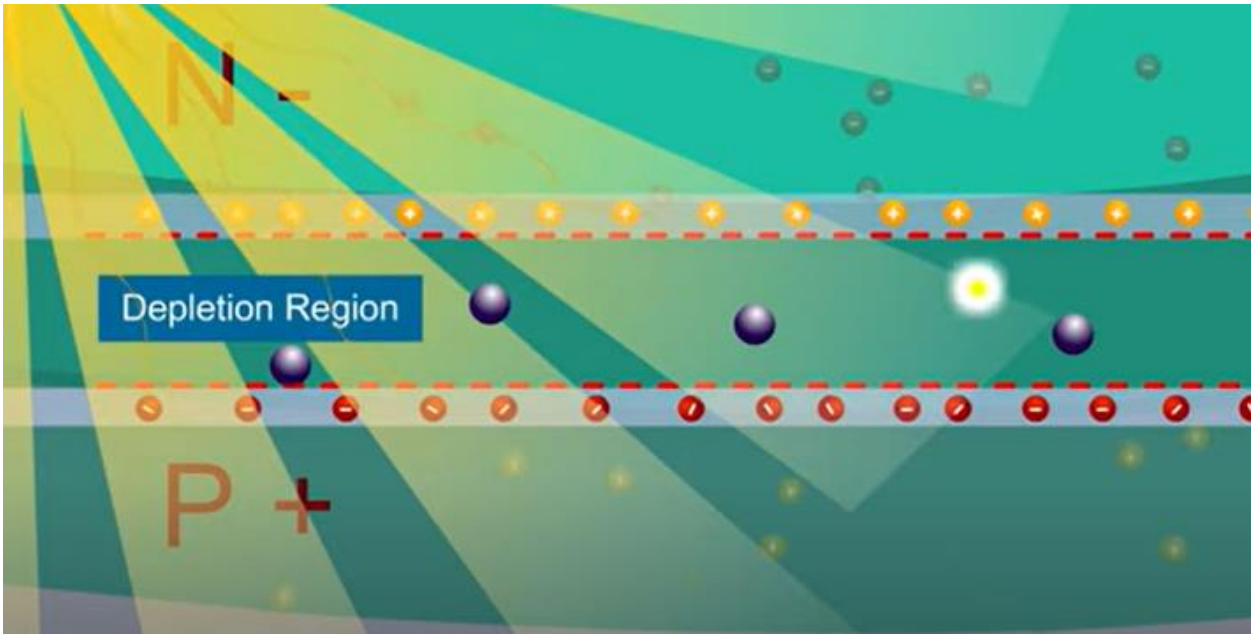

Region between two layers is depletion region of semiconductor

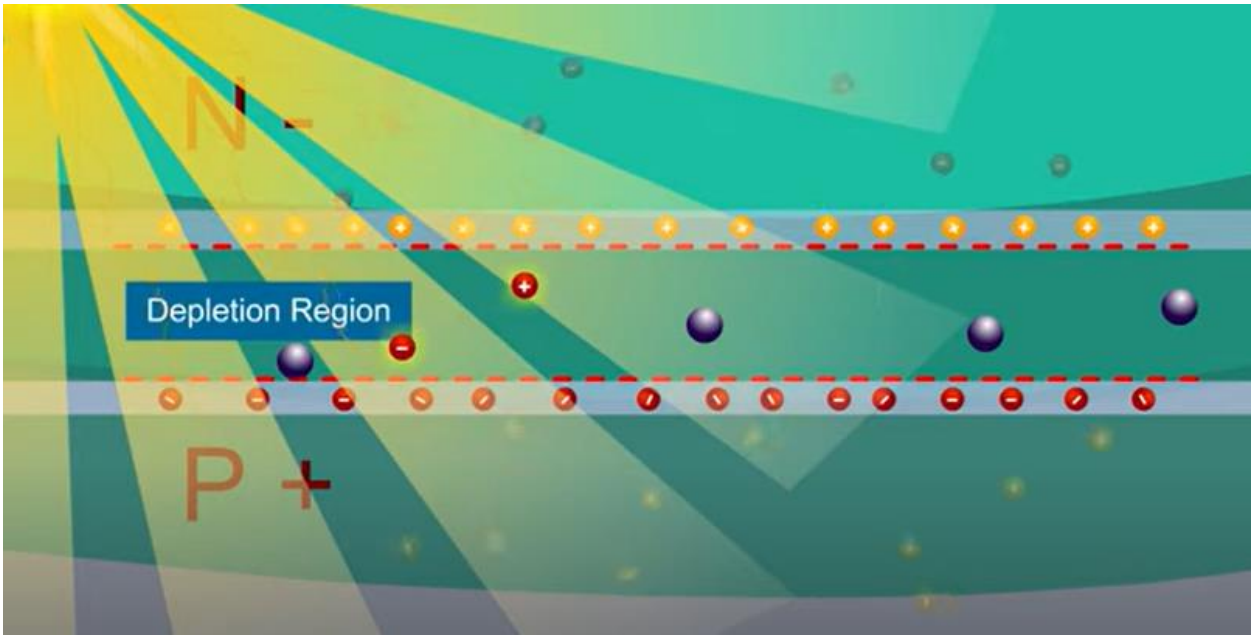



Sun light easily cross thin N layer to reach the depletion region

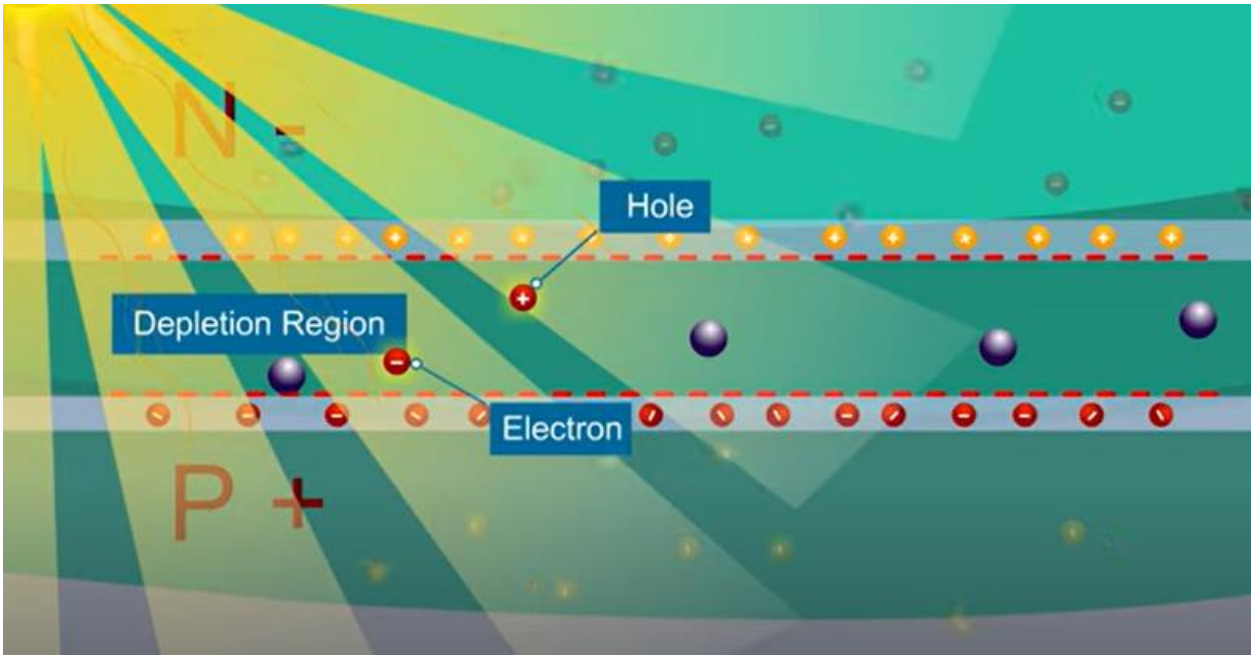


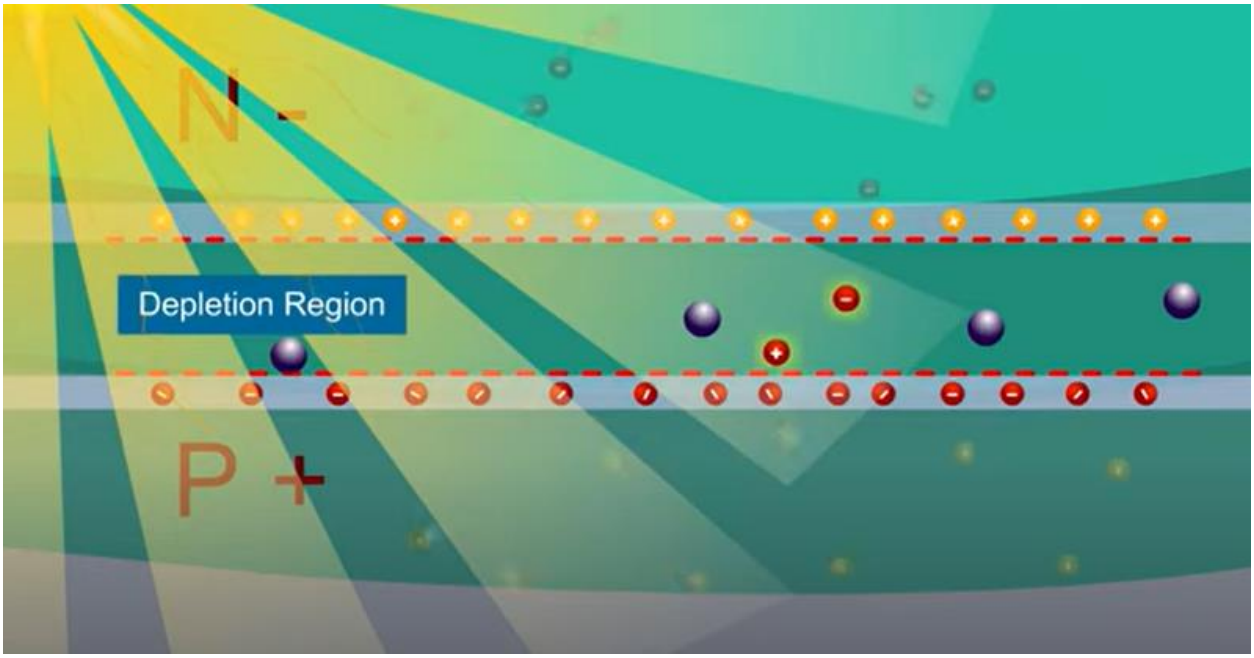

Due to charge deficiency in depletion region, it contains neutral atoms.



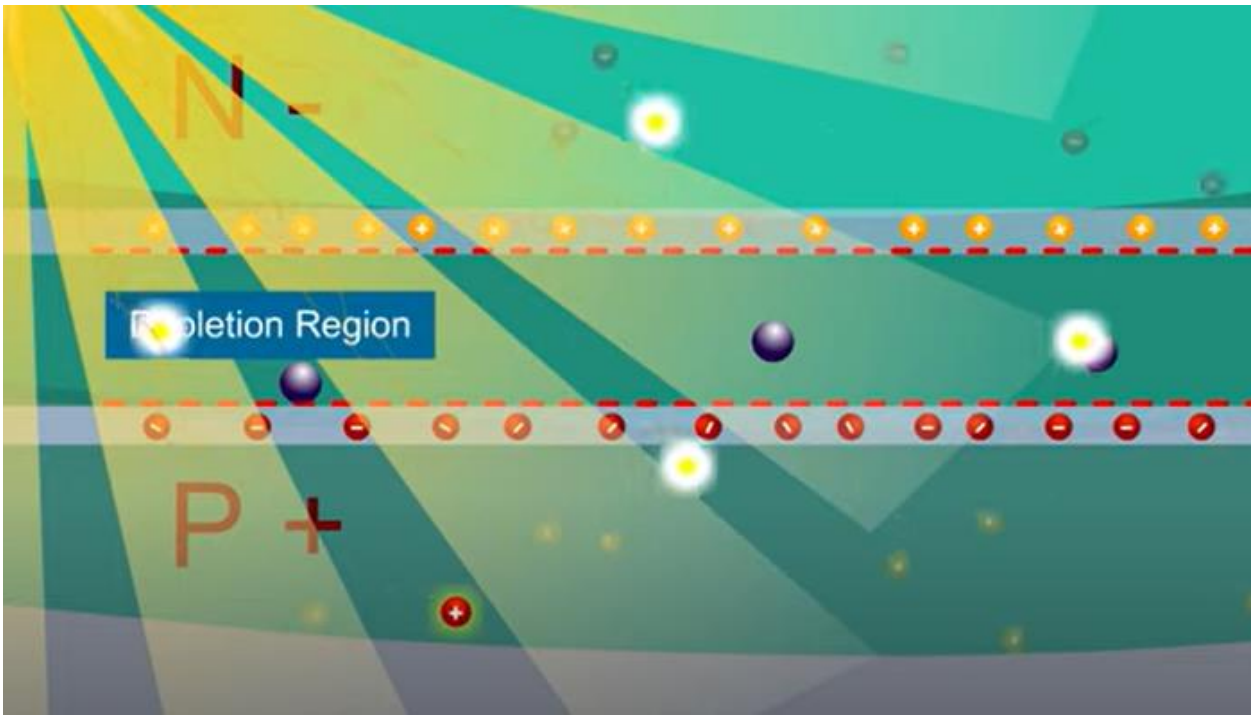




Neutral atoms broken by photons of sun light.  Knocks the e from neutral atom leaving behind the holes and producing free charge carriers.

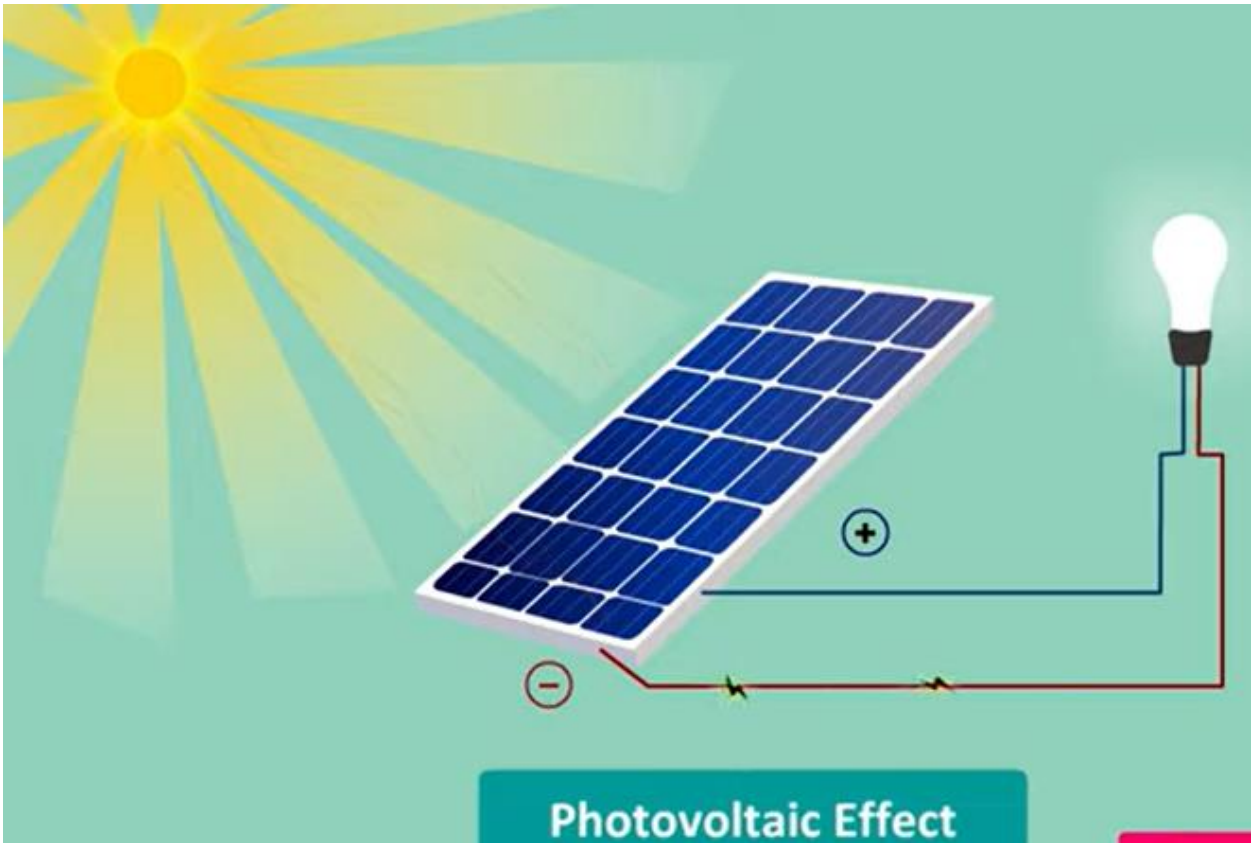


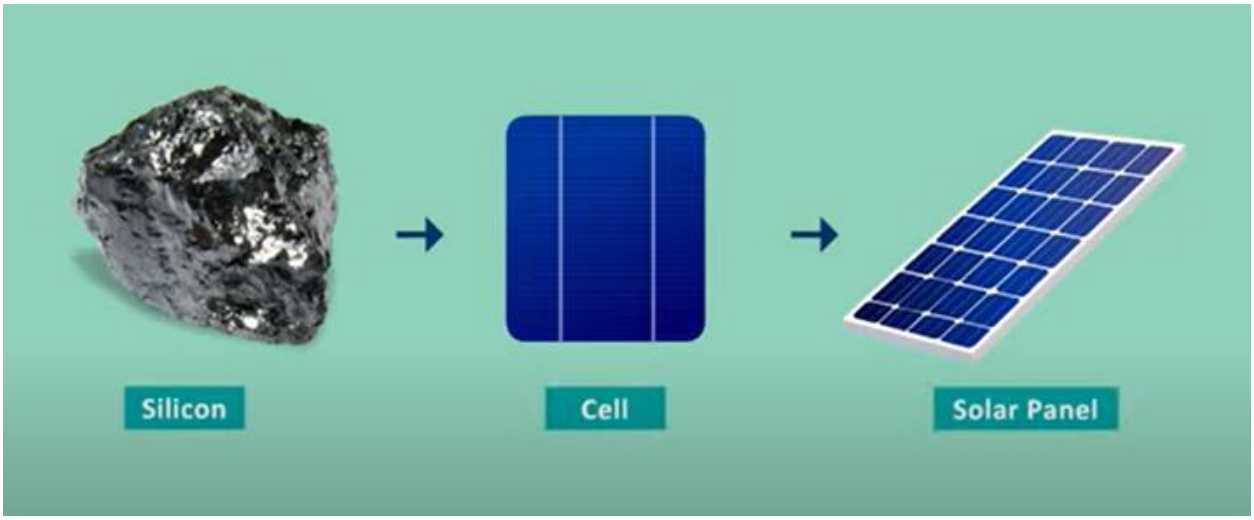




Then e moves to n type layer and holes move to p type layer due to electric field present in the depletion region.

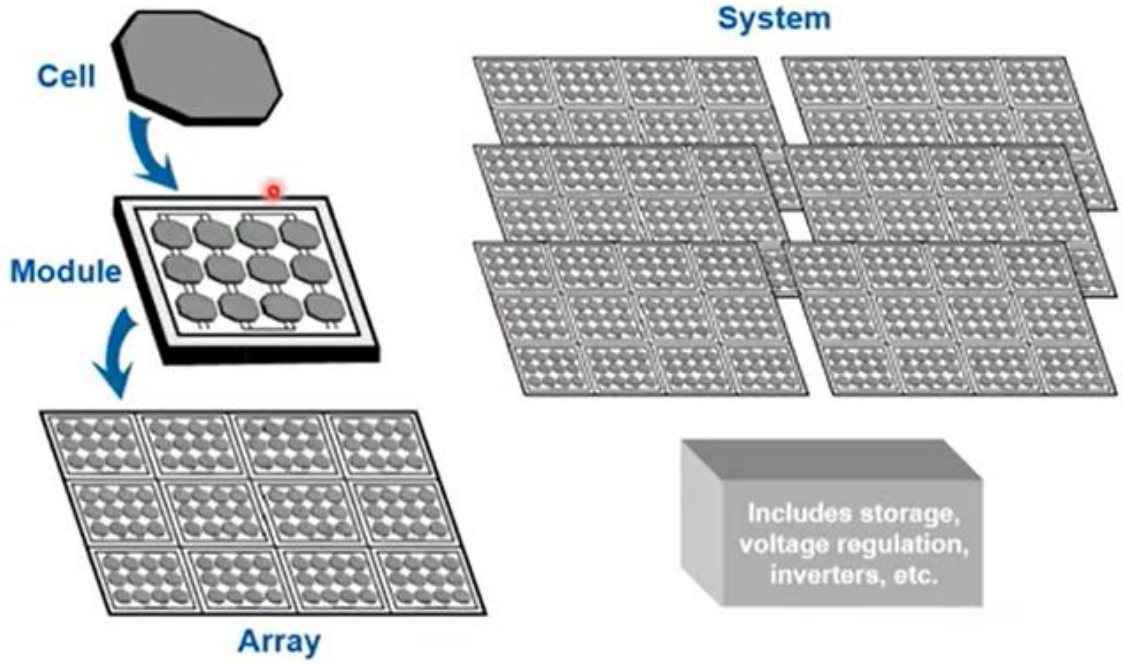



On connecting the electronic circuit, e flow through to generating an electricity to electric devices like bulb, fans etc


+
−
Photovoltaic Effect


Silicon
Cell
Solar Panel

# Photovoltaic Building Blocks




# How do Solar Panels Work?

- PV Panels are made of a semiconductor material
- Examples of semiconductors:
  - Monocrystalline silicon
  - Polycrystalline silicon
  - Amorphous silicon
  - Gallium Arsenide
  - Cadmium Telluride

# Polycrystalline vs. Monocrsystalline

Polycrystalline Solar Cell



Monocrystalline Solar Cell

Poly less efficiency

Mono Limited space

| Factor | Monocrystalline Solar Panels | Polycrystalline Solar Panels |
|---|---|---|
| **Silicone Arrangement** | One pure silicon crystal | Many silicon fragments melded together |
| **Cost** | More expensive | Less expensive |
| **Appearance** | Panels have black hue | Panels have blue hue |
| **Efficiency** | More efficient | Less efficient |
| **Lifespan** | 25-40 years | 20-35 years |
| **Temperature Coefficient** | Lower temperature coefficient,<br><br>making them more efficient in heat | Higher temperature coefficient,<br><br>making them less efficient in heat |

# Three Main Solar Panel Types

**Monocrystalline**

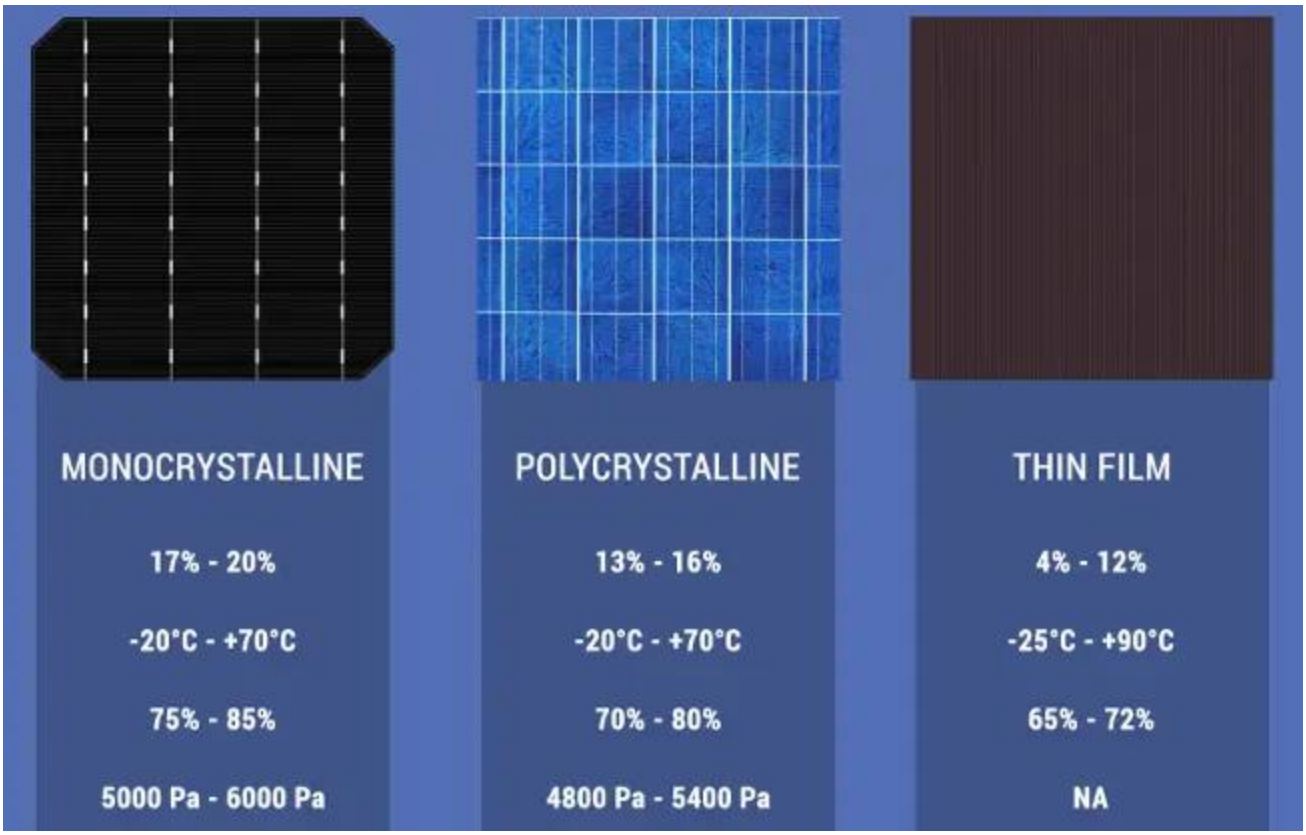
- Pure silicon
- 24.4% efficiency
- Moderate cost
- Longest lifespan
- 38.1 g CO2-eq/kWh

**Polycrystalline**

- Melted silicon crystals
- 19.9% efficiency
- Least expensive
- Moderate lifespan
- 27.2 g CO2-eq/kWh

**Thin-Film**

- Variety of material
- 18.9% efficiency
- Most expensive
- Shortest lifespan
- As little as 21.4 g CO2-eq/kWh




100W poly vs 120W mono

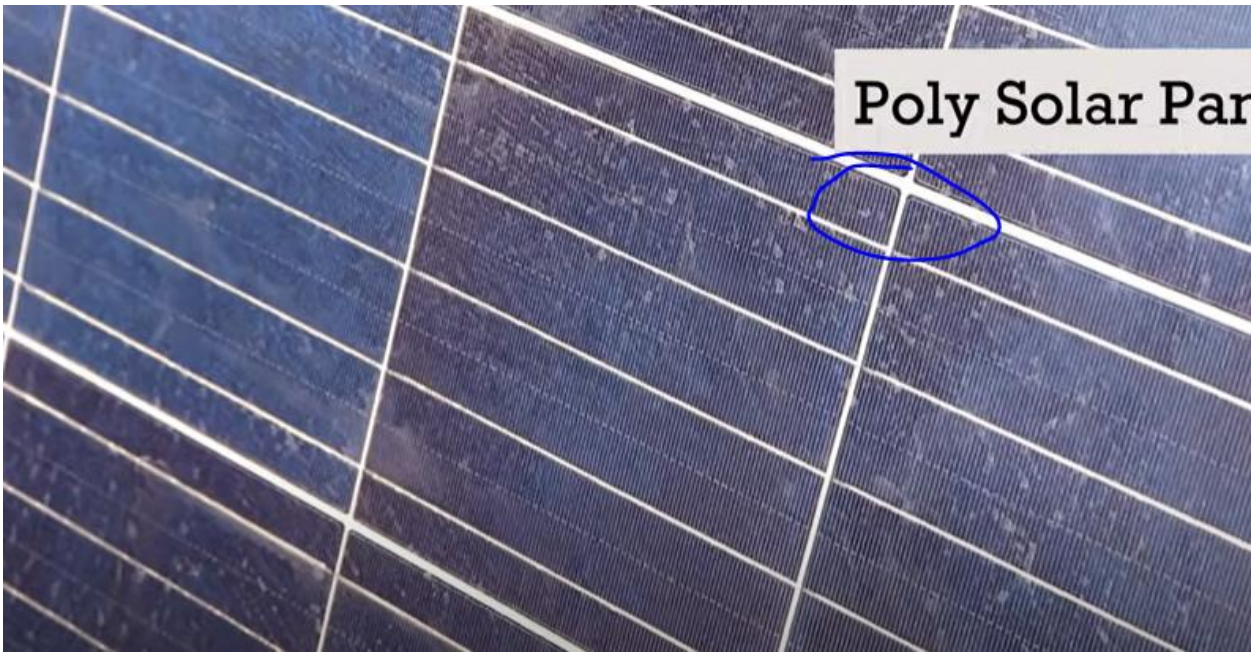
Rainy season

0.21 A for poly Isc

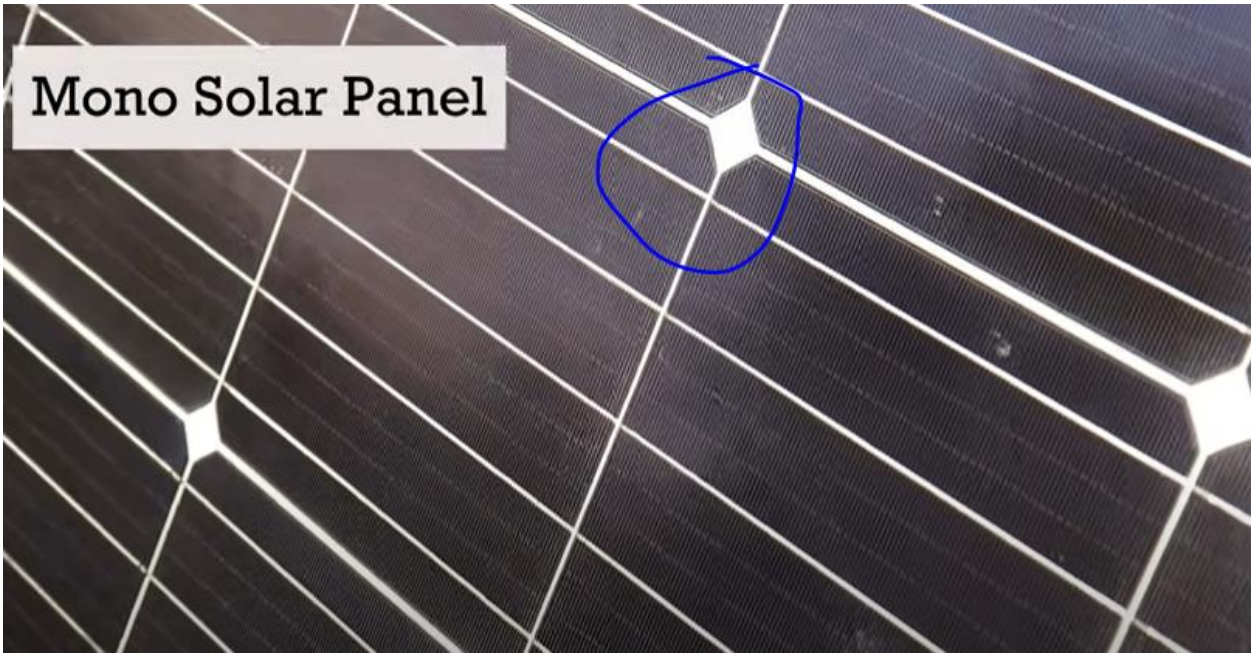
0.21 A for mono Isc

# Half Cut mono Vs Mono Vs Poly Solar Panel

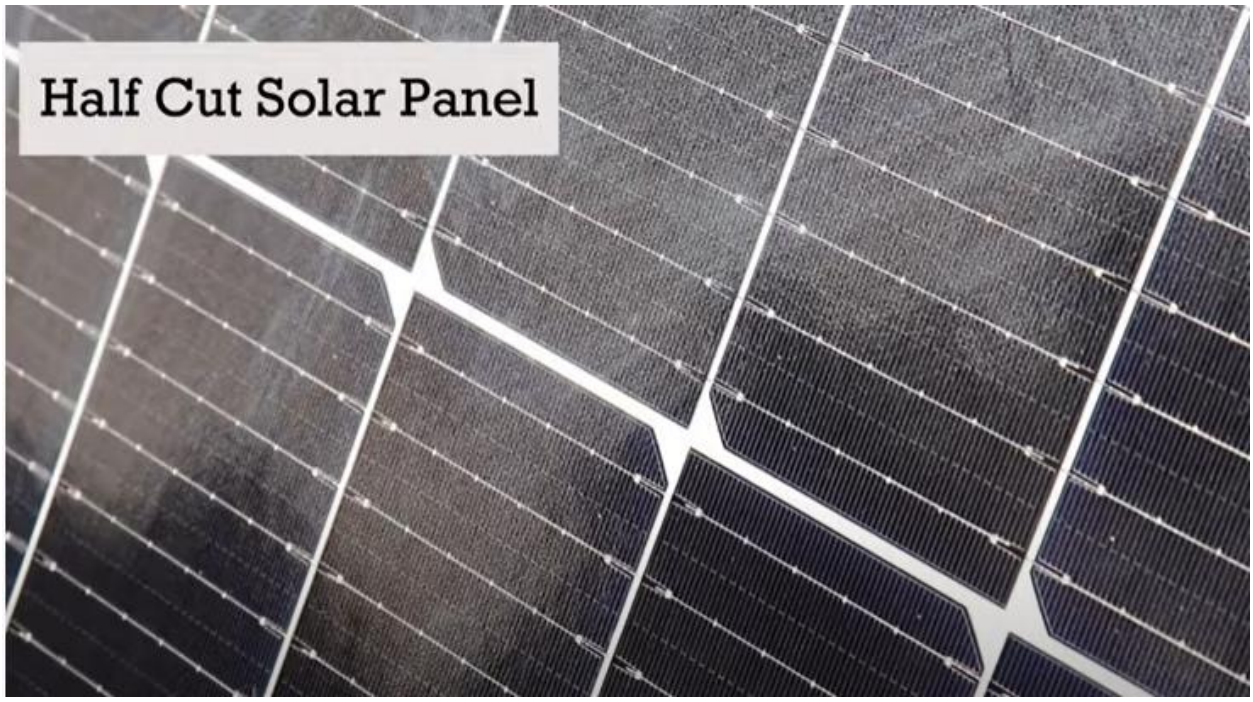

440W half cut mono vs 375W mono vs 270W poly (half cut & mono same size, poly less size)



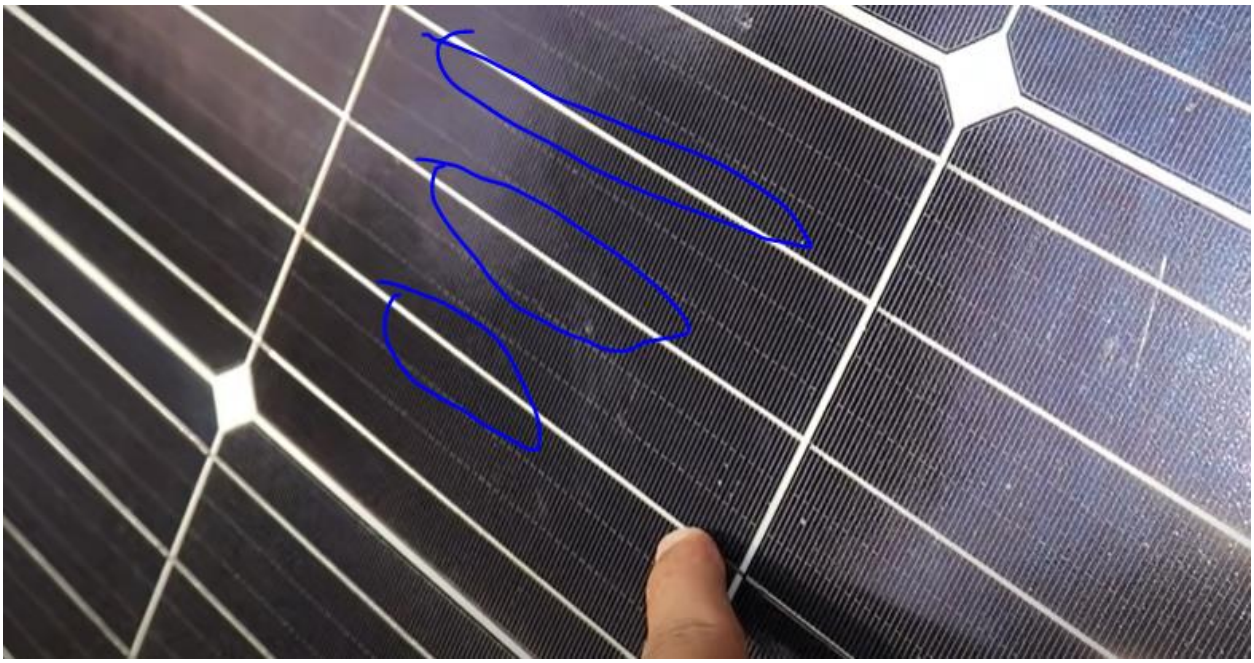

Poly corner square shape

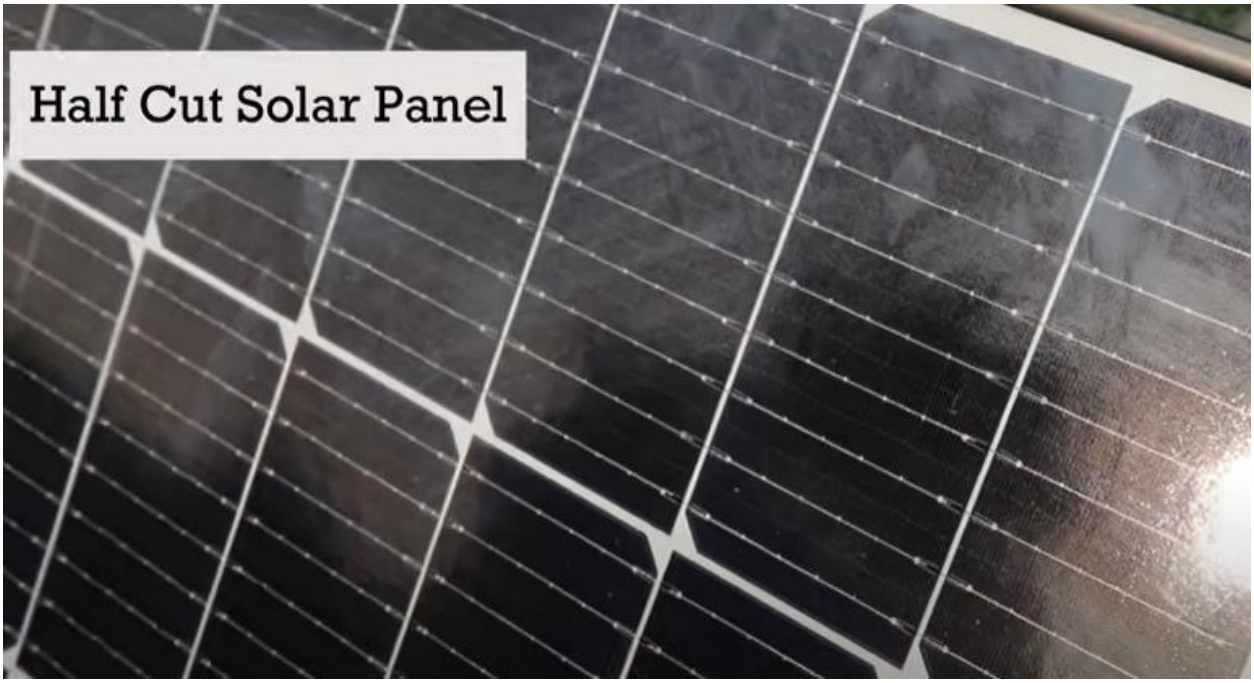



Mono diamond shape corner

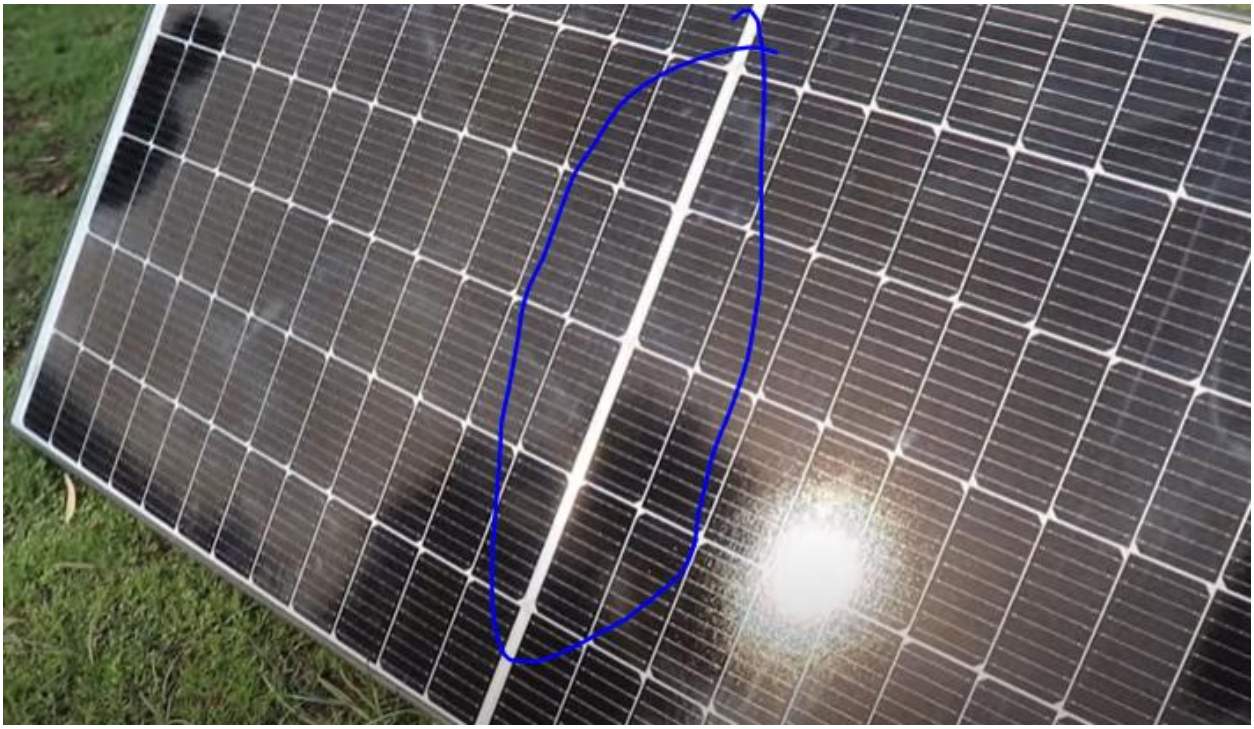



Half cut mono

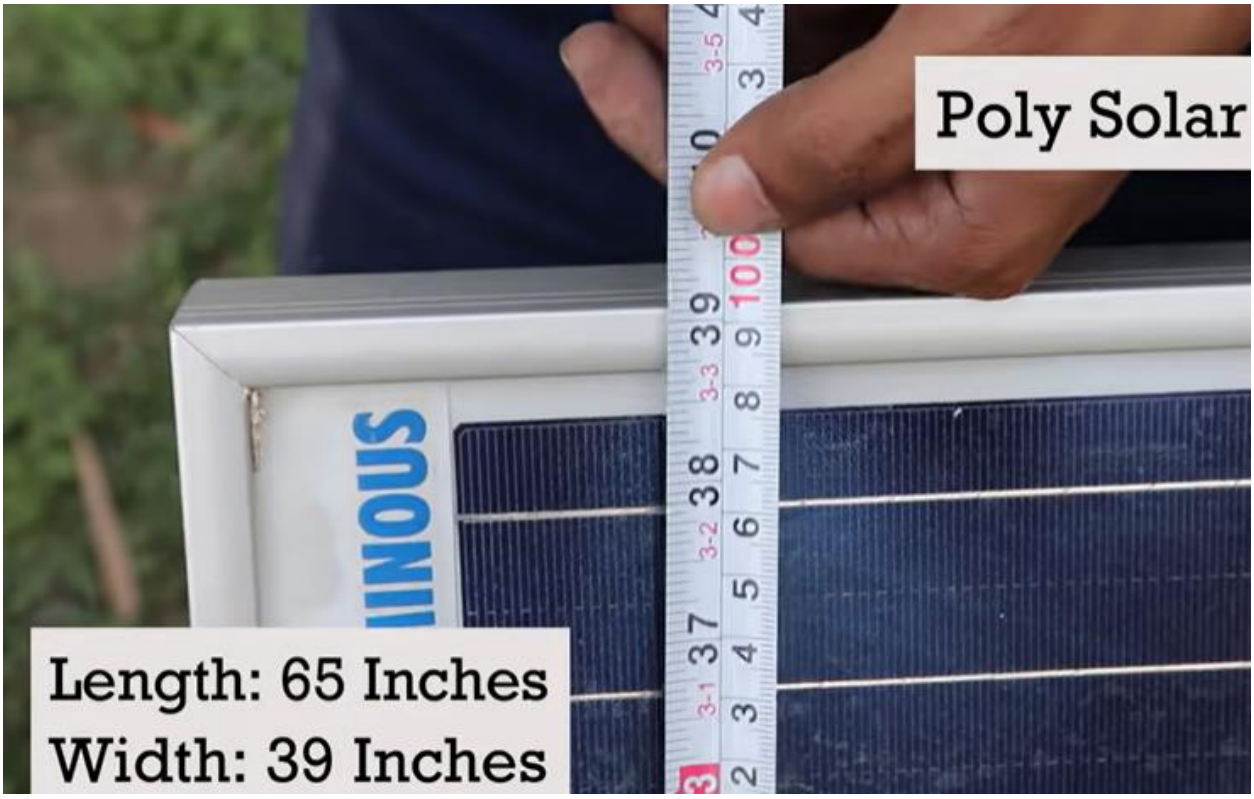


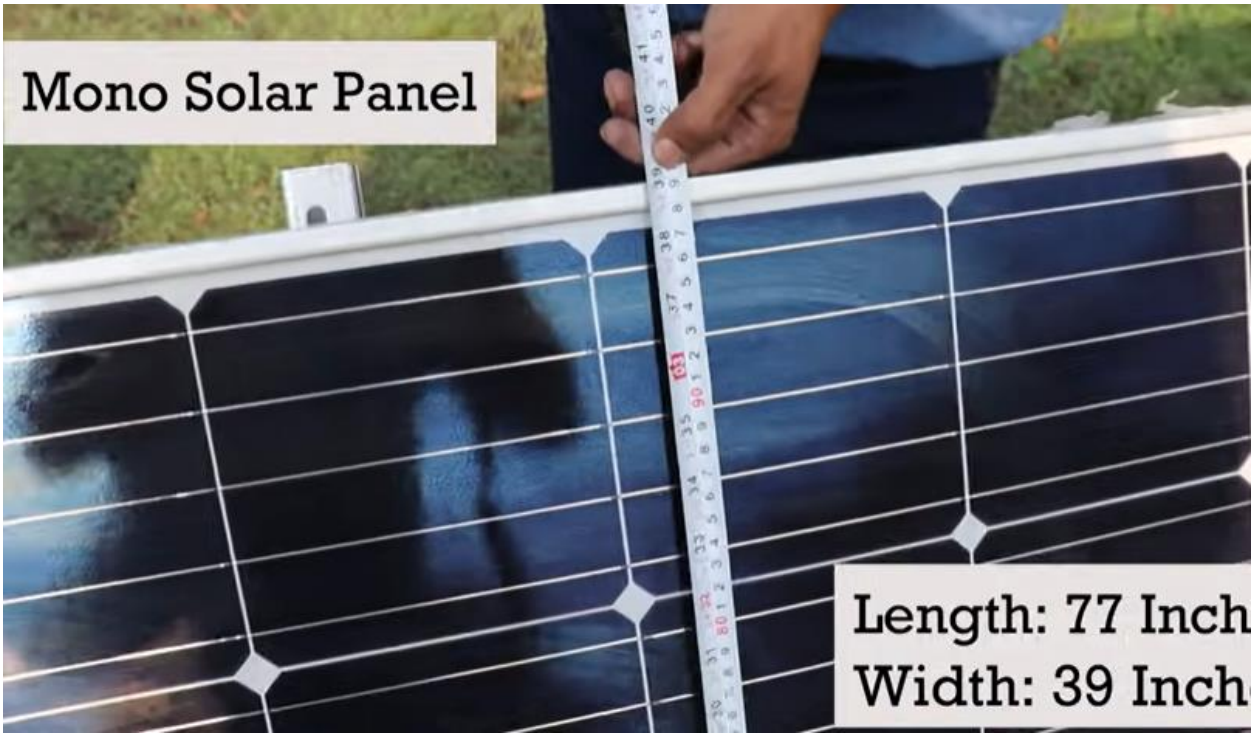


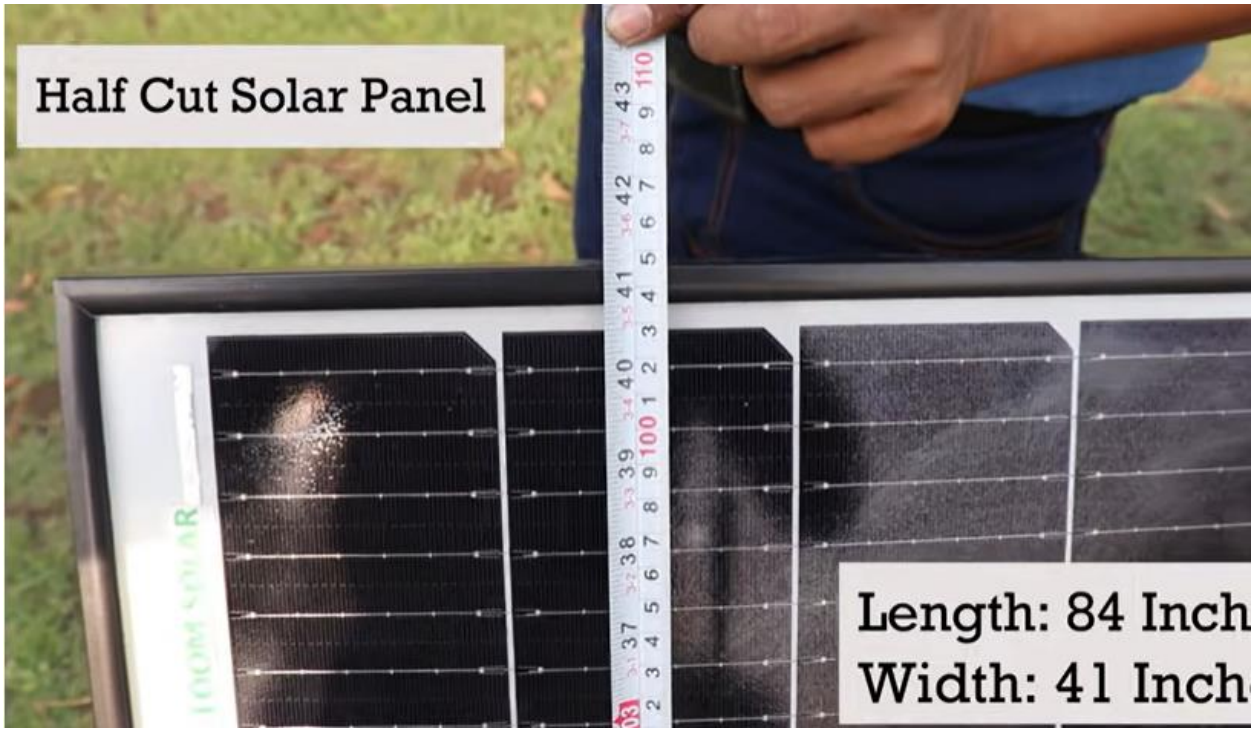

5 Bus bars in 1 cell in poly mono, 9 bus bars in half cut mono (more I flow, shadow impact less due to not all cells in series)

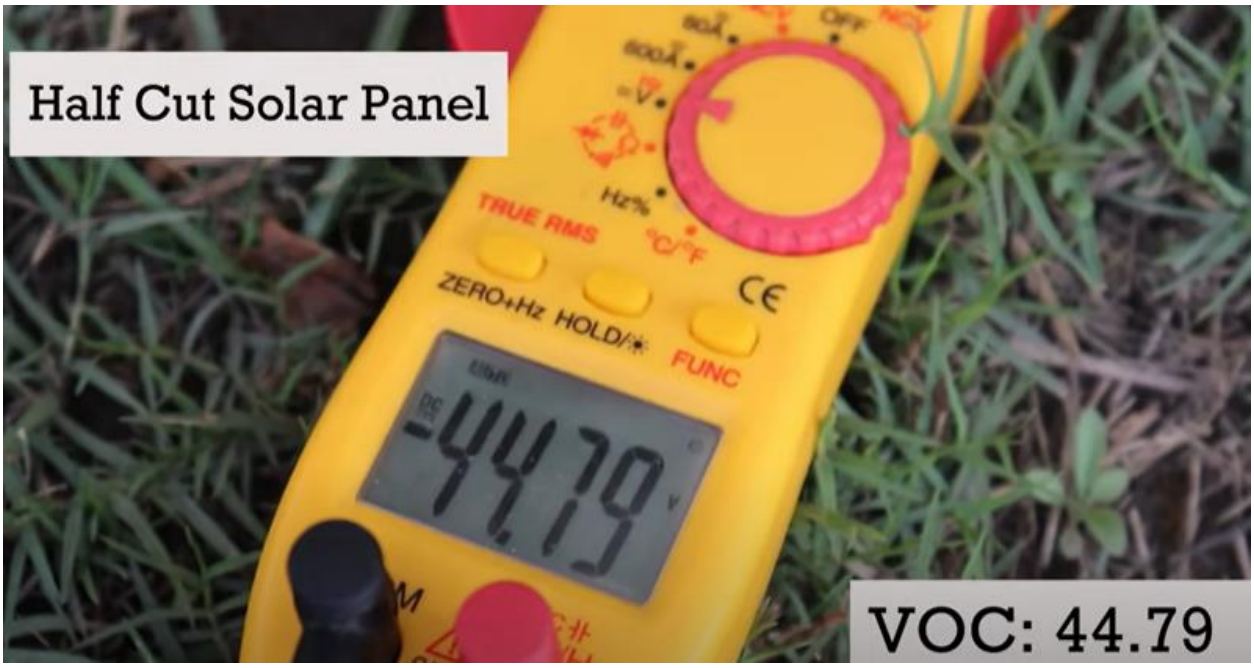


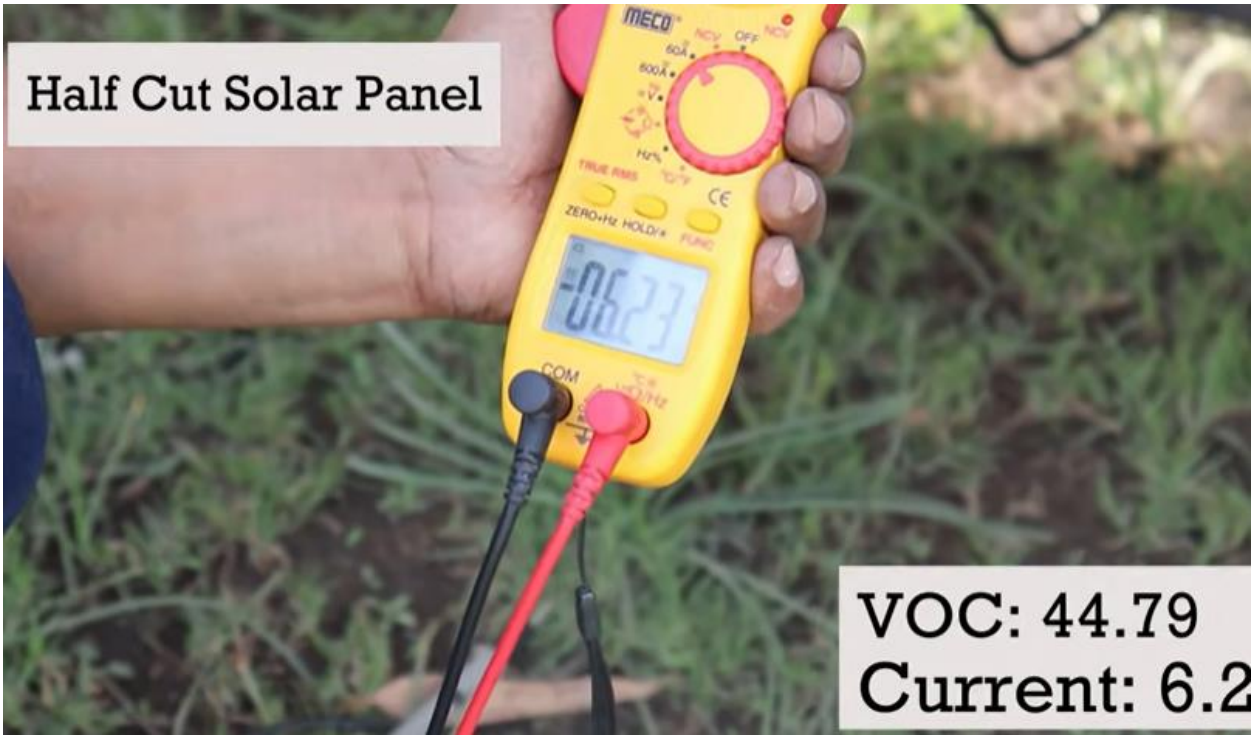
Two half cut panels

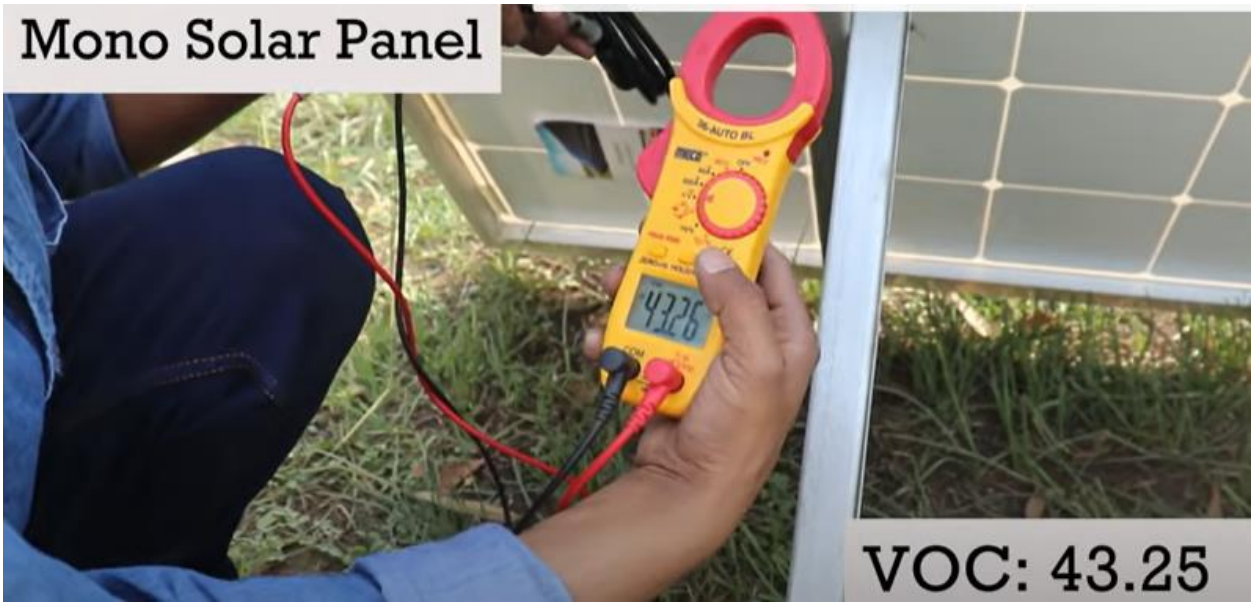

Poly Solar
Length: 65 Inches
Width: 39 Inches

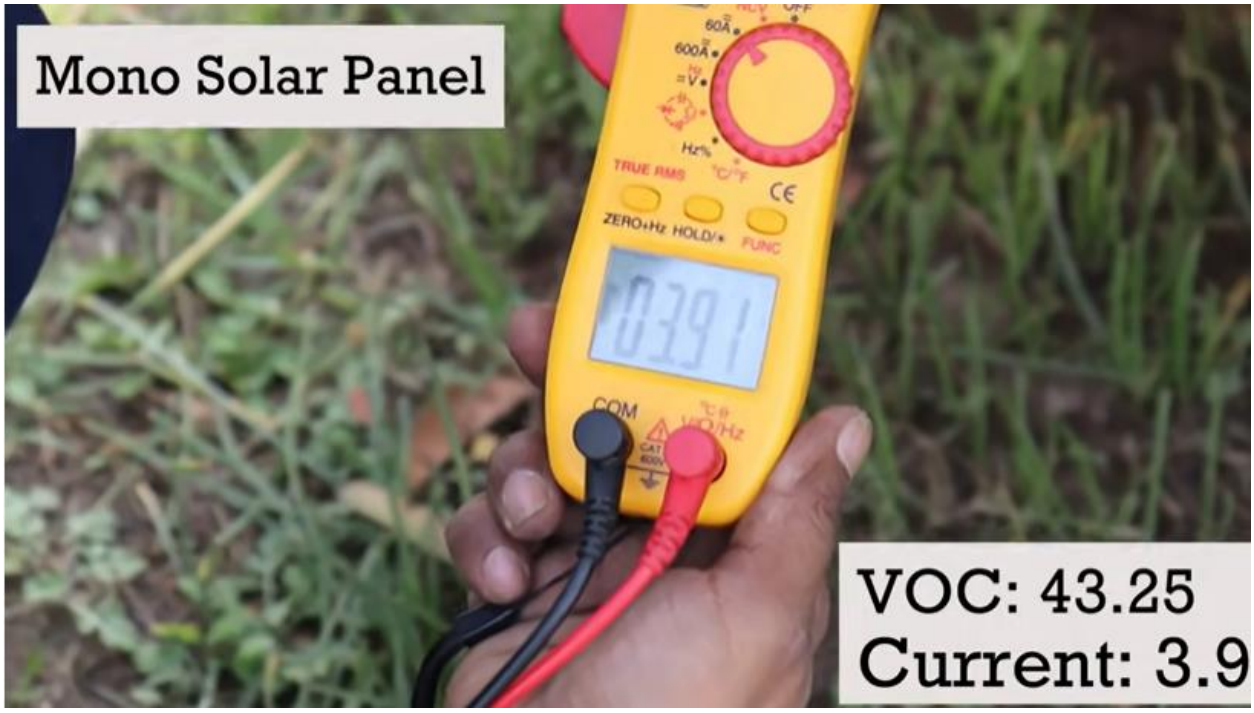

Mono Solar Panel
Length: 77 Inch
Width: 39 Inch


Half Cut Solar Panel
Length: 84 Inch
Width: 41 Inch

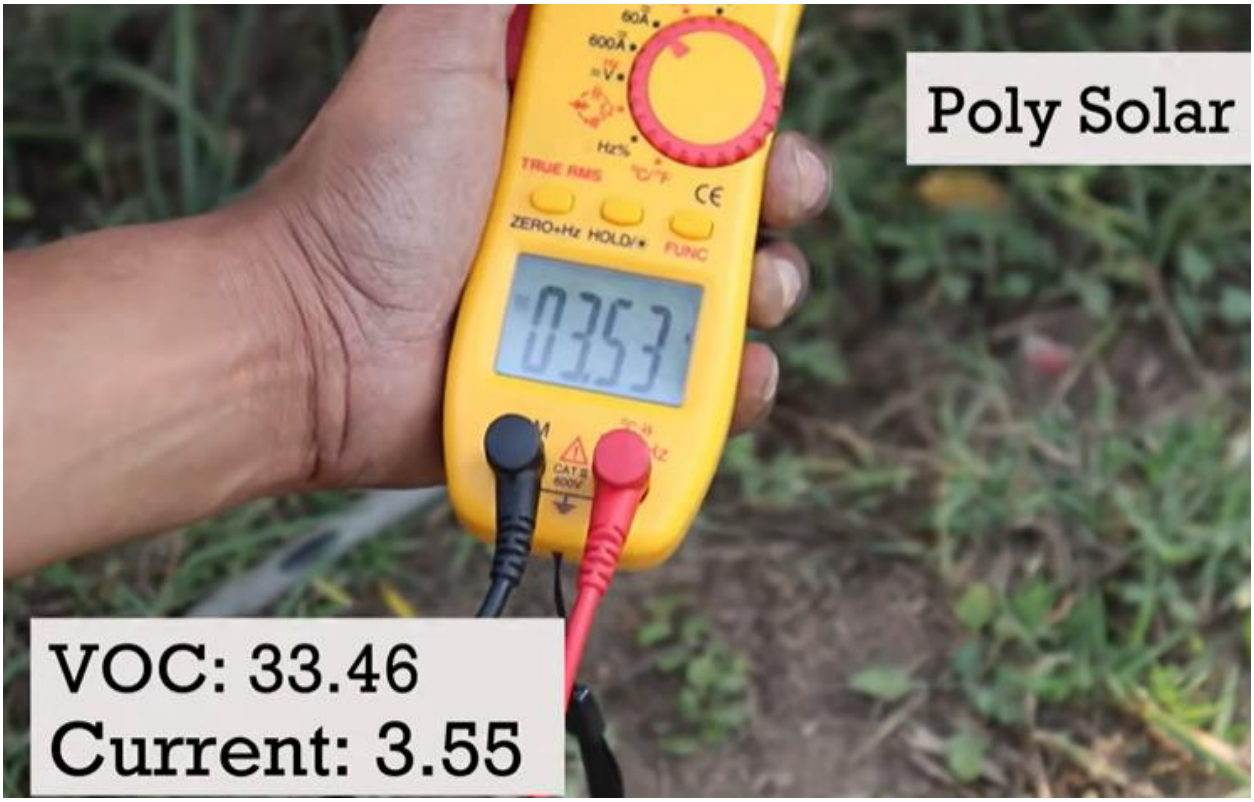

Half Cut Solar Panel
TRUE RMS
ZERO+Hz HOLD/
FUNC
44.79
VOC: 44.79


Half Cut Solar Panel
MECO
ZERO+Hz HOLD/+
VOC: 44.79
Current: 6.2

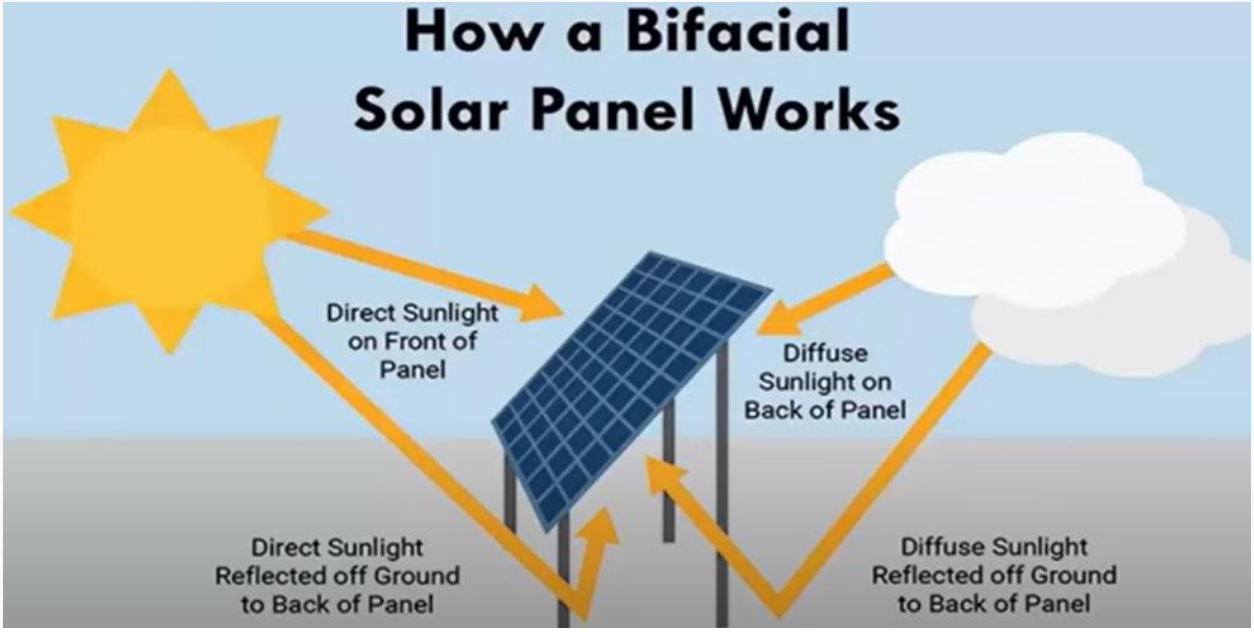

Mono Solar Panel
VOC: 43.25

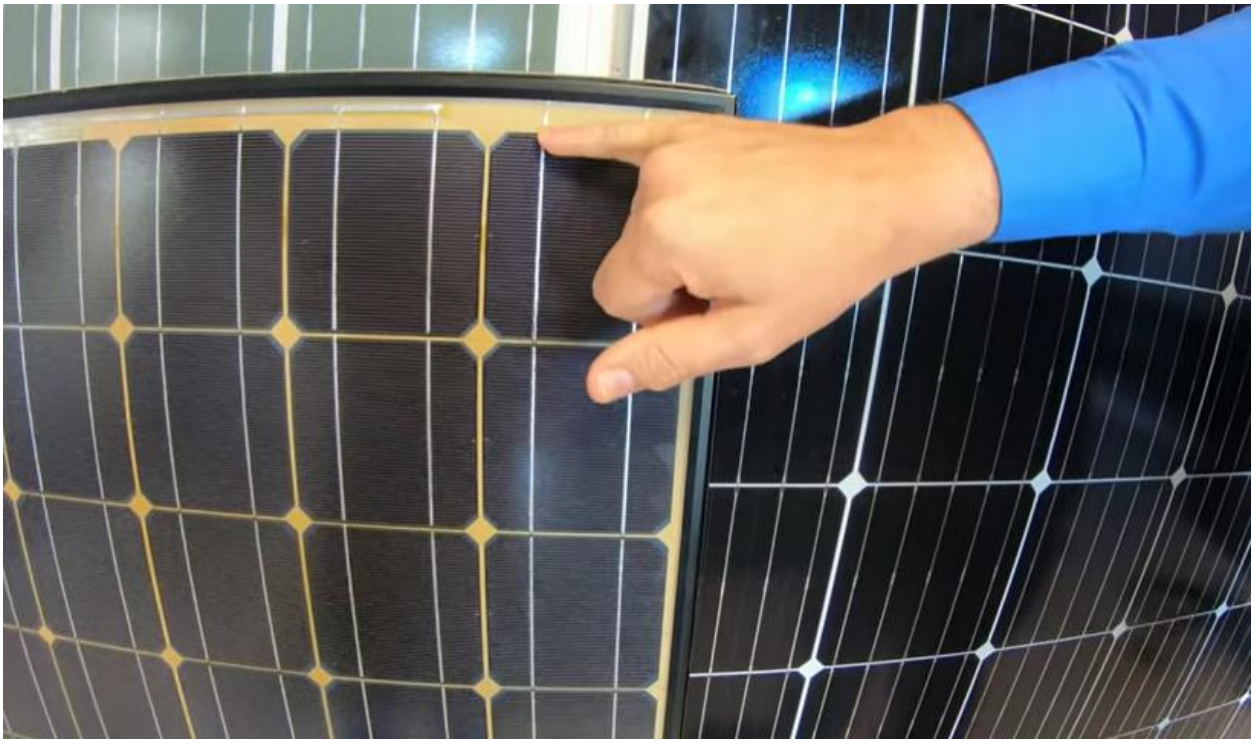

Mono Solar Panel
TRUE RMS
ZERO+Hz HOLD/•
FUNC
COM
VOC: 43.25
Current: 3.9

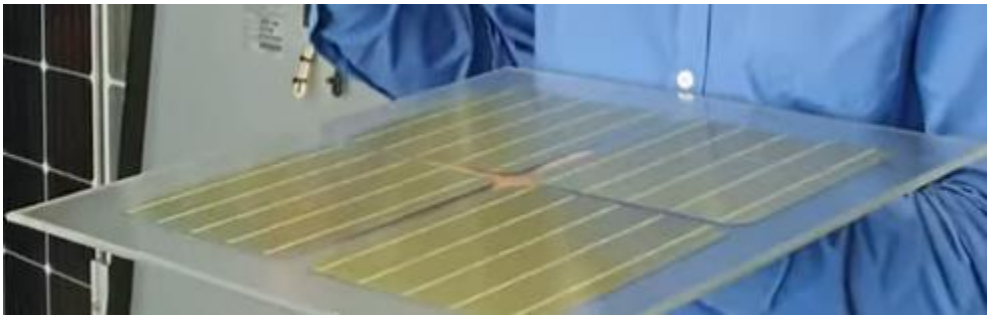

Poly Solar
TRUE RMS
ZERO+Hz HOLD/•
FUNC
COM
VOC: 33.46

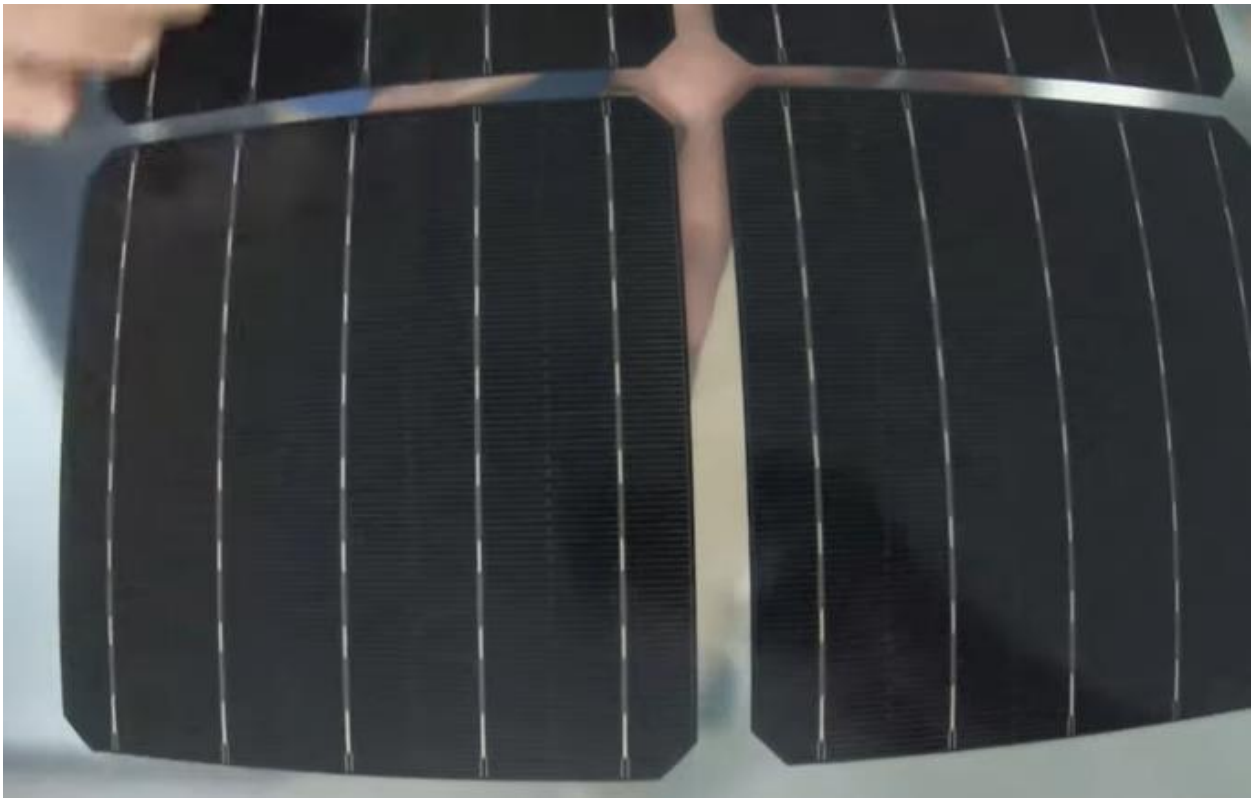



Mono Double Glass Bifacial Solar Panels









More bus bars more efficiency

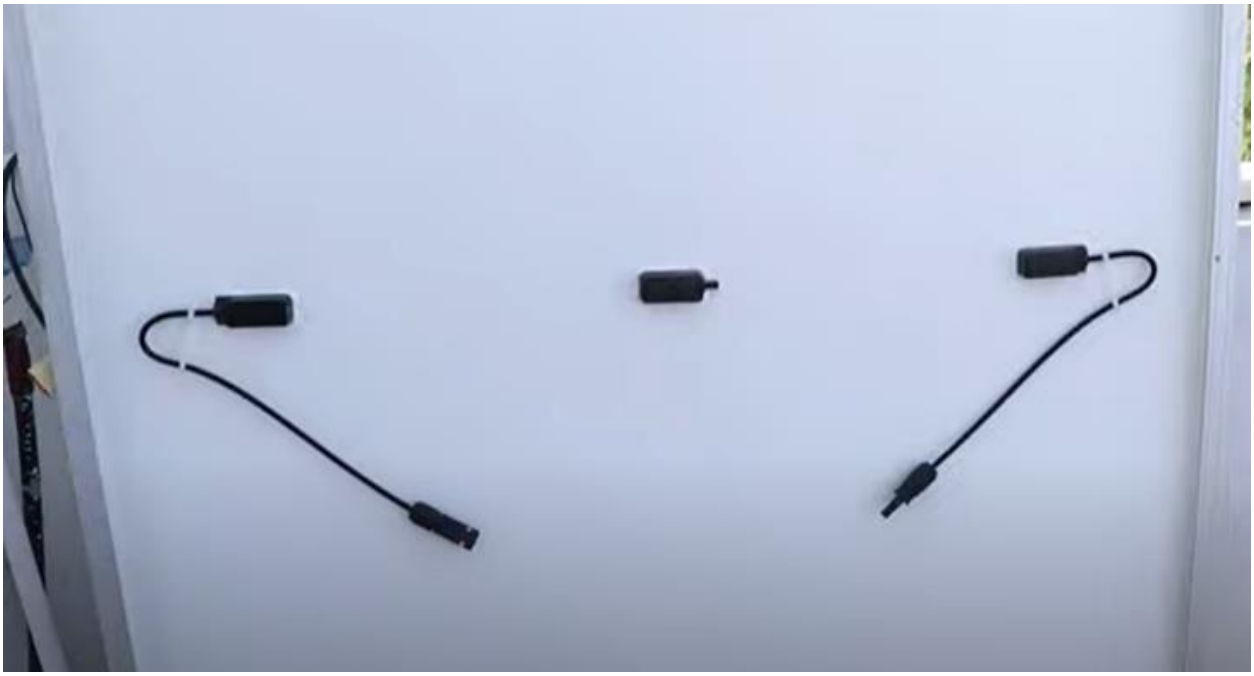
# Canadian Solar 535 W Bifacial Double glass Mono PERC halfcut




Bcz Normal panel backside Al sheet, its glass (life 30 years, 12 years warranty, HV Low current design, 49V, 13A, compatiable with all market inverters hybrid inverters, 525-540W) Longi same two panels as compared to 1 mono, Rs 49/W


Others 20 or 19%


Others 28 kg

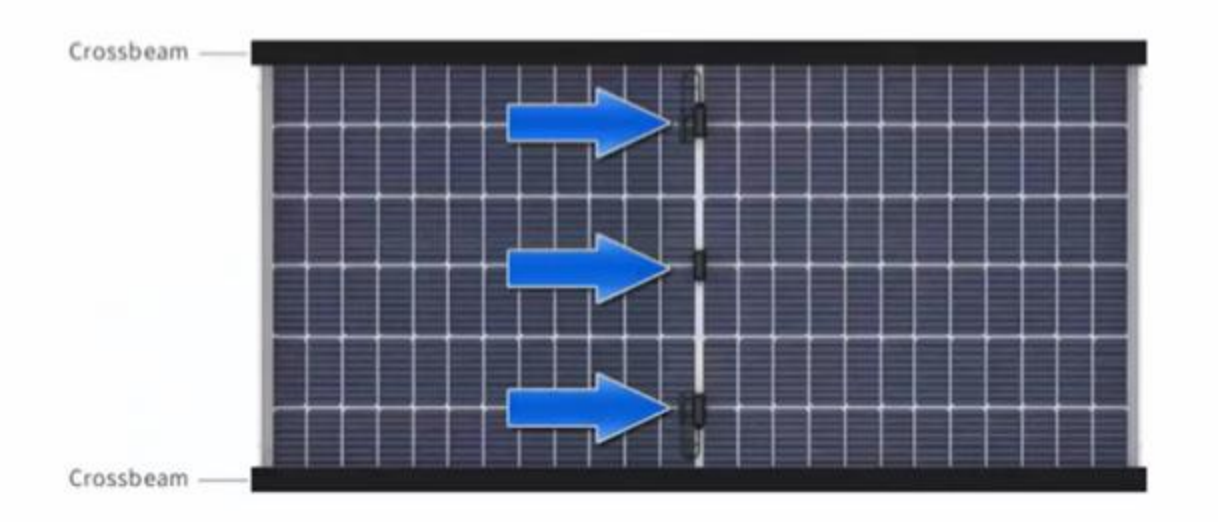
Left to right: -ve, two half cut parallel junction point, +ve

Power loss 25% less than others

3 junction box backside


4mm cable, sound Al structure

Hard




3 split junction box, IP-68 standard weather proof

Longi data sheet

- Based on M10-182mm wafer, best choice for ultra-large power plants
- Advanced module technology delivers superior module efficiency
  - M10 Gallium-doped Wafer
  - Smart Soldering
  - 9-busbar Half-cut Cell
- Globally validated bifacial energy yield
- High module quality ensures long-term reliability

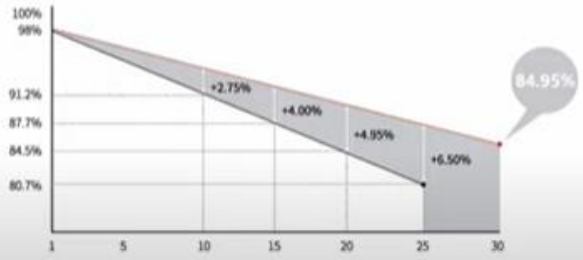
12 12-year Warranty for Materials and Processing

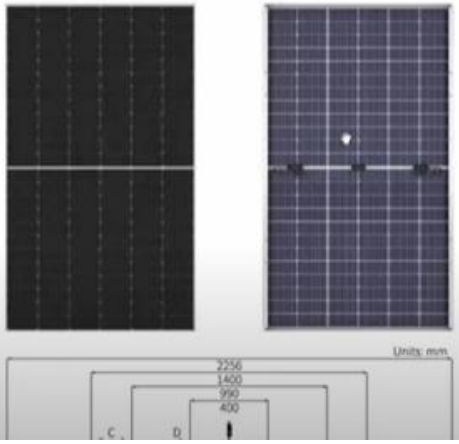
30 30-year Warranty for Extra Linear Power Output

| 21.3% | 0~+5W | <2% | 0.45% | HALF-CELL |
|---|---|---|---|---|
| MAX MODULE EFFICIENCY | POWER TOLERANCE | FIRST YEAR POWER DEGRADATION | YEAR 2-30 POWER DEGRADATION | Lower operating temperature |

## Additional Value

30-Year Power Warranty






## Mechanical Parameters

## Mechanical Parameters

| | |
|---|---|
| Cell Orientation | 144 (6×24) |
| Junction Box | IP68, three diodes |
| Output Cable | 4mm², +400, -200mm/±1400mm<br>length can be customized |
| Glass | Dual glass, 2.0mm coated tempered glass |
| Frame | Anodized aluminum alloy frame |
| Weight | 32.3kg |
| Dimension | 2256×1133×35mm |
| Packaging | 31pcs per pallet / 155pcs per 20' GP / 620pcs per 40' HC |

**Electrical Characteristics** STC : AM1.5 1000W/m² 25°C NOCT : AM1.5 800W/m² 20°C 1m/s Test uncertainty for Pmax: ±3%

| Module Type | LR5-72HBD-525M | | LR5-72HBD-530M | | LR5-72HBD-535M | | LR5-72HBD-540M | | LR5-72HBD-545M | |
|---|---|---|---|---|---|---|---|---|---|---|
| Testing Condition | STC | NOCT | STC | NOCT | STC | NOCT | STC | NOCT | STC | NOCT |
| Maximum Power (Pmax/W) | 525 | 392.1 | 530 | 395.8 | 535 | 399.5 | 540 | 403.3 | 545 | 407.0 |
| Open Circuit Voltage (Voc/V) | 49.05 | 45.89 | 49.20 | 46.03 | 49.35 | 46.17 | 49.50 | 46.31 | 49.65 | 46.46 |
| Short Circuit Current (Isc/A) | 13.65 | 11.03 | 13.71 | 11.08 | 13.78 | 11.14 | 13.85 | 11.19 | 13.92 | 11.24 |
| Voltage at Maximum Power (Vmp/V) | 41.20 | 38.41 | 41.35 | 38.55 | 41.50 | 38.69 | 41.65 | 38.83 | 41.80 | 38.97 |
| Current at Maximum Power (Imp/A) | 12.75 | 10.21 | 12.82 | 10.27 | 12.90 | 10.33 | 12.97 | 10.39 | 13.04 | 10.44 |
| Module Efficiency(%) | 20.5 | | 20.7 | | 20.9 | | 21.1 | | 21.3 | |

## Operating Parameters

| | |
|---|---|
| Operational Temperature | -40°C ~ +85°C |
| Power Output Tolerance | 0 ~ +5 W |
| Voc and Isc Tolerance | ±3% |
| Maximum System Voltage | DC1500V (IEC/UL) |
| Maximum Series Fuse Rating | 30A |
| Nominal Operating Cell Temperature | 45±2°C |
| Protection Class | Class II |
| Fire Rating | UL type 29 |
| Bifaciality | 70±5% |

| Testing Condition | STC | NOCT | STC | NOCT | STC | NOCT | STC | NOCT | STC | NOCT |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximum Power (Pmax/W) | 525 | 392.1 | 530 | 395.8 | 535 | 399.5 | 540 | 403.3 | 545 | 407.0 |
| Open Circuit Voltage (Voc/V) | 49.05 | 45.89 | 49.20 | 46.03 | 49.35 | 46.17 | 49.50 | 46.31 | 49.65 | 46.46 |
| Short Circuit Current (Isc/A) | 13.65 | 11.03 | 13.71 | 11.08 | 13.78 | 11.14 | 13.85 | 11.19 | 13.92 | 11.24 |
| Voltage at Maximum Power (Vmp/V) | 41.20 | 38.41 | 41.35 | 38.55 | 41.50 | 38.69 | 41.65 | 38.83 | 41.80 | 38.97 |
| Current at Maximum Power (Imp/A) | 12.75 | 10.21 | 12.82 | 10.27 | 12.90 | 10.33 | 12.97 | 10.39 | 13.04 | 10.44 |
| Module Efficiency(%) | 20.5 | | 20.7 | | 20.9 | | 21.1 | | 21.3 | |

**Operating Parameters**

| | |
|---|---|
| Operational Temperature | -40°C ~ +85°C |
| Power Output Tolerance | 0 ~ +5 W |
| Voc and Isc Tolerance | ±3% |
| Maximum System Voltage | DC1500V (IEC/UL) |
| Maximum Series Fuse Rating | 30A |
| Nominal Operating Cell Temperature | 45±2°C |
| Protection Class | Class II |
| Fire Rating | UL type 29 |
| Bifaciality | 70±5% |

**Mechanical Loading**

| | |
|---|---|
| Front Side Maximum Static Loading | 5400Pa |
| Rear Side Maximum Static Loading | 2400Pa |
| Hailstone Test | 25mm Hailstone at the speed of 23m/s |

**Temperature Ratings** (STC)

| | |
|---|---|
| Temperature Coefficient of Isc | +0.050%/°C |
| Temperature Coefficient of Voc | -0.284%/°C |
| Temperature Coefficient of Pmax | -0.350%/°C |

www.jinkosolar.com

Solar
JinKO
Building Your Trust in Solar

# Tiger Pro 72HC-TV

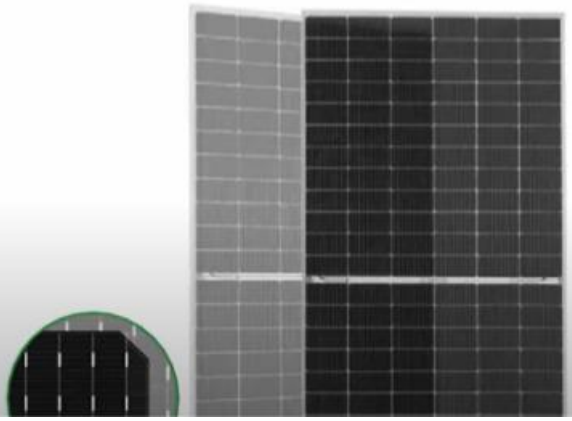
## 525-545 Watt

BIFACIAL MODULE WITH
TRANSPARENT BACKSHEET

**P-Type**

Positive power tolerance of 0~+3%

IEC61215(2016), IEC61730(2016)



Less costly but backside plastic sheet, not dual glass. Front glass only

# Waaree 445 Watt 24 V Mono Perc Half-Cut 144 Cells Solar Panel


Mono
PERC
Half-Cell


Half-Cut
Mono


72 cells

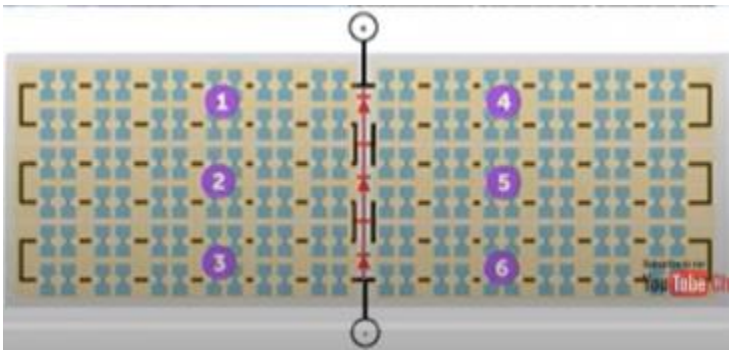


6.5feet x 3.5 feet 23.5 kg

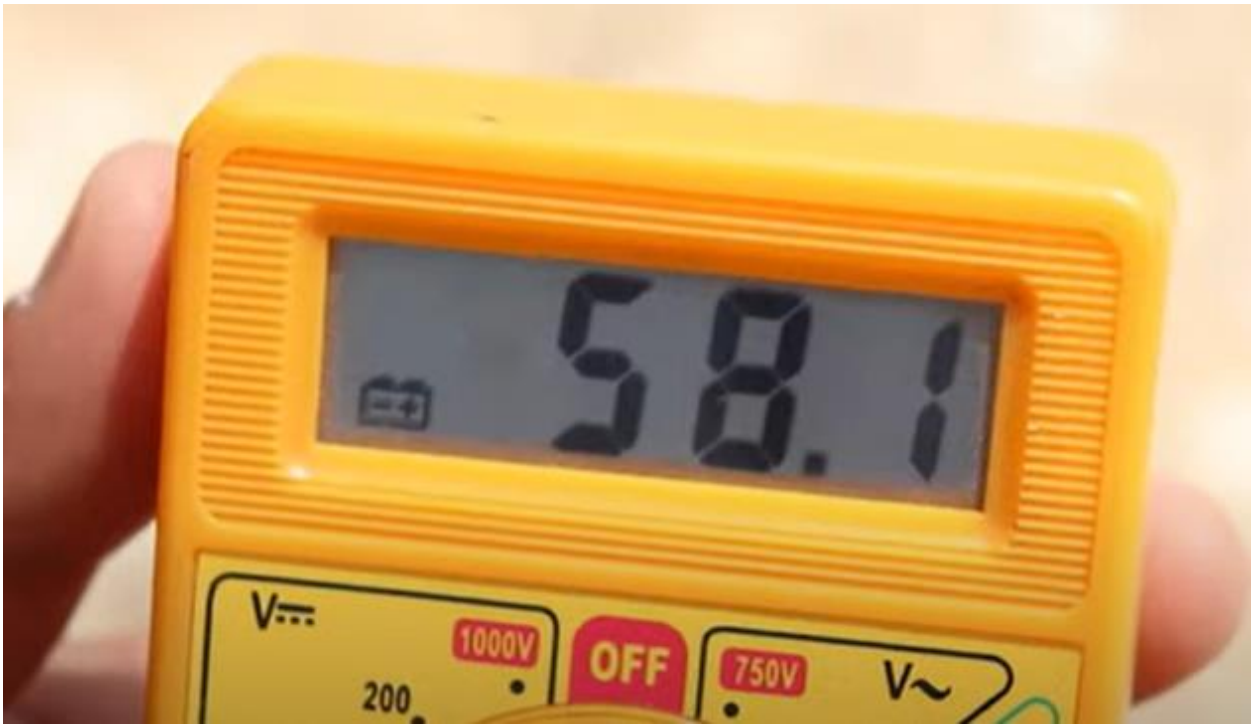
front glass: 3.2mm low iron ARC coating, frame Al

10y manufacturer warranty

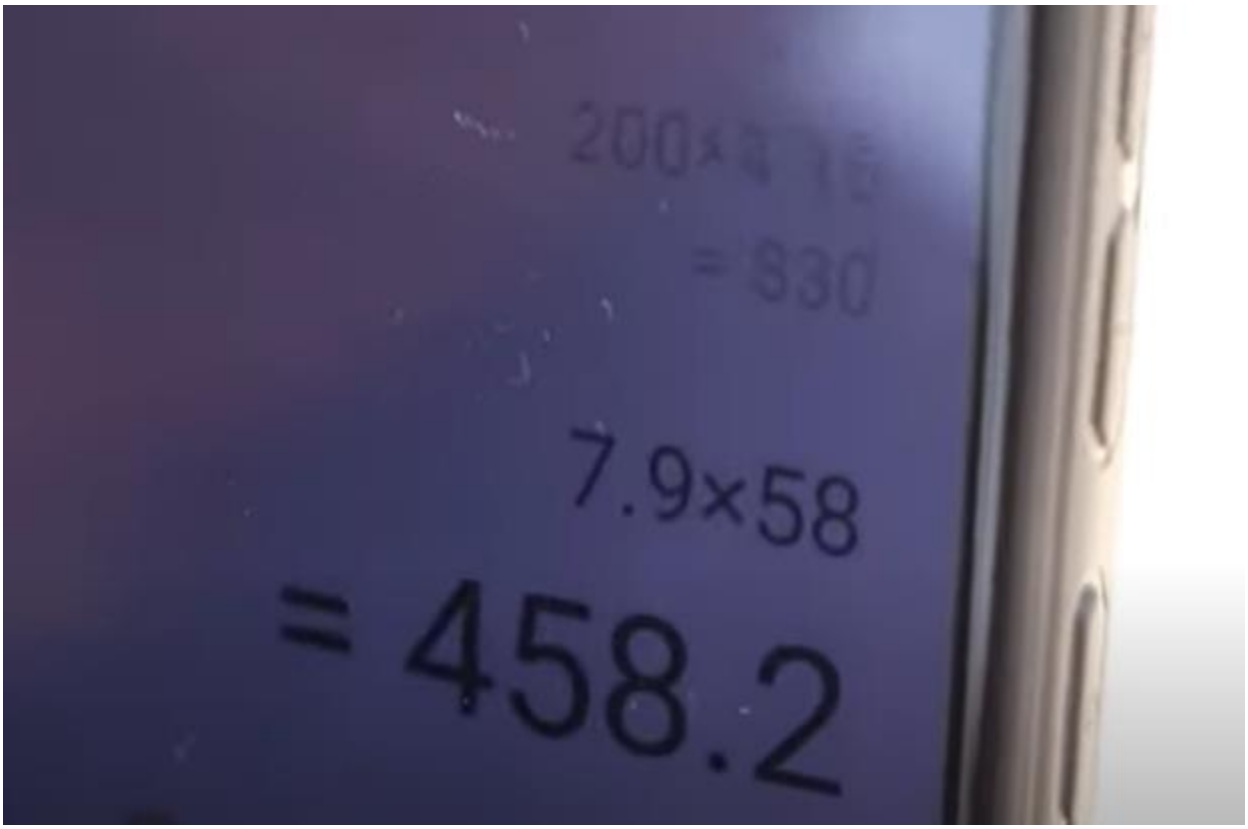
25 y performance warranty




| WSMD-445 | |
|---|---|
| Maximum Power (Pmax) | 445.0 W |
| Open Circuit Voltage (Voc) | 49.86 V |
| Short Circuit Current (Isc) | 11.41 A |
| Maximum Power Voltage(Vmp) | 41.19 V |
| Maximum Power Current(Imp) | 10.81 A |
| Maximum System Voltage | 1500 V DC |
| Weight | 23.5 Kg |
| Dimension | 2094*1038 mm |
| Application Class | A |
| Maximum Series Fuse Rating | 20 A |

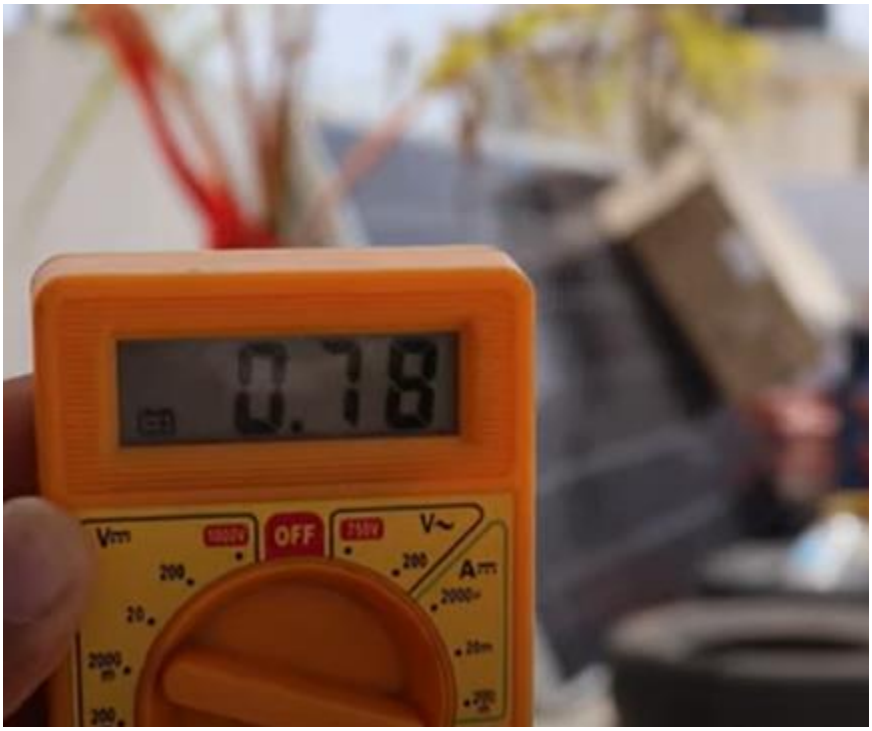

58.1
V⎓
1000V
200
OFF
750V
V~


1.92
V⎓
1000V
200
20
2000
m
OFF
750V
V~
200


200×
=830
7.9×58
=458.2


ANT
ESPORTS
Glass

Shadowing

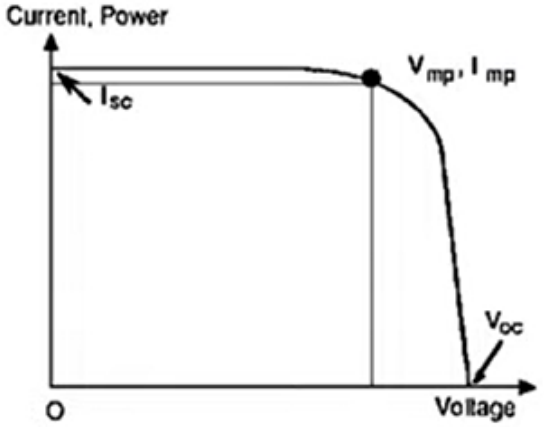
Mono less current on shadow


Without shadow

More flexible

# IV Curve of a Solar Cell

- IV Curve → I stands for Current, V stands for Voltage. Shows the relationship of current to voltage in a solar cell



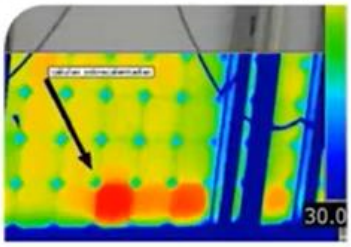

# Photovoltaic Facts

- PV Panels produce DC Power
- PV Panels can be used to charge batteries directly
- If AC power is needed, you must use an inverter to convert the DC to AC.

# PV Module PM Activities

| Activity | Interval | Service Provider |
|---|---|---|
| Clean PV modules with plain water or mild dishwashing detergent. Do not use hard brushes, any types of solvents, abrasives, or harsh detergents | Condition dependent | Module cleaners |
| Snow Removal | Condition dependent | Module cleaners |
| Dust: Agricultural/Industrial/ Pollen cleaning | Condition dependent | Module cleaners |
| Use infrared camera to inspect for hot spots; bypass diode failure | Annual | PV Module/ Array Specialist |

Hot spots may result in a voltage reduction




# PV Module PM Activities

| Activity | Interval | Service Provider |
|---|---|---|
| PV module torque check & visual inspection | 5 years | PV Module/ Array Specialist |
| Racking torque check and inspection | 5 years | PV Module/ Array Specialist |
| Inspection: corrosion and encapsulate yellowing | Annual | PV Module/ Array Specialist |
| Galvanization inspection | Annual | PV Module/ Array Specialist |

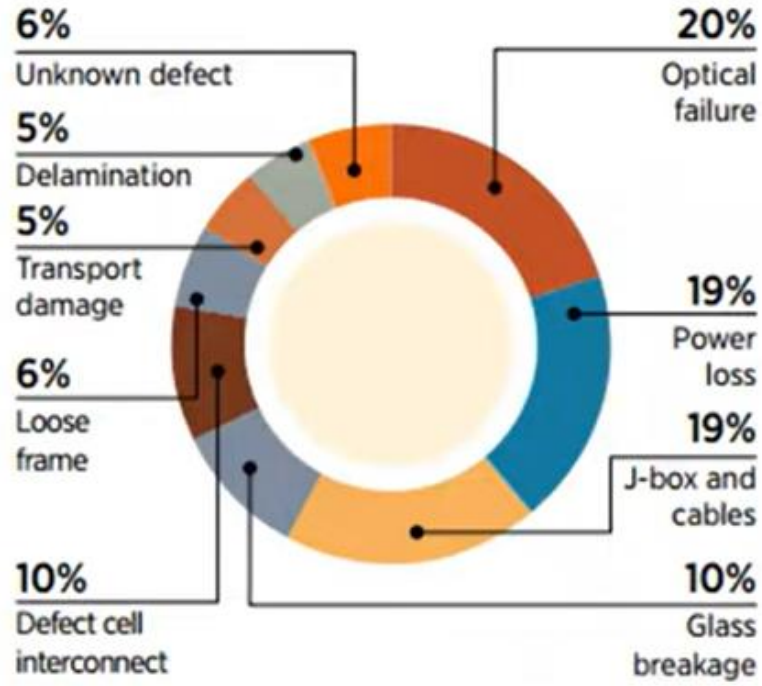
# Cleaning Panels

- Proper cleaning annually can make panels over 20% more efficient!
- Recommended to use official panel cleaning services


# Before Installation: Check for Defects

- Manufacturing defects include:
  - Defective frames
  - Yellowing
  - Defective connection boxes
  - Broken glass
  - Water penetration in panel

## Failure Rates According to Customer Complaints




*Based on IEA-PVPS (2014a)*

# AC Wiring PM Activities

| Activity | Interval | Service Provider |
|---|---|---|
| Inspect electrical boxes for corrosion or intrusion of water or insects. Seal boxes if required. | Annual | Electrician |
| Check position of disconnect switches and breakers. | Annual | Electrician |
| Exercise operation of all protection devices. | Annual | Electrician |
| AC disconnect box inspection | Annual | Electrician |
| Re-torque all electrical connections on AC side of system | Annual | Electrician |

# PV Array PM Activities, cont'd

| Activity | Interval | Service Provider |
|---|---|---|
| Remove bird nests from array and rack area | Annual | Vermin Removal |
| Nesting vermin removal, nesting vermin prevention | Annual | Vermin Removal |

# PV Array PM Activities

| Activity | Interval | Service Provider |
|---|---|---|
| Test open circuit voltage of series strings of modules | Annual | Journeyman electrician |
| Check all hardware for signs of corrosion, and remove rust and repaint if necessary. | Annual | Mechanical Technician |
| Walk through each row of the PV array and check the PV modules for any damage. Report any damage to rack and damaged modules for warranty replacement. Note location and serial number of questionable modules. | Annual | PV Module/ Array Specialist |
| Inspect ballasted, non-penetrating mounting system for abnormal movement | Annual | Mechanic |
| Determine if any new objects, such as vegetation growth, are causing shading of the array and move them if possible. Remove any debris from behind collectors and from gutters. | Annual | Tree Trimming |

# Roof Mount Considerations

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

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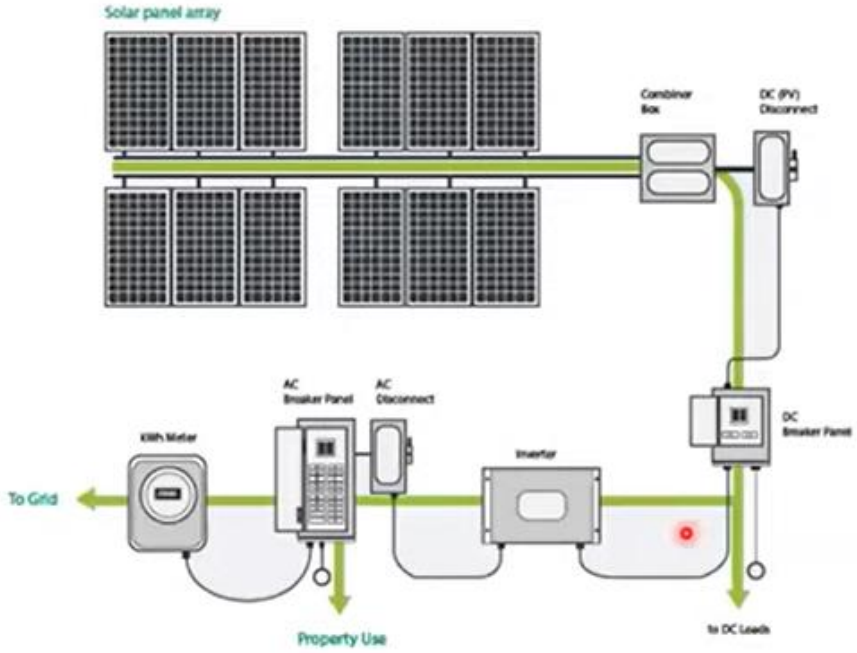
- simple and cheap to install
- offer no flexibility in the orientation of your solar panel
- can only support small photovoltaic units.

# Repair Costs for Different Types of Roofs

| Roofing Type | Repair Materials ($/m²) | Repair Labor (h/m²) |
|---|---|---|
| Thermoplastic Polyolefin (TPO) | $20.00 | 1.0 |
| Ethylene Propylene Diene Monomer (EPDM) | $20.00 | 1.0 |
| PolyVinyl Chloride (PVC) | $20.00 | 1.0 |
| Built-up, Bituminous | $15.00 | 1.5 |
| Styrene-Butadiene-Styrene (SBS) | $20.00 | 1.0 |
| Asphalt Shingle | $15.00 | 1.0 |
| Composite Shingle | $25.00 | 1.0 |
| Wood Shingle | $40.00 | 2.0 |
| Slate | $50.00 | 1.0 |
| Metal Roof | $50.00 | 0.5 |
| Tile | $50.00 | 1.0 |

* Large variations can exist based on size, site access, location, and labor markets.

# The PV System – Other Components to Consider!



# Solar Cell Characteristics Experiment

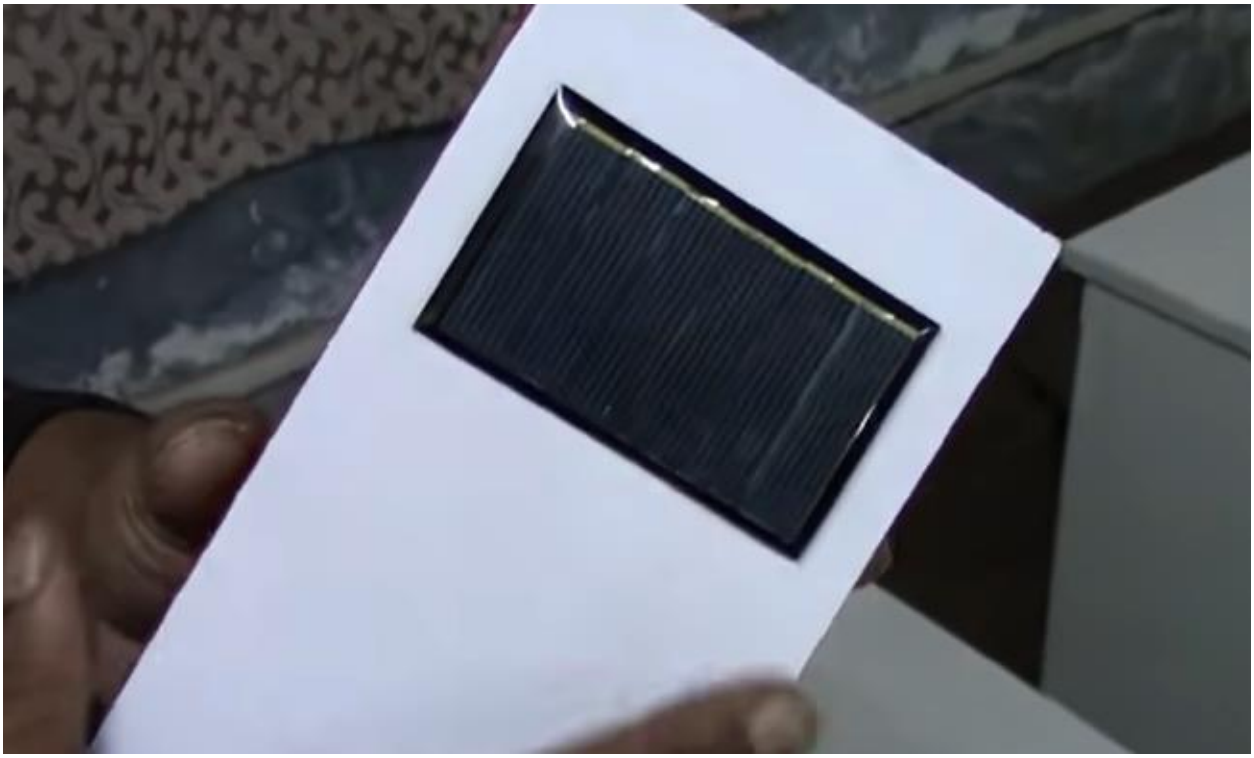
A 100 W lamp is arranged over the solar panel such that light falls on it at normal. The lamp is placed at maximum distance and is switched on.

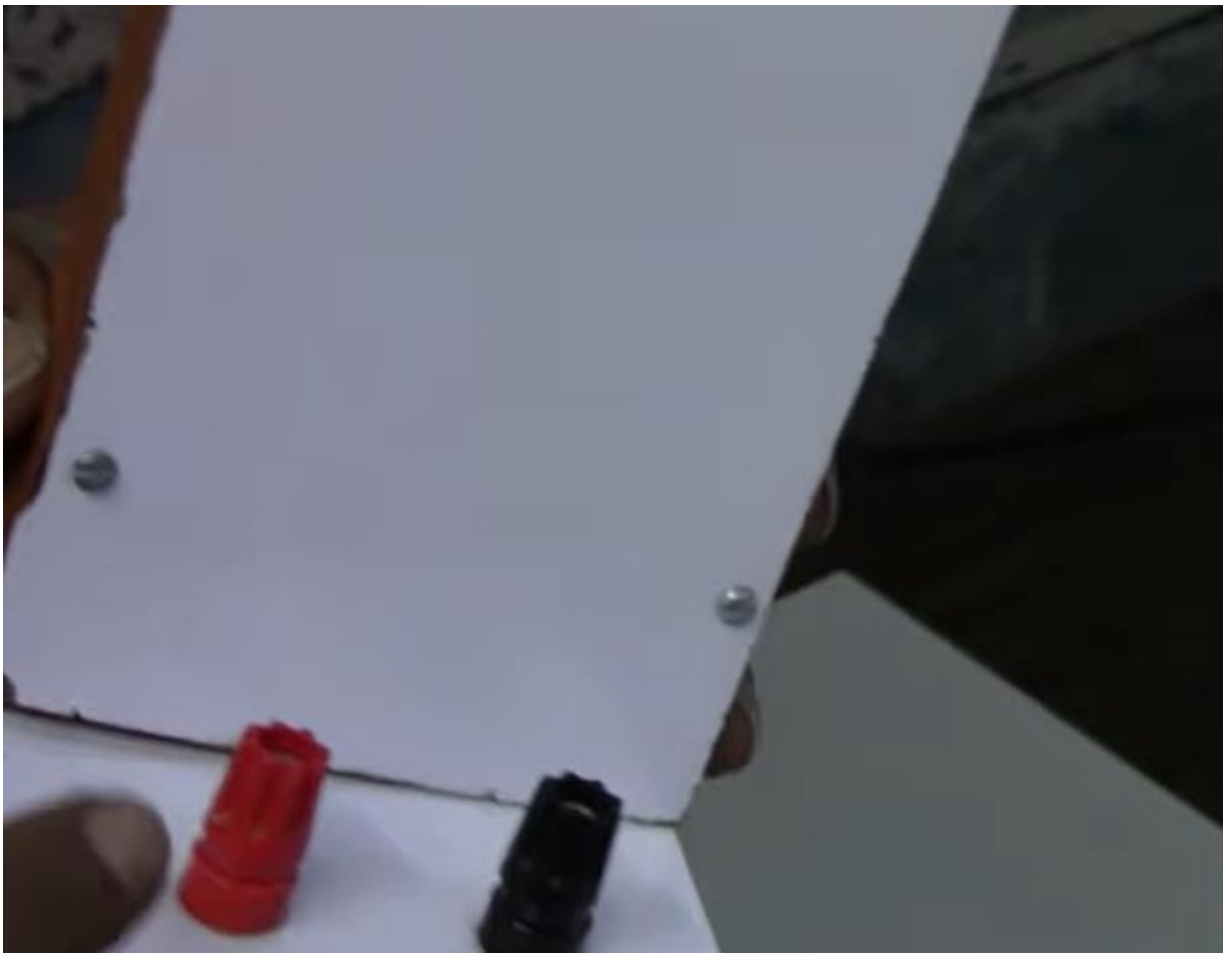

Now ,note down the voltage and the position of the solar cell and take readings by changing the distance of solar cell.


SOLAR CELL CHARACTERISTICS APPARATUS
V
mA
SOLAR CELL
SET RL

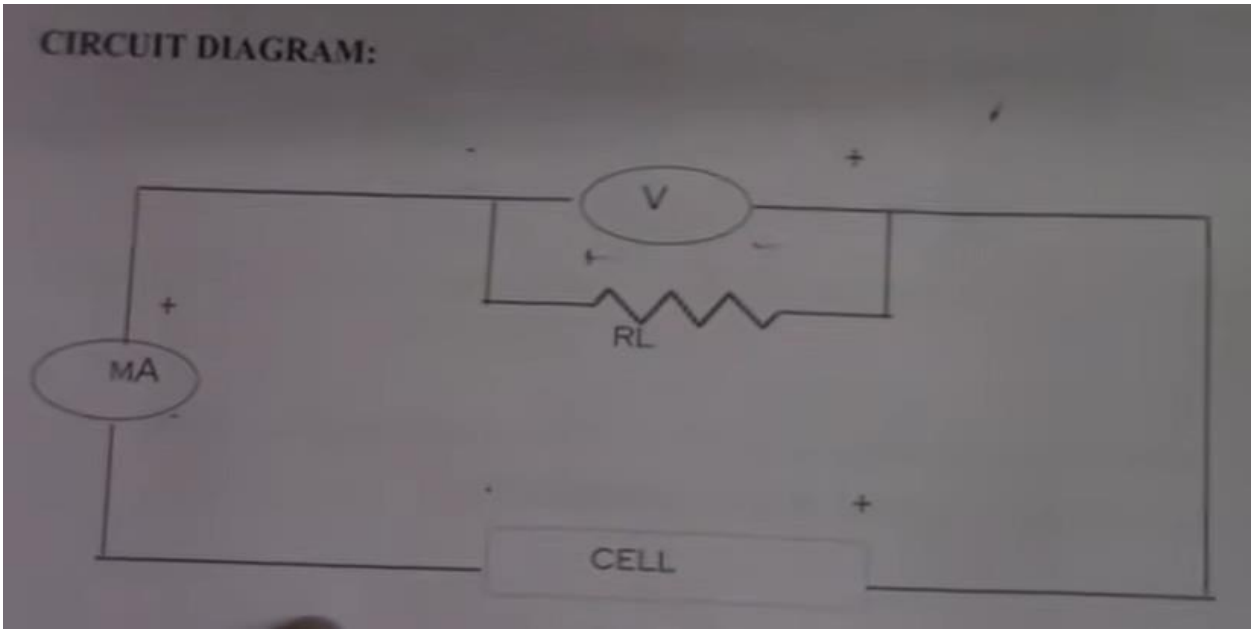

SOLAR CELL CHARACTERISTICS APPARATUS
V
mA
SOLAR CELL
SET RL

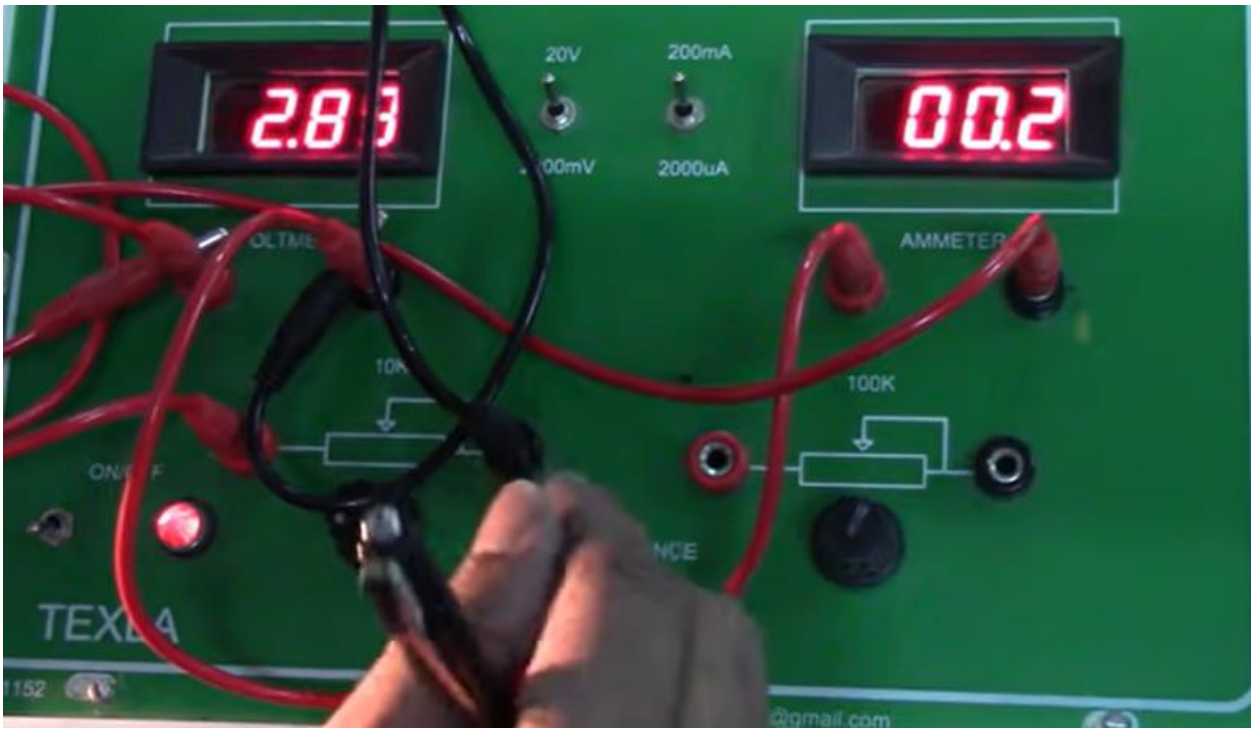

SOLAR CELL CHARACTERISTICS
20V
200mA
2000mV
2000uA
VOLTMETER
AMMETER
10R
100R
LOAD RESISTANCE
TEXLA





Cell

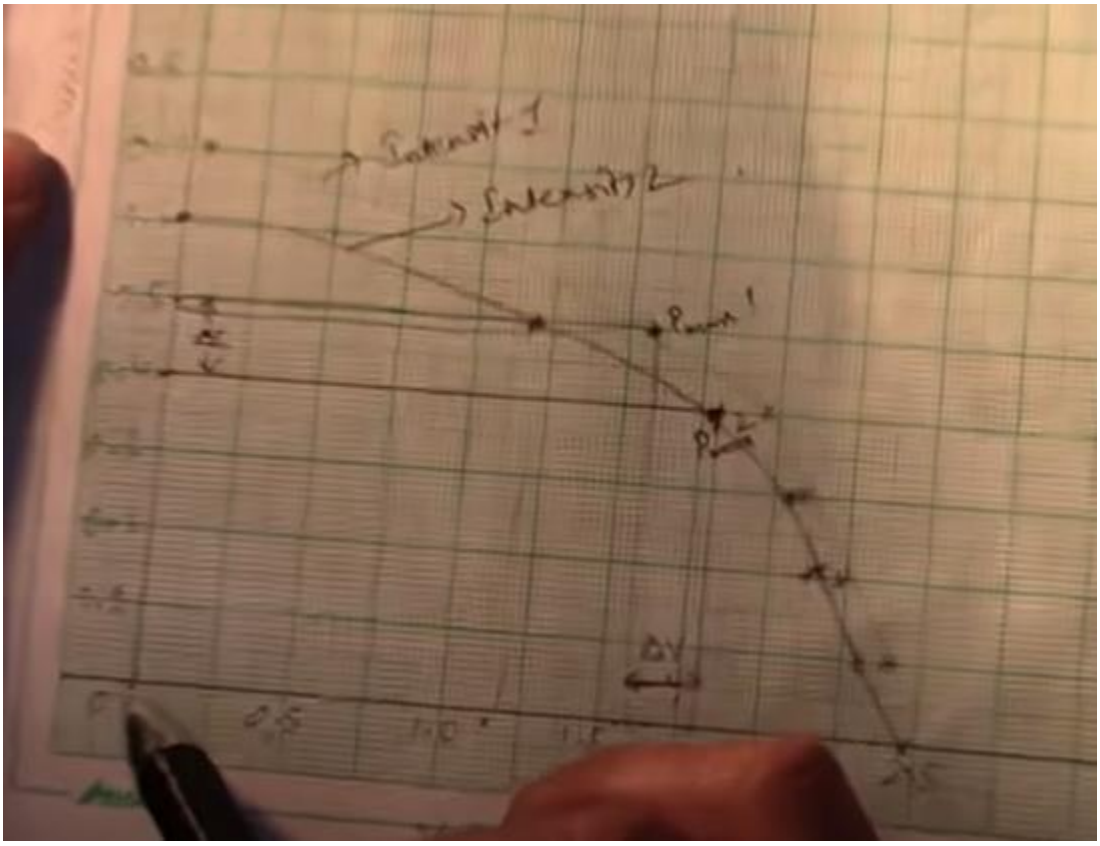

CIRCUIT DIAGRAM:
V
RL
MA
CELL


20V
200mA
00mV
2000uA
AMMETER
100K
TEXE

Observations:

Table-1: For one intensity of Source.

| S.No | Voltage (volts) | Current (mA) | $R_H$ | $P_{max} = V \times I \times 10^{-3}$ |
|---|---|---|---|---|
| 1 | 0 | 0.6 $I_{sc_2}$ | 0 | 0 |
| 2 | 1.24 | 0.5 | 96 Ω | 0.62 |
| 3 | 1.78 | 0.4 | 1.74 KΩ | 0.712 ← $R_{opt}$ |
| 4 | 2.02 | 0.3 | 2.84 KΩ | 0.602 |
| 5 | 2.16 | 0.2 | 3.62 KΩ | 0.432 |
| 6 | 2.28 | 0.1 | 5.86 KΩ | 0.228 |
| 7 | 3.48 ($V_{OC_2}$) | 0 | | |



# $V_{oc}$= Open Circuit Voltage ($V_{oc} > V_m$)

Definition: It is when no current flows through a circuit.

Depend on:

1. Cell Technology
2. Cell Temperature

# FF= Fill Factor

If the Value is high, cell is better quality.

$$\text{Fill Factor (FF)} = \frac{P_{max}}{I_{sc} \times V_{oc}} = \frac{I_m \times V_m}{I_{sc} \times V_{oc}}$$

The value of fill factor lies between 0.8 and 0.9.

$$\text{Efficiency } (\eta) = \frac{\text{output electric energy per second}}{\text{Incident light energy per second}}$$

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

We know:

$$\text{Fill Factor (FF)} = \frac{P_{max}}{I_{sc} \times V_{oc}}$$

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

Let for a solar cell having

$I_{sc}$= 350 A/m²

$V_{oc}$= 0.6V

FF = 0.8

The Irradiance value for $P_{in}$= 1000W/m²

$$\text{Efficiency } (\eta) = \frac{I_{sc} \times V_{oc} \times FF}{P_{in}}$$

$$= \frac{350 \times 0.6 \times 0.8}{1000} \times 100 = 16.8 = 17\%$$

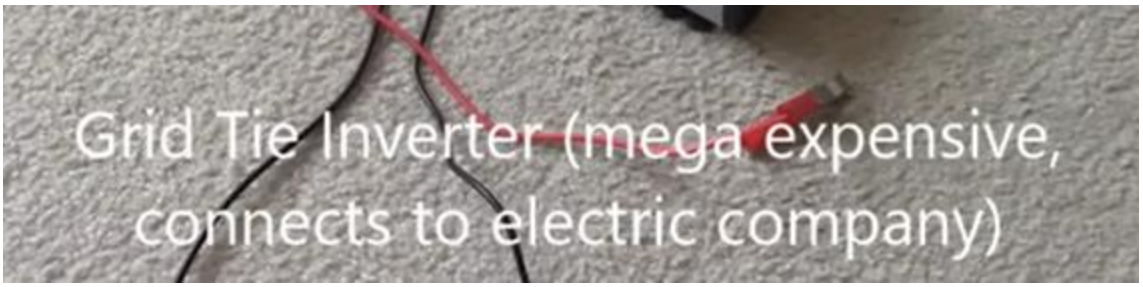
Shading analysis??

# Solar Panel Systems for Beginners

Off grid: charge controller 6 terminals of solar battery load


Modified Sine Wave (cheap, but poor quality power)


xantrex
Pure Sine Wave (expensive, high quality power)




Grid-connected: inverter