AMERICAN RIVER COLLEGE

PV Module Fundamentals

Lesson Plan

- Review midterm exam
- Solar Energy Fundamentals – any questions?
- NABCEP Learning Objectives: PV Module Fundamentals

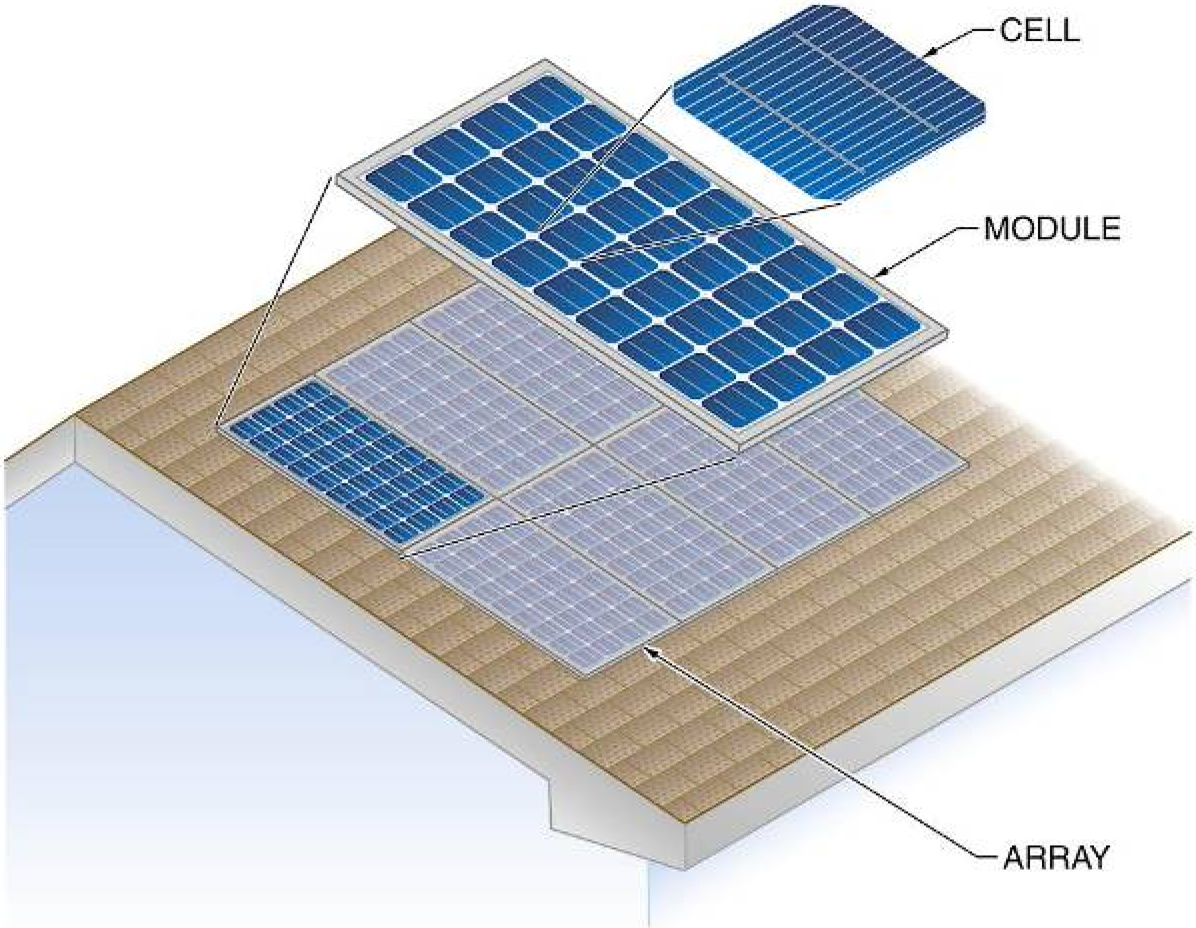
NABCEP Learning Objectives

Category	Course Time By %	Exam Items	Level of Testing
1. PV Markets & Applications	5%	3	Comprehension
2. Safety Basics	5%	3	Comprehension Application
3. Electricity Basics	10%	6	Comprehension Problem Solving
4. Solar Energy Fundamentals	10%	6	Comprehension Application Problem Solving
5. PV Module Fundamentals	10%	6	Comprehension Application Problem Solving
6. System Components	15%	9	Comprehension Application Problem Solving
7. PV System Sizing Principles	10%	6	Application Problem Solving Design
8. PV System Electrical Design	15%	9	Application Problem Solving Design
9. PV System Mechanical Design	10%	6	Application Problem Solving Design
10. Performance Analysis, Maintenance and Troubleshooting	10%	6	Analysis Problem Solving
Totals	100%	60	

NABCEP Learning Objectives

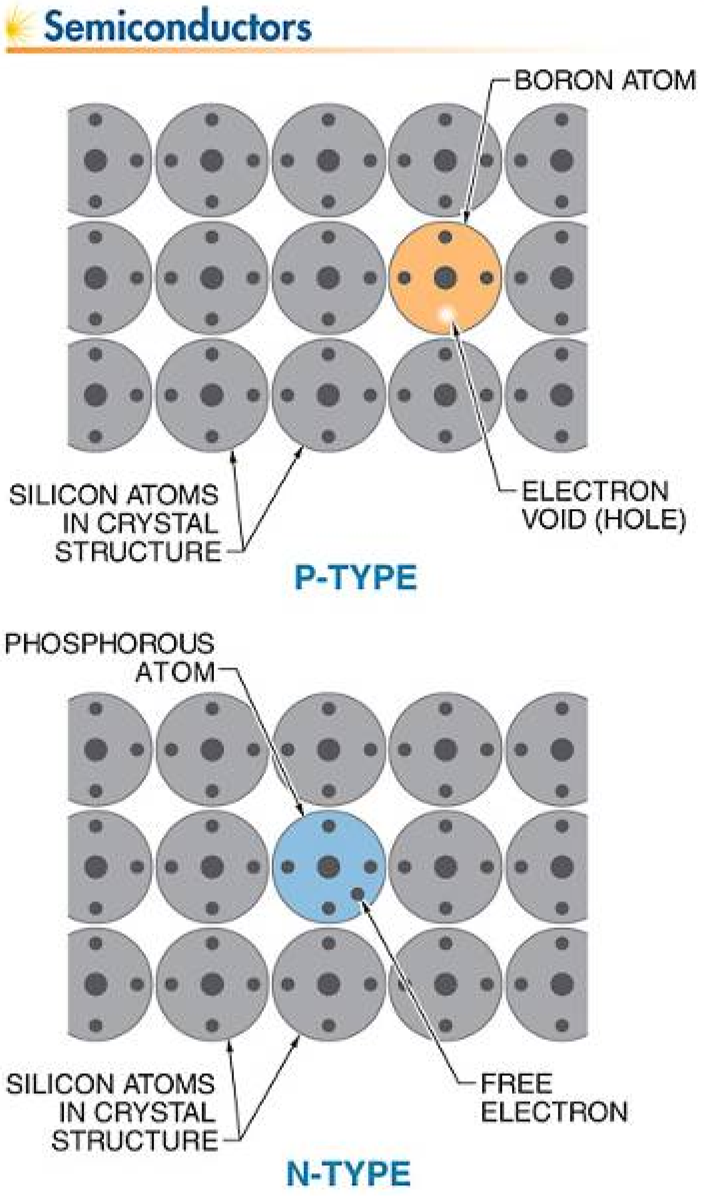
5.	**PV Module Fundamentals** *Suggested Percentage Time Allotment: 10%*	**Learning Priority**
5.1	Explain how a solar cell converts sunlight into electrical power.	Useful
5.2	Distinguish between PV cells, modules, panels and arrays.	Useful
5.3	Identify the five key electrical output parameters for PV modules using manufacturers' literature (Voc, Isc, Vmp, Imp and Pmp), and label these points on a current-voltage (I-V) curve.	Critical
5.4	Understand the effects of varying incident solar irradiance and cell temperature on PV module electrical output, illustrate the results on an I-V curve, and indicate changes in current, voltage and power.	Critical
5.5	Determine the operating point on a given I-V curve given the electrical load.	Important
5.6	Explain why PV modules make excellent battery chargers based on their I-V characteristics.	Useful
5.7	Understand the effects of connecting similar and dissimilar PV modules in series and in parallel on electrical output, and diagram the resulting I-V curves.	Critical
5.8	Define various performance rating and measurement conditions for PV modules and arrays, including STC, SOC, NOCT, and PTC.	Critical
5.9	Compare the fabrication of solar cells from various manufacturing processes.	Useful
5.10	Describe the components and the construction for a typical flat-plate PV module made from crystalline silicon solar cells, and compare to thin-film modules.	Important
5.11	Given the surface area, incident solar irradiance and electrical power output for a PV cell, module or array, calculate the efficiency and determine the power output per unit area.	Important
5.12	Discuss the significance and consequences of PV modules being limited current sources.	Useful
5.13	Explain the purpose and operation of bypass diodes.	Important
5.14	Identify the standards and design qualification testing that help ensure the safety and reliability of PV modules.	Important

Cells, Modules, and Arrays

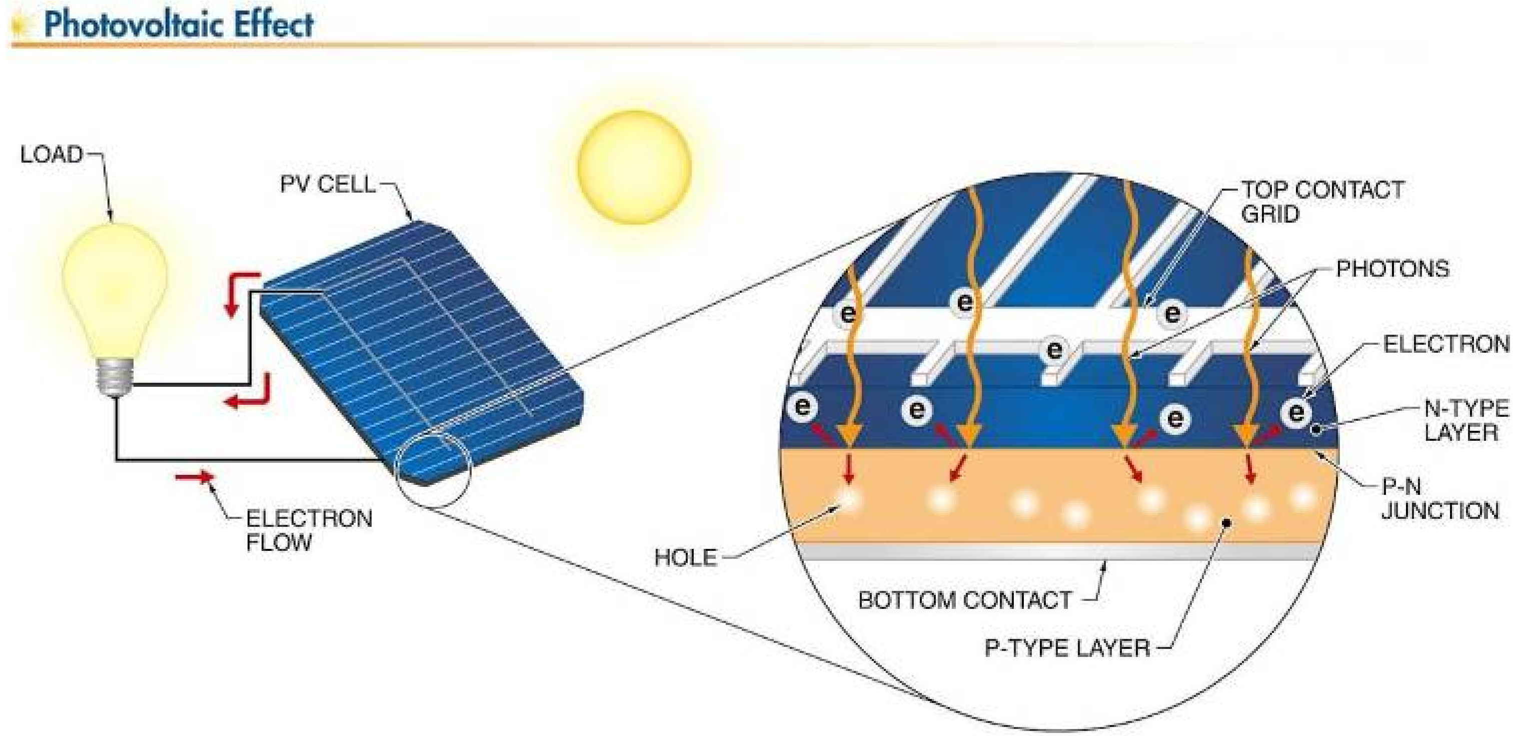


- The basic building blocks for PV systems include cells, modules, and arrays.

- Semiconductor materials with special electrical properties can be made by adding small amounts of other elements to silicon crystals.



- The photovoltaic effect produces free electrons that must travel through conductors in order to recombine with electron voids, or "holes."

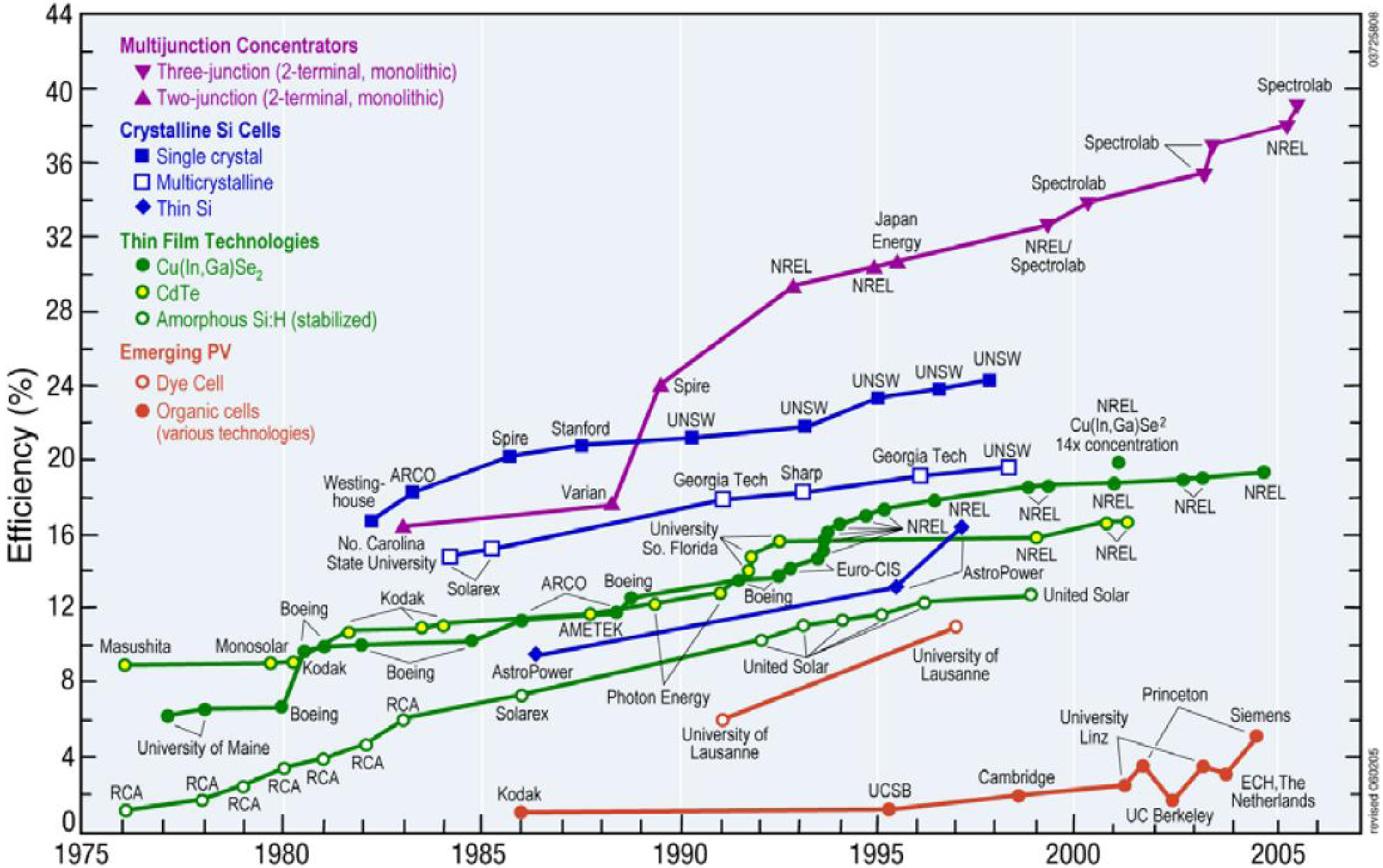


- Various PV materials and technologies produce different efficiencies.

PV Material Efficiencies*

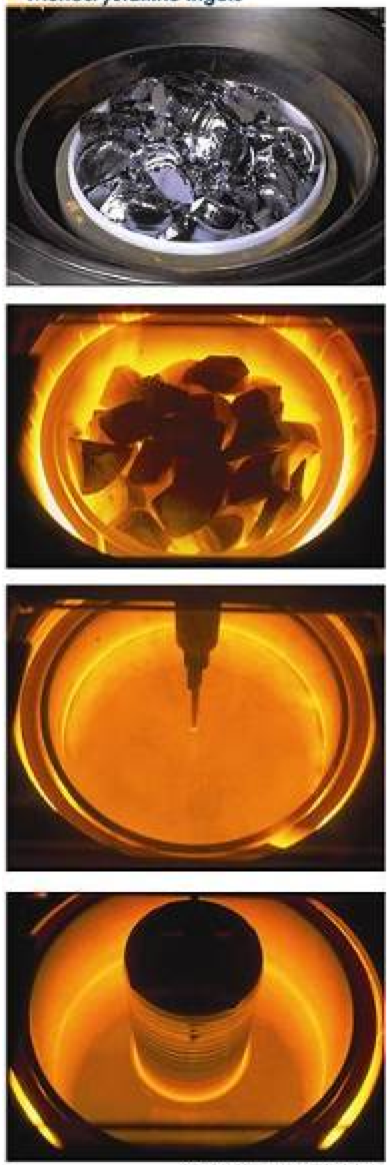
MATERIAL	TYPICAL EFFICIENCIES	BEST LABORATORY EFFICIENCY
Gallium arsenide (GaAs)	20	32
Monocrystalline silicon	14 to 17	25
Polycrystalline silicon	11.5 to 14	20
Ribbon silicon	11 to 13	16.5
Copper indium gallium selenide (CIGS)	9 to 11.5	19
Cadmium telluride (CdTe)	8 to 10	16.5
Amorphous silicon (a-Si)	5 to 9.5	13
Graetzel	4 to 5	11
Polymer	1 to 2.5	5

* in %



GCEP Solar Energy Technology Assessment - Summer 2006

Monocrystalline Ingots



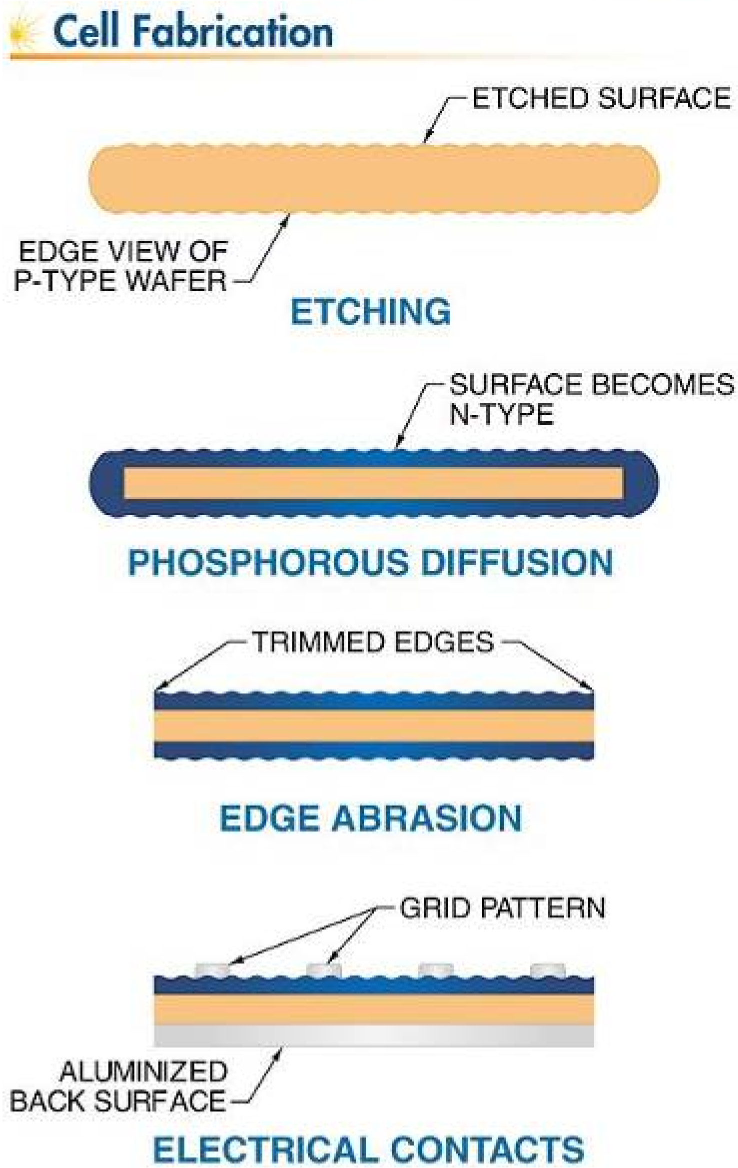
SolarWorld Industries America

Monocrystalline silicon wafers are sawn from grown cylindrical ingots.

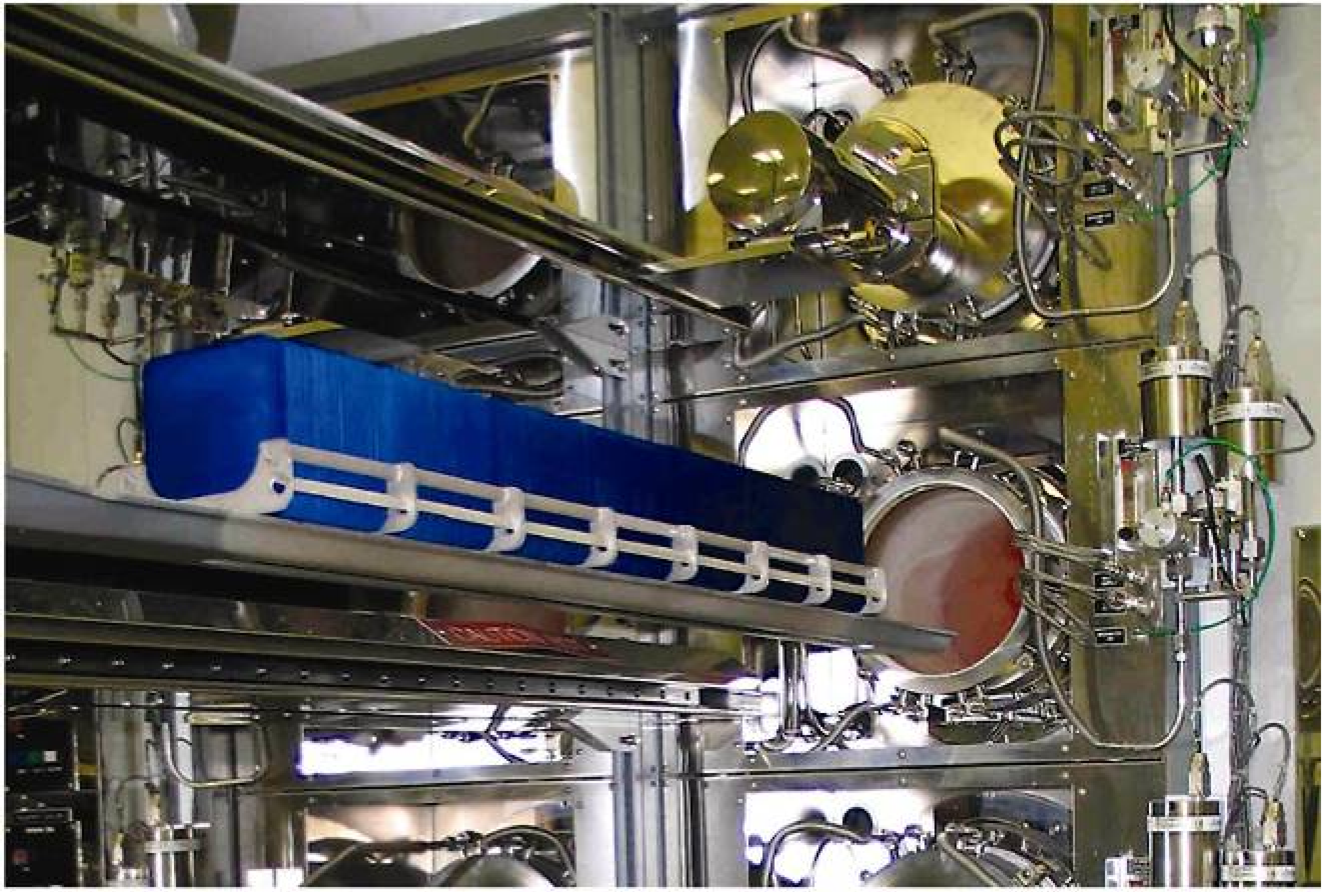
Polycrystalline Ingots

DOE/NREL, John Wohlgemuth—Solarex

Polycrystalline silicon wafers are sawn from cast rectangular ingots.



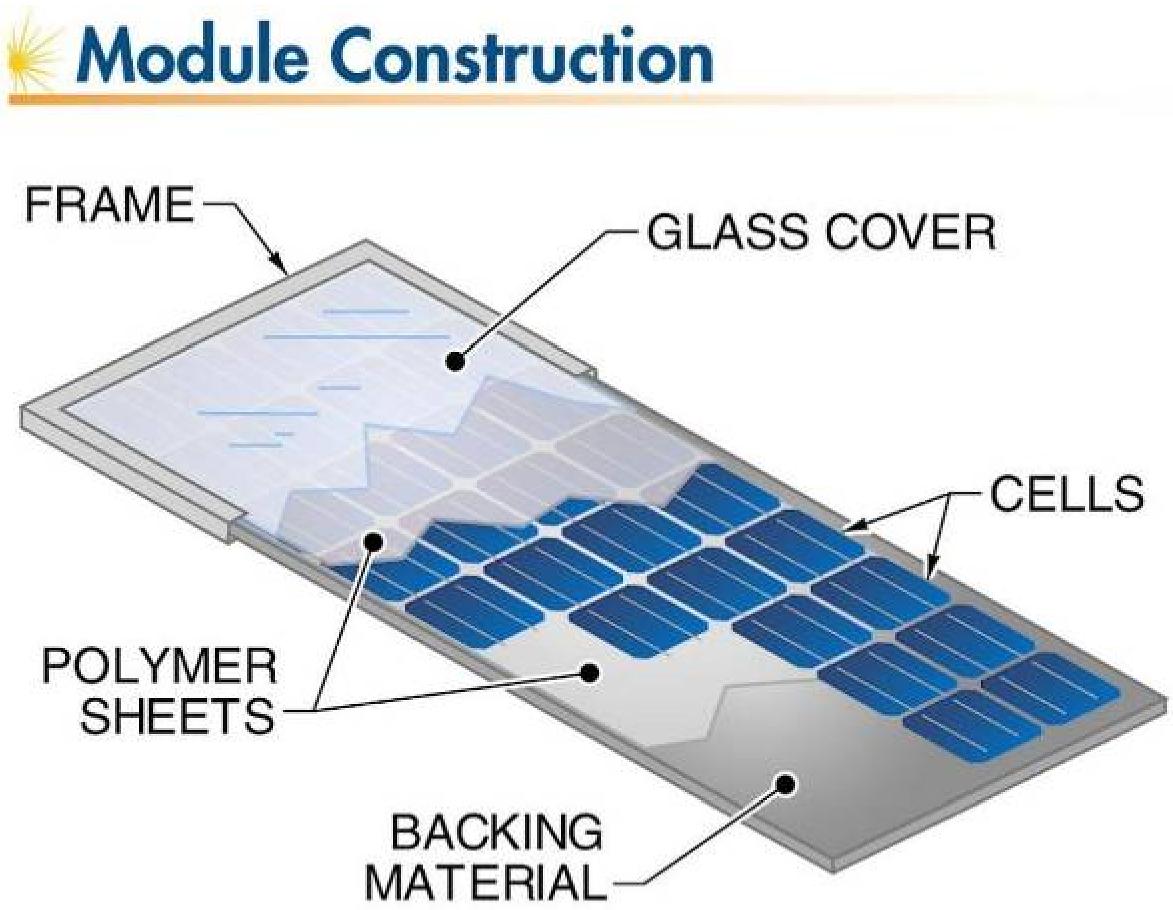
- Several steps are involved in turning silicon wafers into PV cells.



SolarWorld Industries America

- Diffusion of phosphorous gas creates a thin n-type semiconductor layer over the entire surface of a p-type wafer.

- Modules are constructed from PV cells surrounded by several layers of protective materials.



Cells, Modules, and Arrays

- Modules are available in several sizes and shapes, including squares, rectangles, triangles, flexible units, and shingles.

SolarWorld Industries America

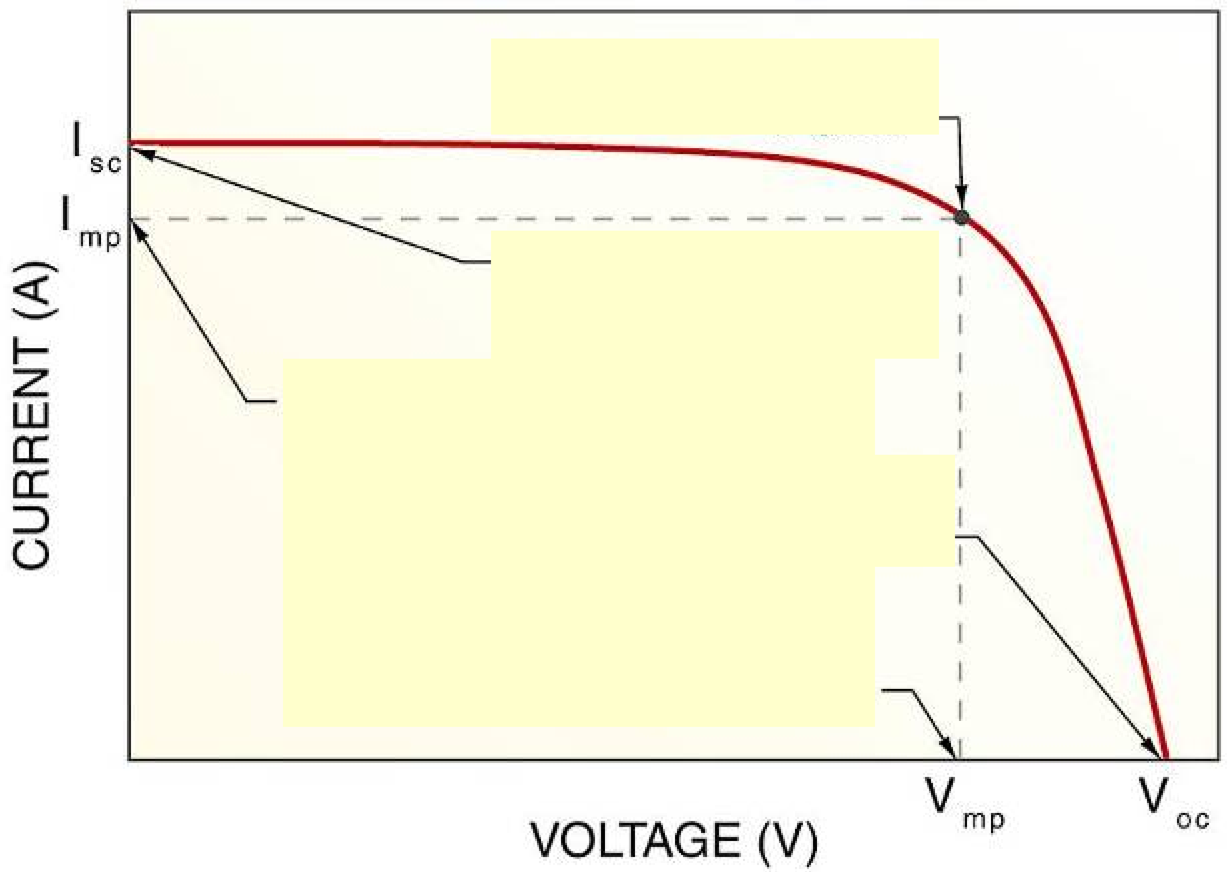
- Several modules may be connected together to form a panel, which is installed as a preassembled unit.

Arrays

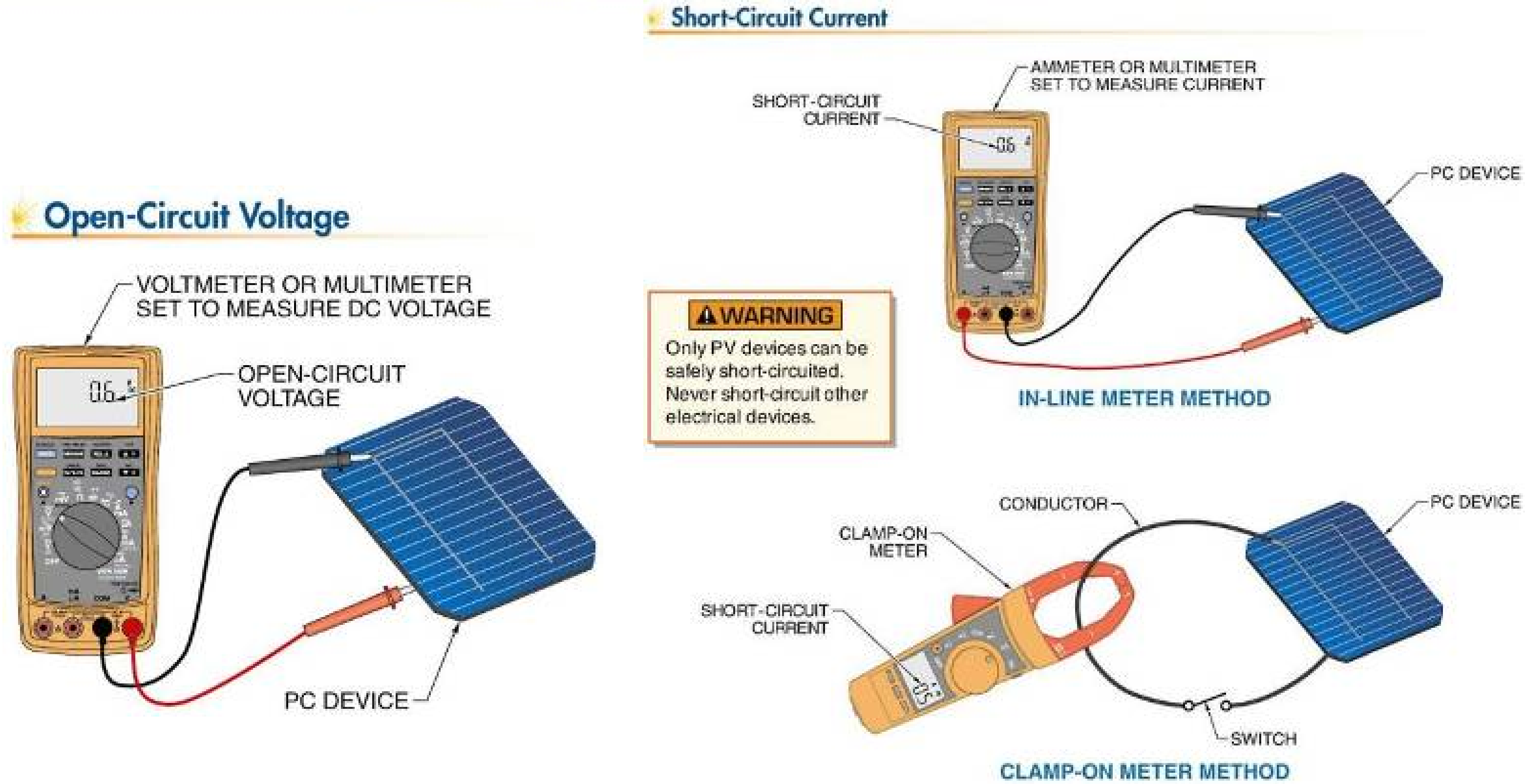
DOE/NREL, Craig Miller Productions

- An array is a group of PV modules integrated as a single power-generating unit.

I-V Curve

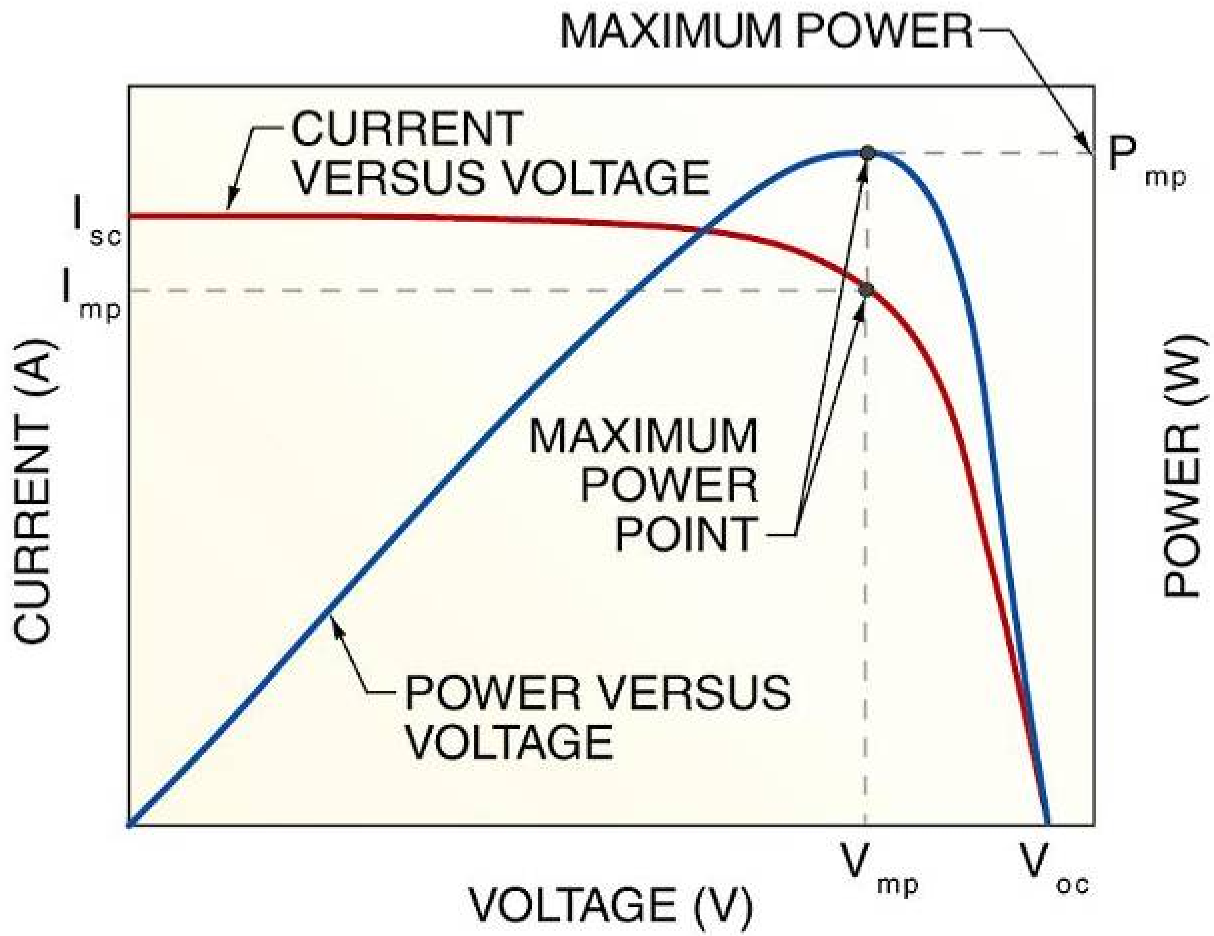


- An I-V curve illustrates the electrical output profile of a PV cell, module, or array.



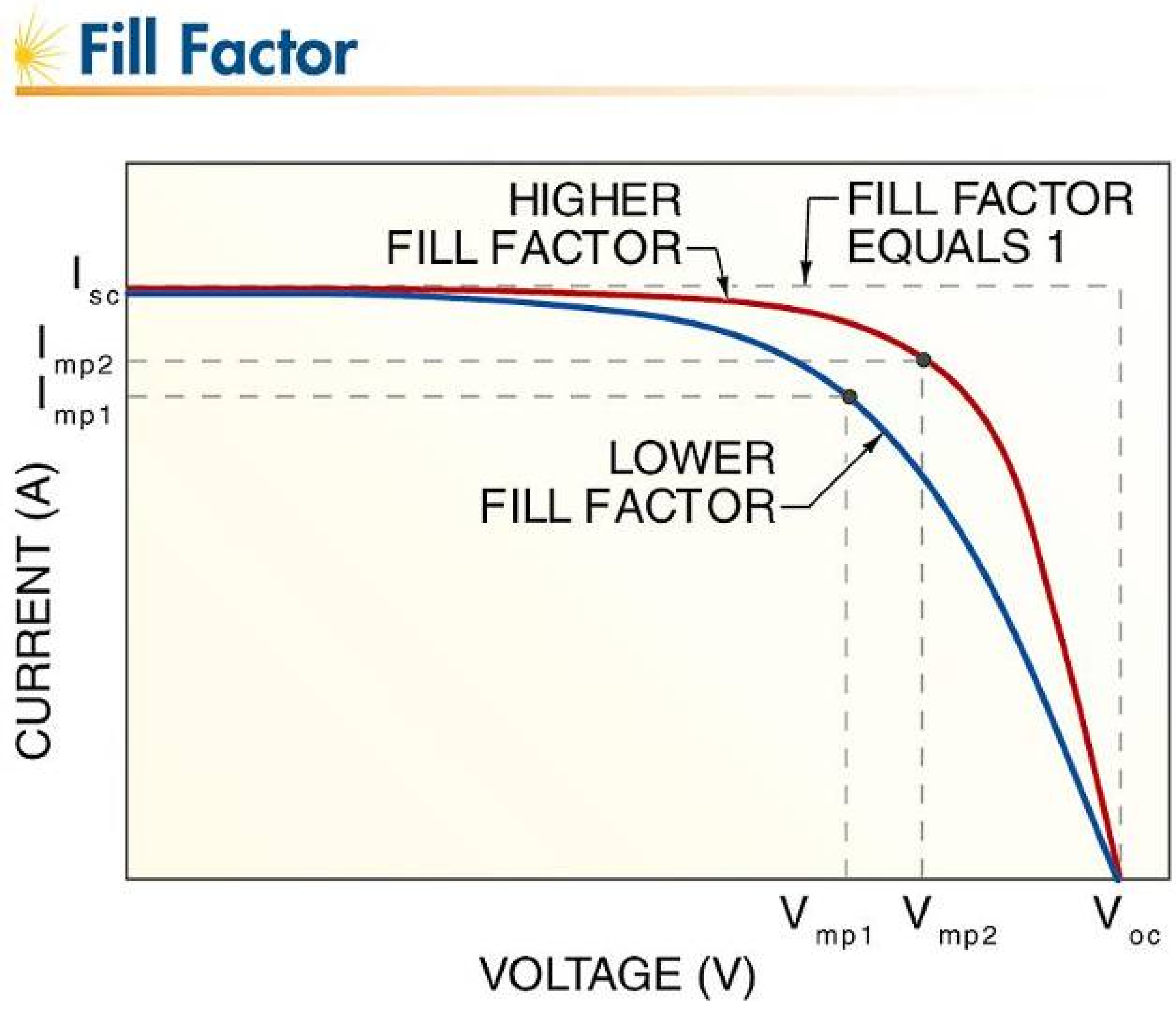
- Open-circuit voltage is easily measured with test instruments.
- Using in-line and clamp-on ammeters are two methods of measuring short-circuit current.

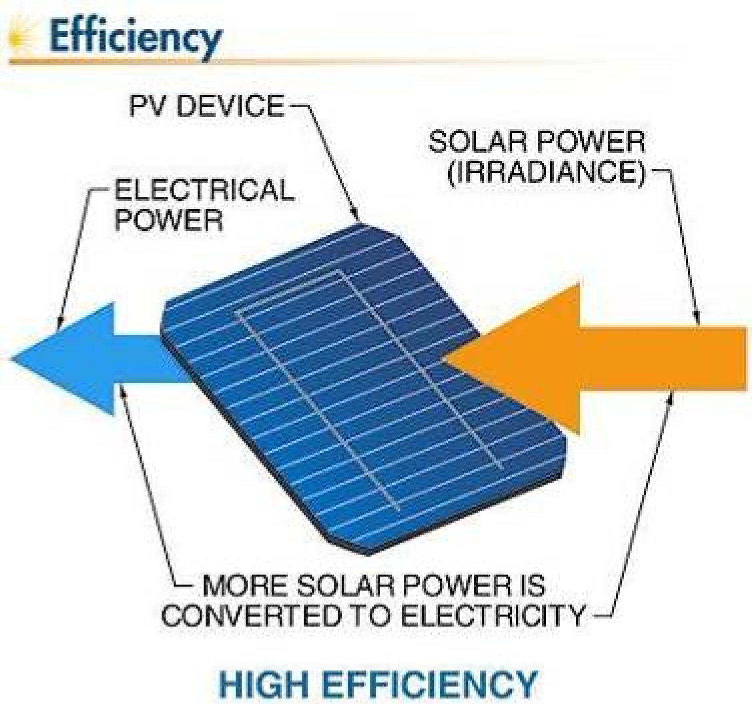
I-V Curve with Power



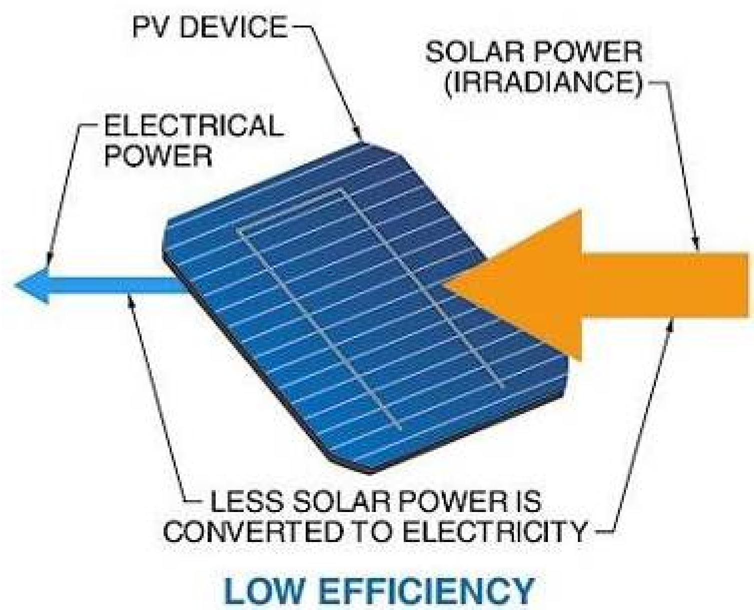
- A power against voltage curve clearly shows the maximum power point.

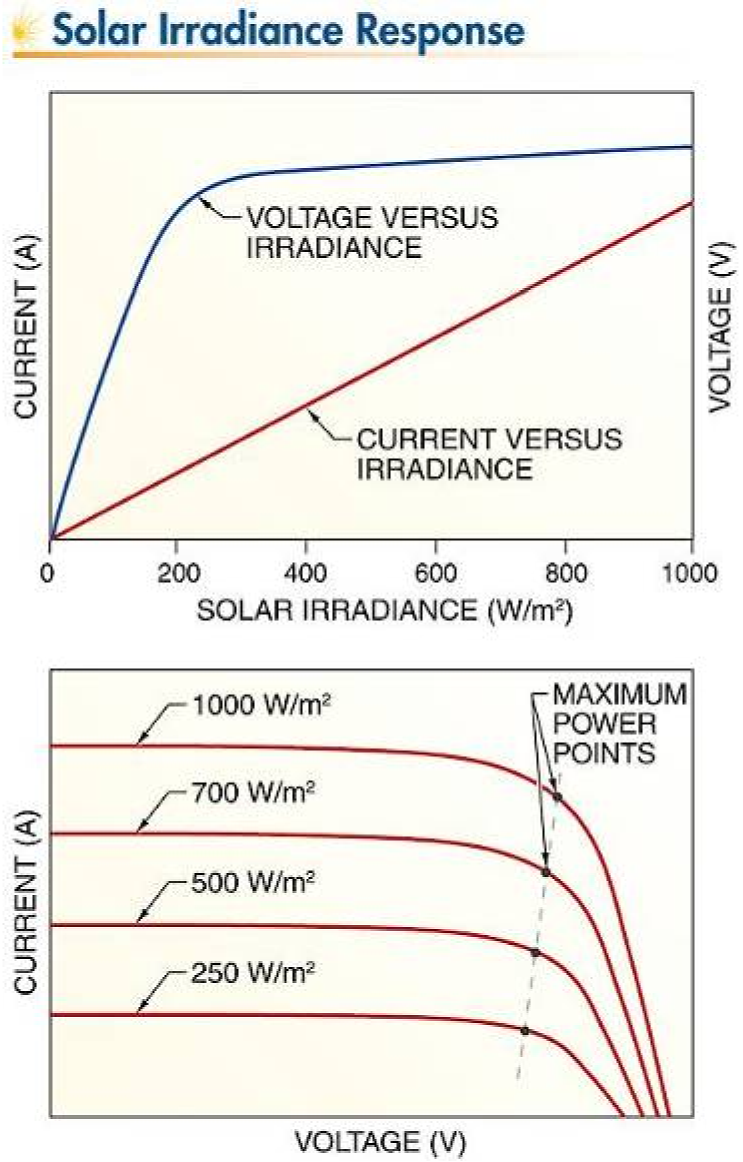
- Fill factor represents the shape of an I-V curve.





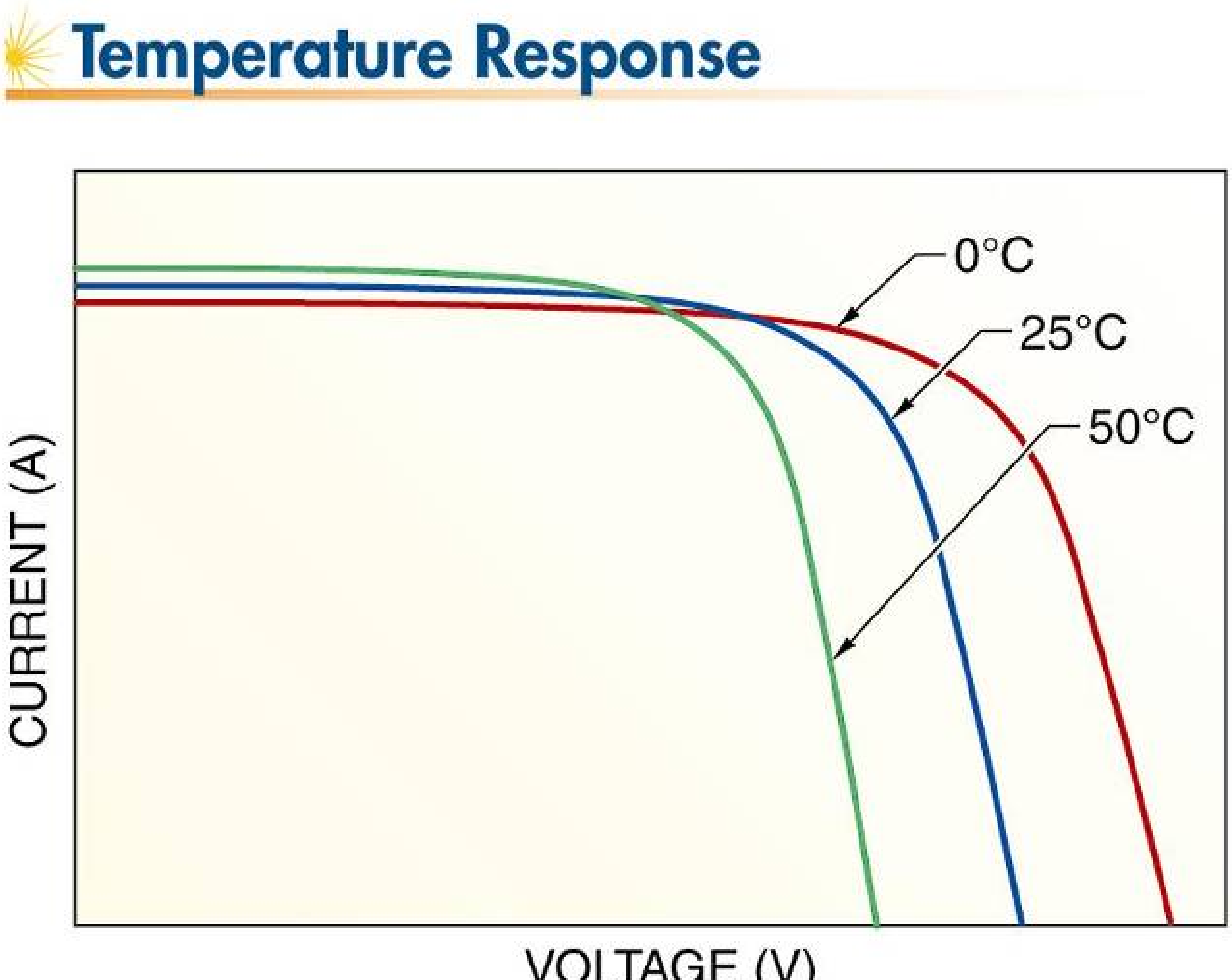
- Efficiency is a measure of how effectively a PV device converts solar power to electrical power.

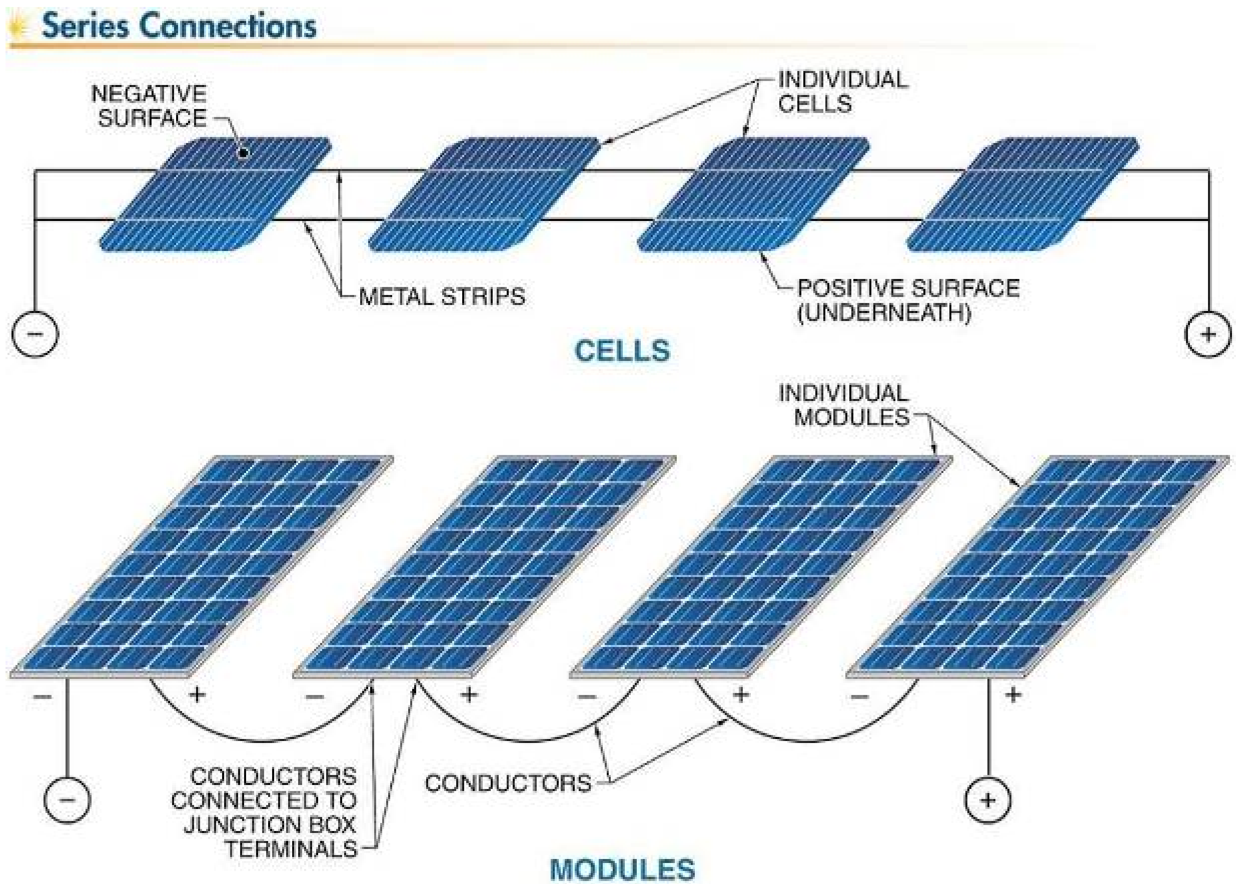




- Voltage increases rapidly up to about 200 W/m^2, and then is almost constant. Current increases proportionally with irradiance

- Increasing cell temperature decreases voltage, slightly increases current, and results in a net loss of power.

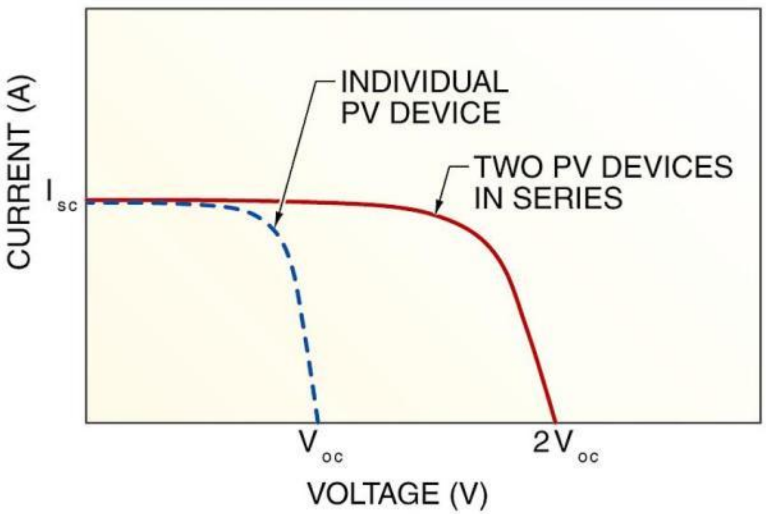




- PV cells or modules are typically connected in series strings to build voltage.

- The overall I-V characteristics of a series string are dependent on the similarity of the current outputs of the individual devices.

PV Devices in Series



SIMILAR PV DEVICES

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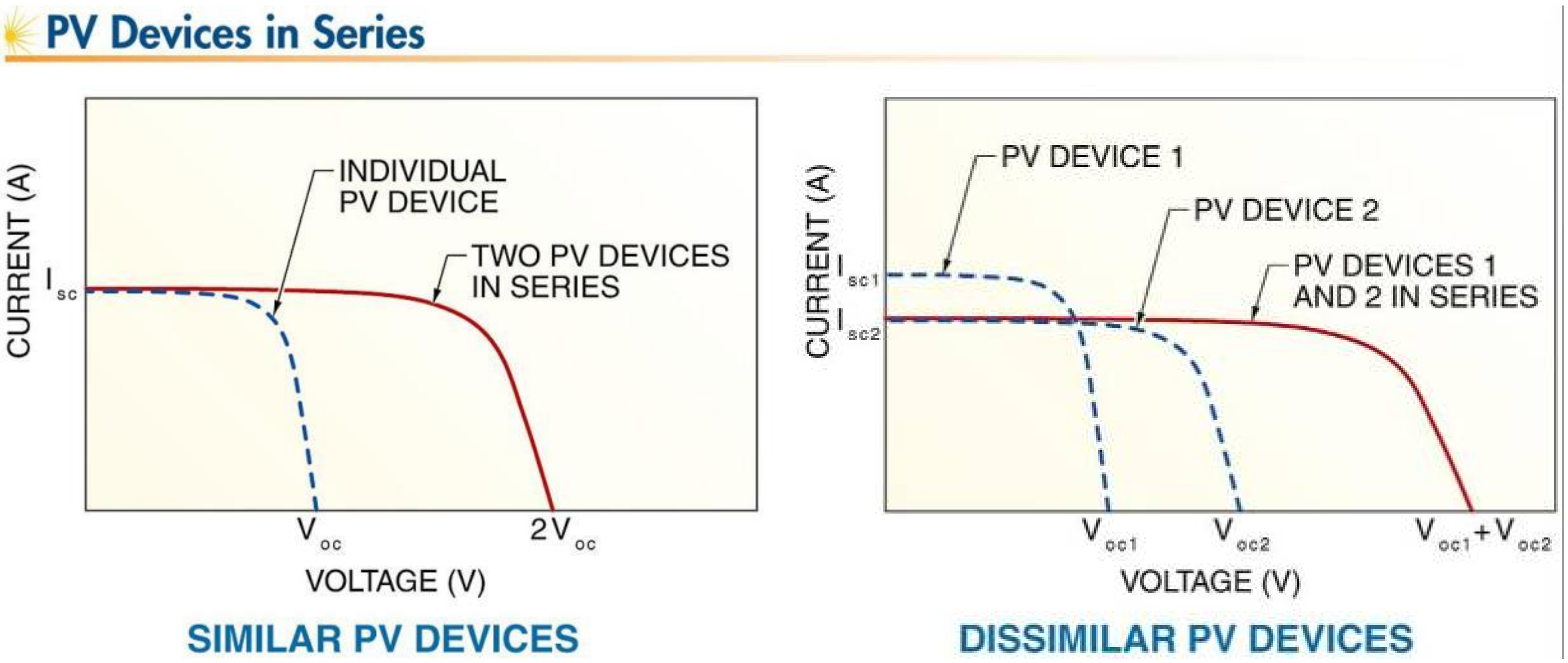
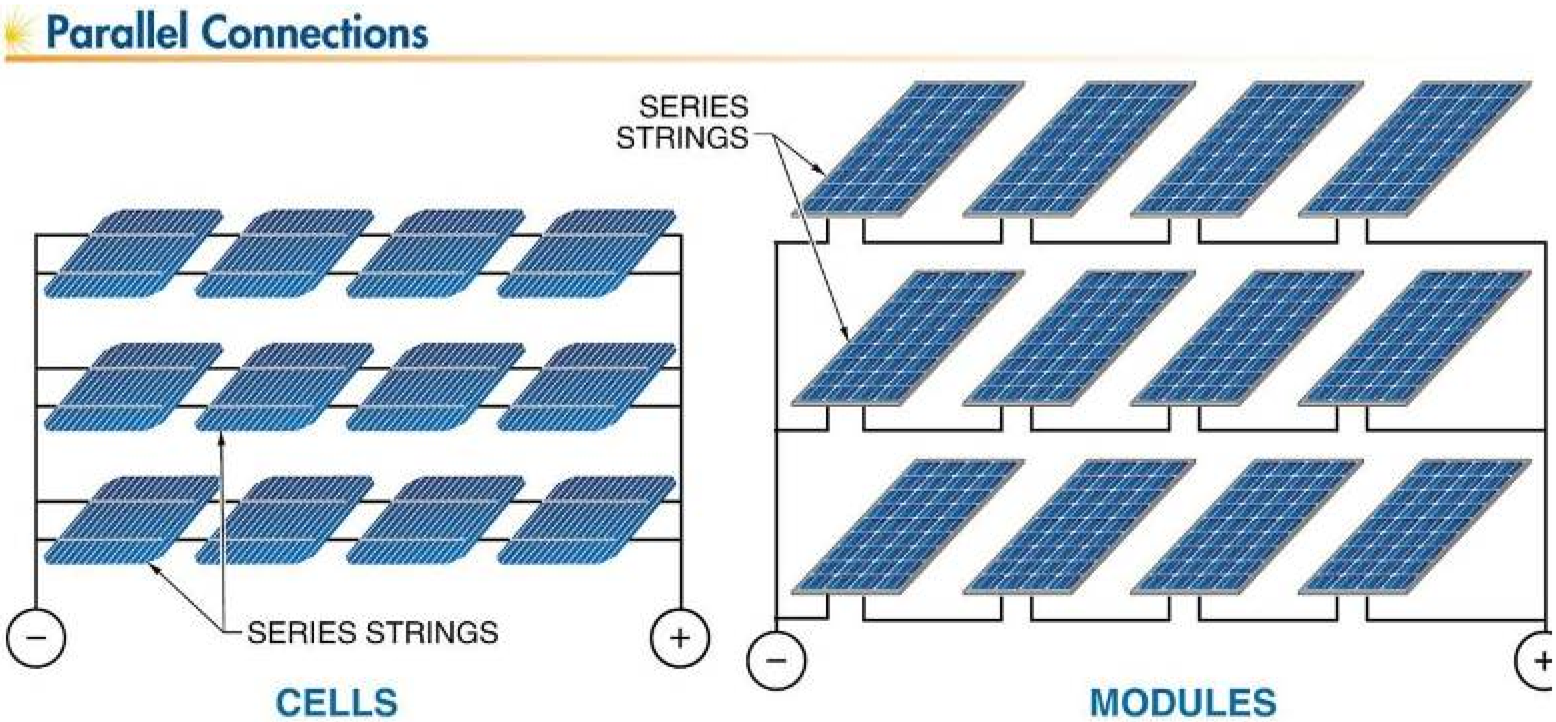
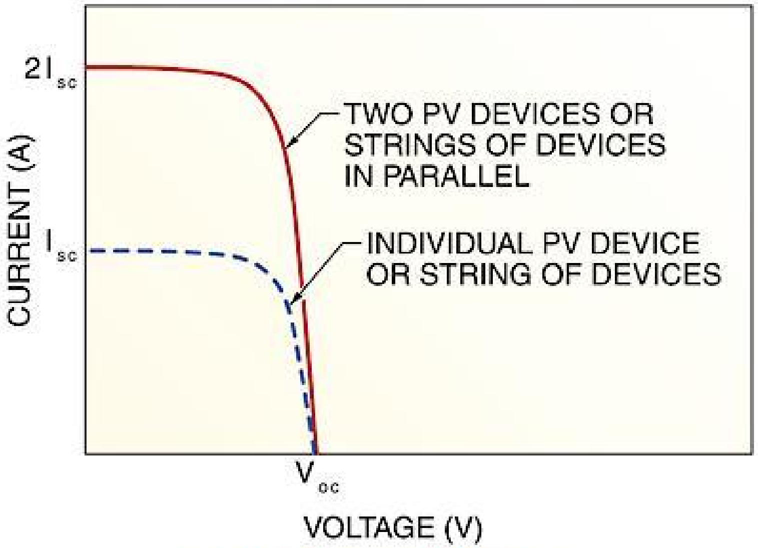




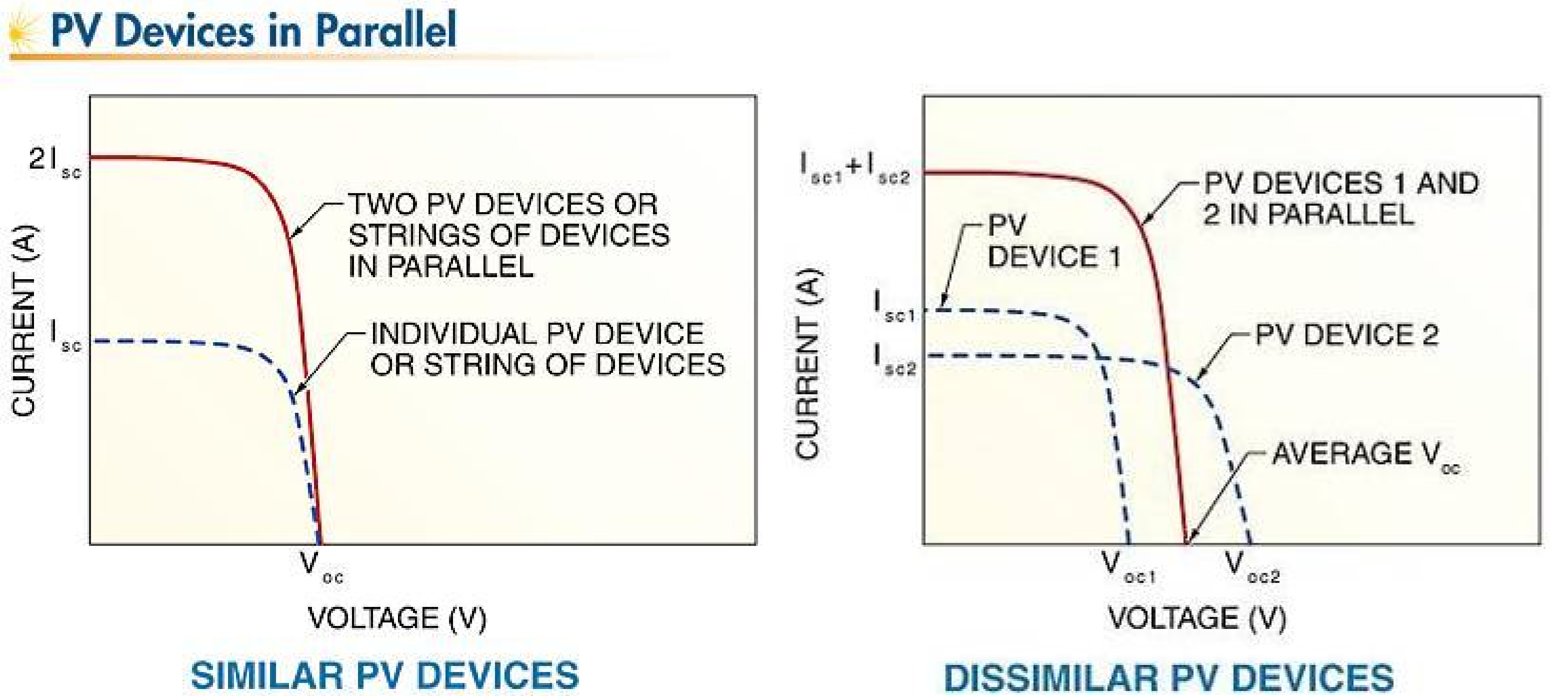
- Strings of PV cells or modules may be connected in parallel to build current.

PV Devices in Parallel



SIMILAR PV DEVICES

- The overall I-V characteristics of a system of PV devices in parallel are dependent on the similarity of the current outputs of the individual devices.



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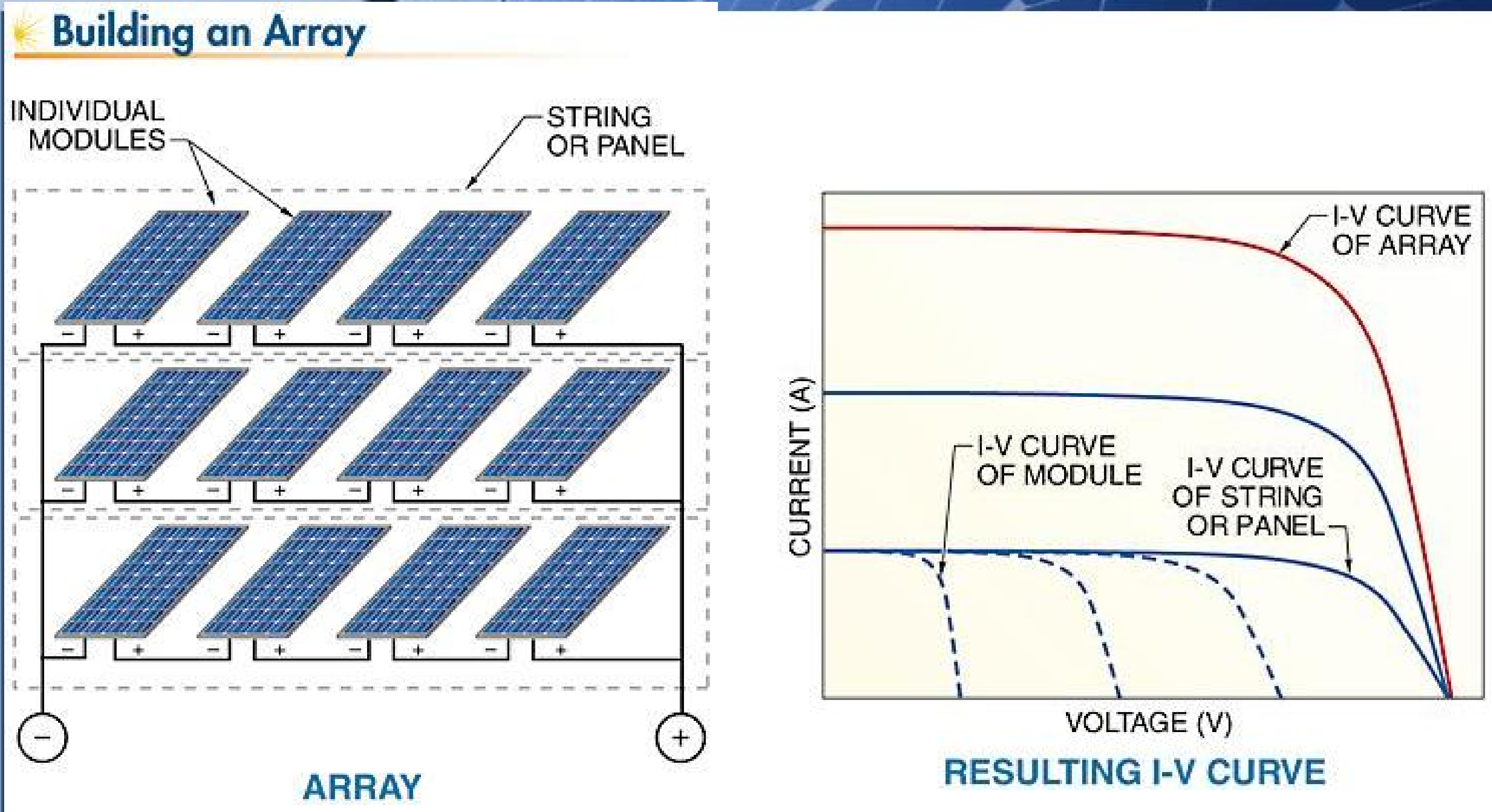
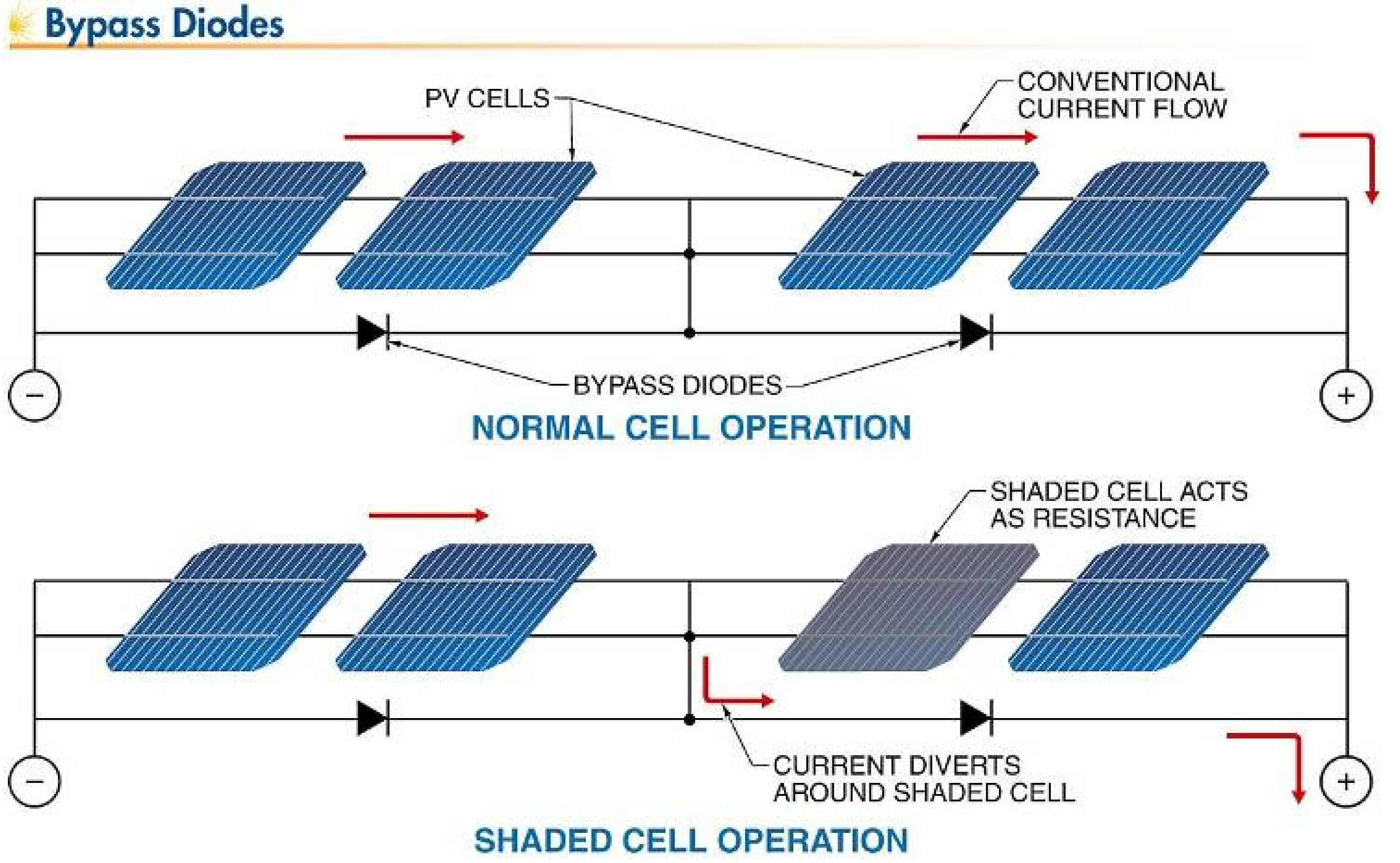
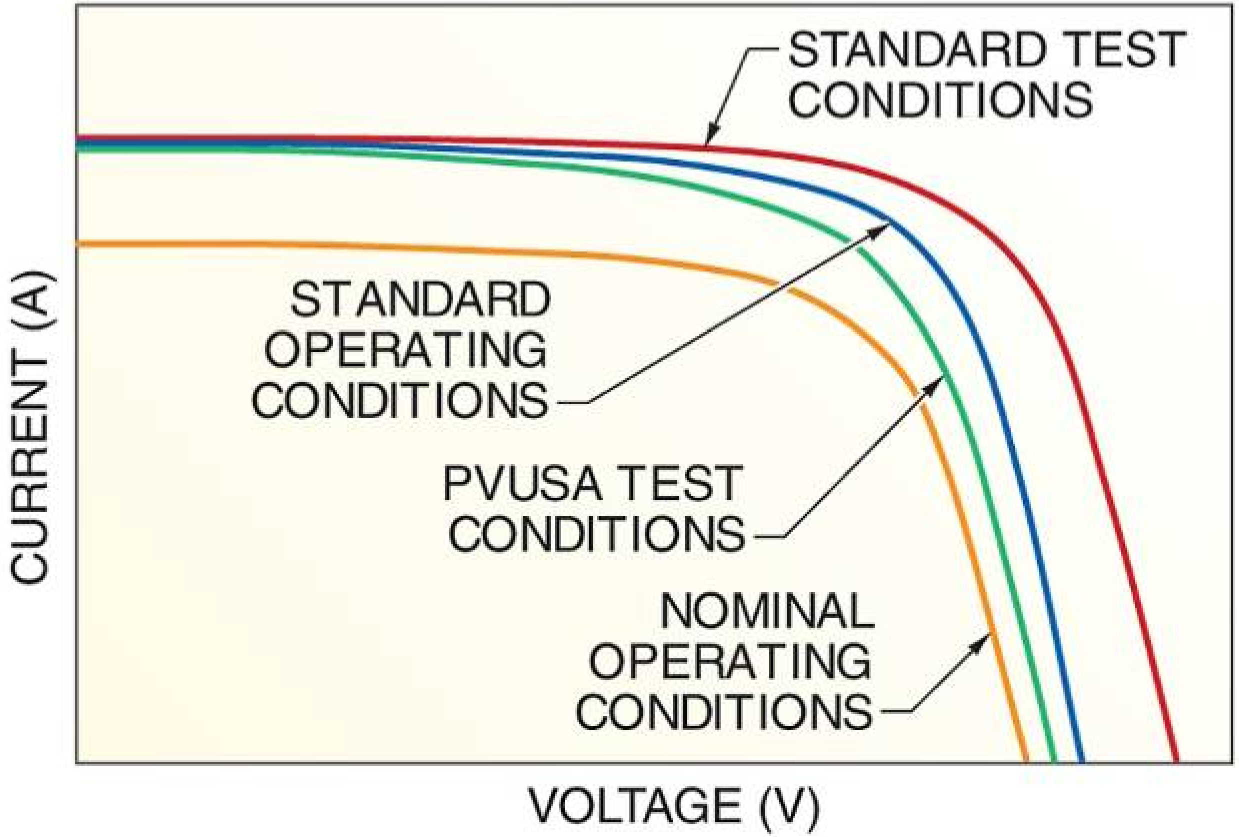


- Modules are added in series to form strings or panels, which are then combined in parallel to form arrays.

- Bypass diodes allow current to flow around devices that develop an open-circuit or high-resistance condition.



Test Conditions



- Various test conditions can be used to evaluate module performance and may produce different results.