Lesson Title: **SOLAR PV: BALANCE OF SYSTEM EQUIPMENT and SYSTEM DESIGN**

Grade level: High School

Lesson length: 1-2 hours, depending on coverage and emphasis

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Created: April, 2017

Instructor's Guide

Learning Goals:

- Students will understand how solar PV systems can be engineered to meet different situations and goals.
- Students will learn what Balance of System equipment is needed to make various systems work and what each piece of equipment does.
- Students will produce energy flow diagrams of five PV systems placing equipment in electrical flow order and showing the interactions between each piece of equipment.

Technology Required:

- Internet-accessible digital device with word processing capability in MSWord or Google Doc platforms.

Introduction to the activity:

This is a straightforward activity that must be completed by the teacher before it is used for the first time.

Most people don't know how a solar PV system works, and what other equipment is needed to make one work. **Solar PV: Balance of System and System Design** will provide fundamental information to fill in those blanks.

Students only need an internet-accessible digital device with word processing capability in MSWord or Google Doc platforms to complete the lesson.

Before beginning, remind students of this information, found in their student lesson for the activity.

Five different solar PV system designs follow. It should be understood:

- These are general system design categories. There are different ways to specifically configure these systems. Some equipment can be different than that shown. Hybrids of these systems can be engineered.
- You will produce energy flow diagrams, not technical drawings. To support a general understanding of solar PV system design, many details have been left out. For example, safety features that need to be engineered into each system design have been intentionally overlooked.

The symbols in the rectangles used to complete the energy flow diagrams are not formal engineering or electrical symbols used to describe each piece of equipment. You may help students with a few of them in advance of the activity. You may also suggest students do an image search to figure out a symbol if they don't understand one of them.

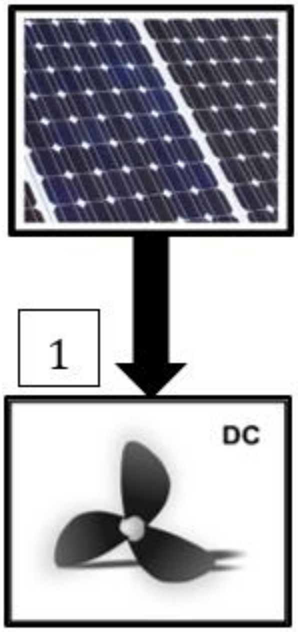
There are many ways to introduce the **Solar PV: Balance of System and System Design** depending on how you are using it and where you are using it in your unit of study. You are of course welcome to use the student introduction to the lesson as your introduction to the activity.

The lesson usually doesn't take a long time for students to complete. Push your students to read the entire activity as they do it. The objective is for students to understand the energy flow diagrams of the five systems, not just to get rectangles in the right order.

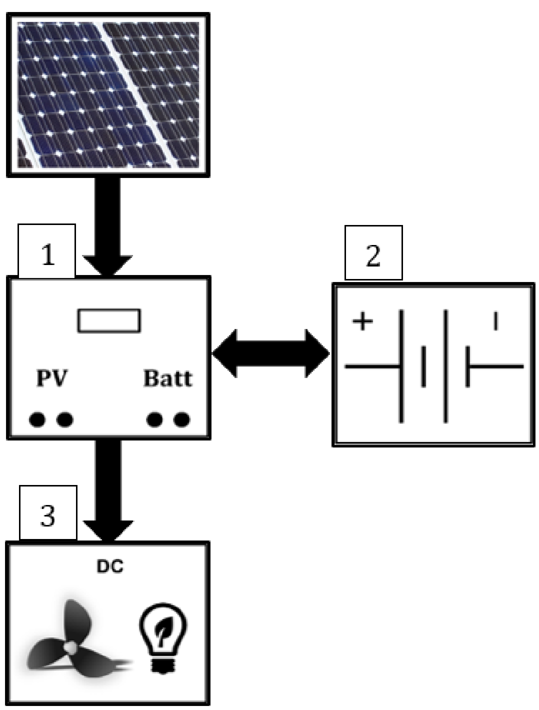
Reviewing the Follow-up Questions will help you summarize the activity with your students. Discuss the questions and help students answer them as necessary. You may want to talk about where you might find (or where students have seen) each kind of system. Follow student interest as you do this. Use their interest to reach back into other activities they have completed, and reach forward to those that are coming up.

Answer Key:

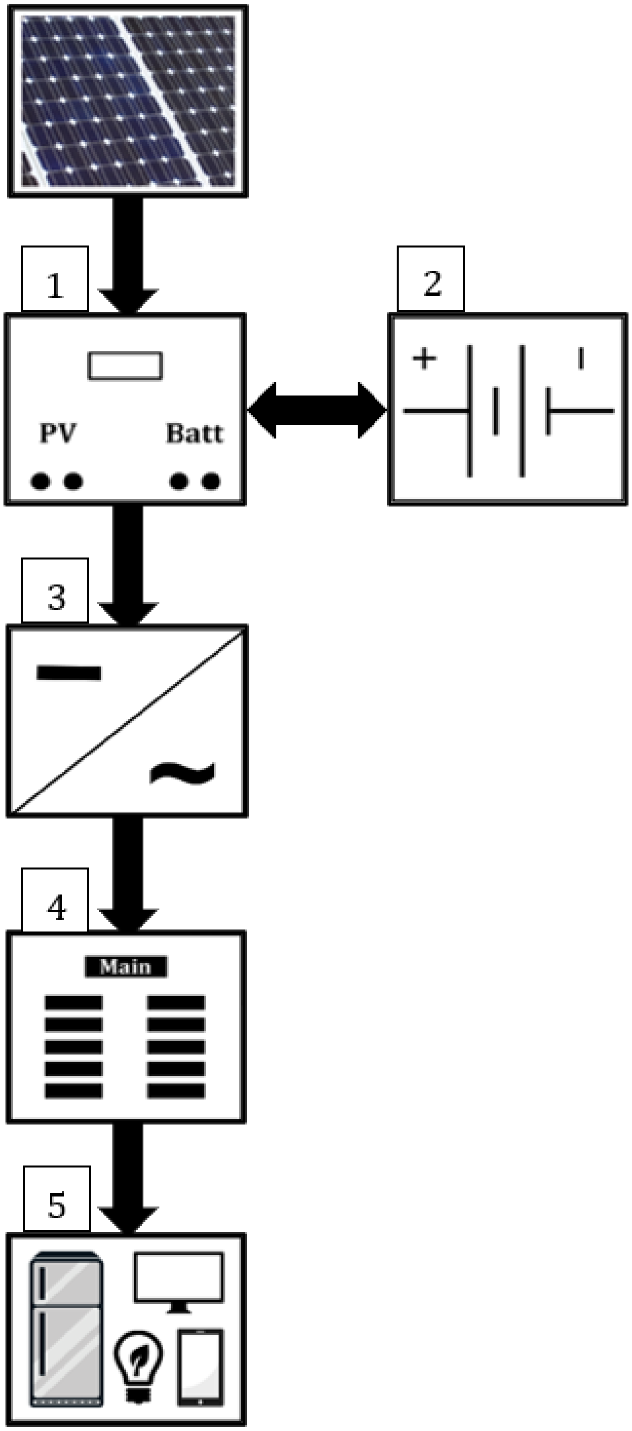
1. PV Direct system.



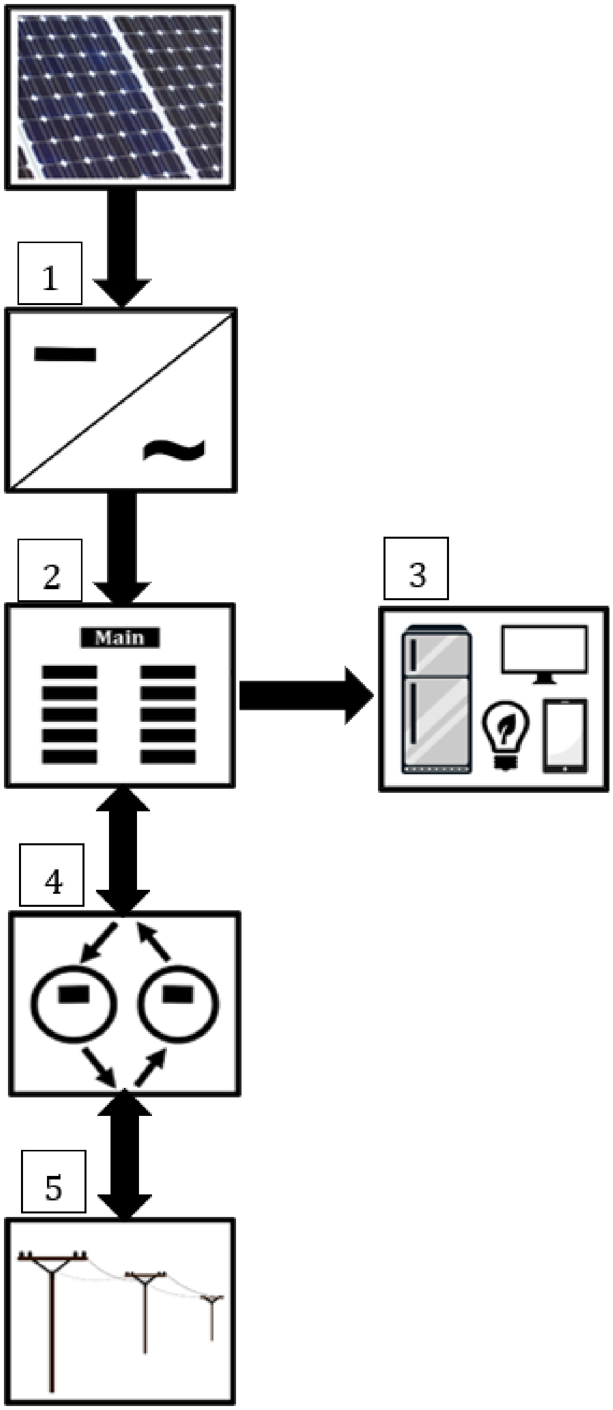
2. DC Stand-Alone system.



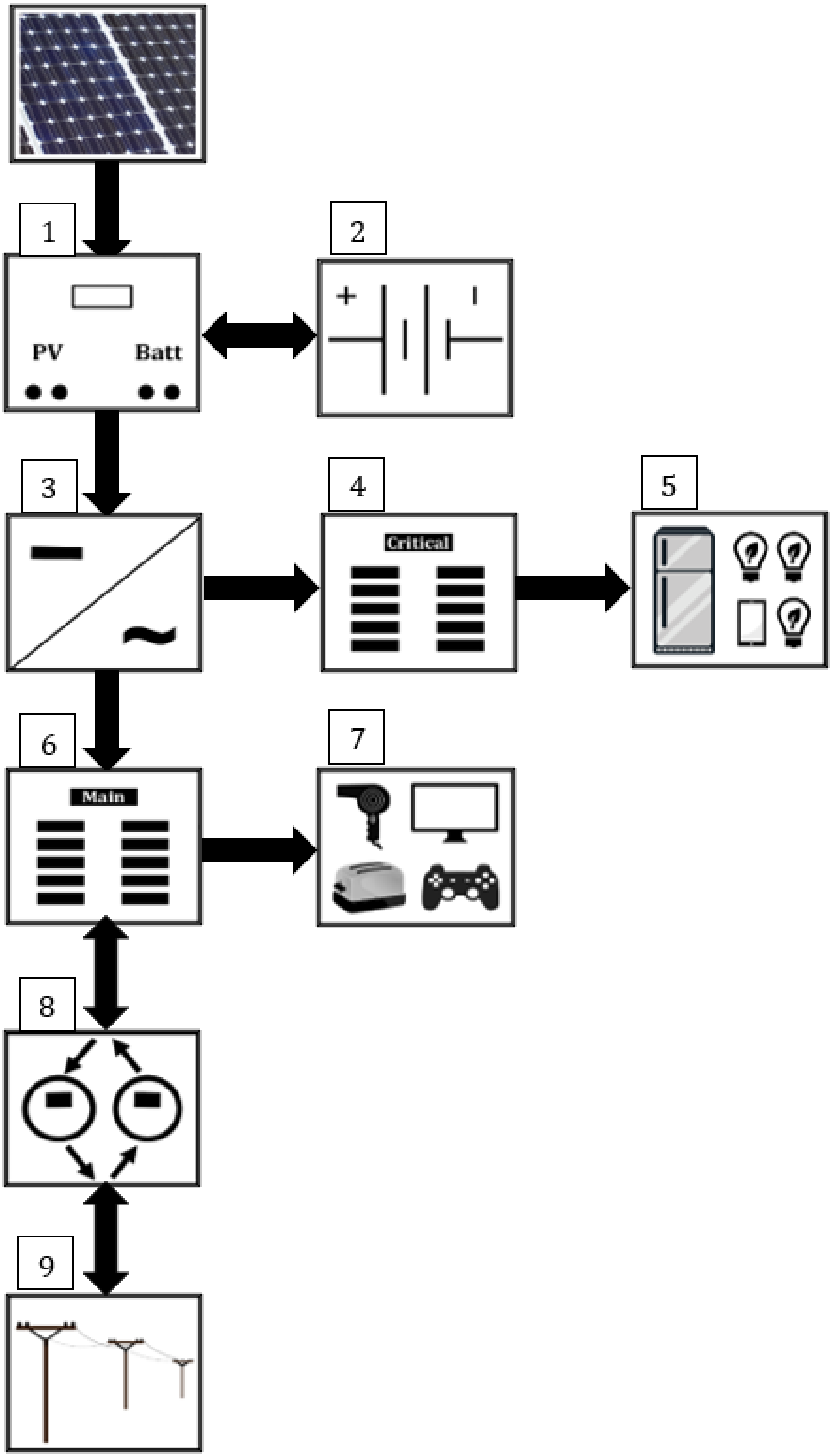
3. AC Stand-Alone system.



4. Grid-Connected system.



5. **Grid-Tied With Battery Backup** system.



Follow-up Questions

It is not expected that students will answer these questions with this kind of detail.

Several of these questions will require you to do some additional research to answer.

1. What is the purpose of a **charge controller**?

*** The charge controller directs the electricity produced from a PV system to the electrical load or to deep cycle battery storage. The charge controller also directs electricity from deep cycle battery storage to the load as needed. Protecting the batteries from being overcharged and overdischarged is another important function of the charge controller.**

2. When batteries are required, why must **deep cycle batteries** be used for electricity storage and discharge in solar PV systems?

*** Deep cycle batteries are designed and manufactured to be deeply charged for many steady and extended discharges throughout its life. This feature is required for anyone who wants to repeatedly and economically store and use electricity at a later time.**

3. What is the purpose of the **inverter**?

*** The inverter changes direct current (DC) electricity produced by a PV array into standard use, alternating current (AC) electricity.**

4. What is the difference between **net metering** and **dual metering** when the solar PV system is grid connected?

*** Net metering basically involves one meter, while dual metering involves two meters. With net metering, when a homeowner produces more electricity than is being used, electricity is directed to the grid. The meter registers an electrical credit. When a homeowner consumes more electricity than is being used, electricity is directed from the grid to the home. The meter now works in the opposite direction to register an electrical debit. At the end of the billing period the "prosumer" pays or receives the net balance on the meter. Dual metering results in the same net balance. However, there is one meter that registers all of the energy directed into the grid. There is a separate meter that registers all of the energy directed from the grid to the home. At the end of the billing period the "prosumer" pays or receives the net balance between the two meters. A dual metering system is necessary to take full advantage of a higher price being paid for the renewable energy produced compared to the standard price for electricity being consumed.**

5. Not mentioned until now in this lesson, a new piece of equipment called a **microinverter**, has recently begun to emerge in the solar PV market. What is a microinverter? Describe one important way the use of microinverters would change solar PV system design.

*** String inverters are in common use today. A string inverter is a single inverter that converts electricity from DC to AC for a string of solar modules connected in series. Microinverters still convert electricity from DC to AC. However, this is done at the module level. Each module's AC electricity is then combined and can be used or sent right into the grid. Generally, there will be one microinverter for each module in a solar array. For this reason microinverters are much smaller in size.**

A microinverter enables the module to which it is connected to perform at its maximum output at any moment depending on weather conditions, shading, and orientation to the sun. For this reason microinverters may be ideal for complex roof designs that face in multiple directions. By contrast a string inverter treats its entire string of modules like one big module. One module that is shaded or malfunctioning can drag down the performance of an entire string.

Microinverters also allow you to monitor the performance and output of individual modules in real time. This is usually done through a smartphone app or web portal. In this way problems with a PV module may be easily and quickly identified and addressed. As mentioned, a string inverter treats its modules like one big module. For this reason, problems with individual modules in a string are more difficult to troubleshoot.

[Microinverters usually come with a much longer warranty than a string inverter. But because of their location, they can be very difficult to replace. They are usually located on the back of each module. Also, because of this location, they are exposed to environmental conditions that are much harsher than a typical string inverter.]

6. Why is the **Grid-Connected system** the most commonly installed solar PV system in America today?

*** A grid-connected system can be installed in most places and is nearly always the least expensive to install. This type of system does not have to be engineered to "stand alone," generating and storing all of the electricity needed during periods of high electrical demand and low production.**

The primary difference between the two types of systems?

A "stand-alone" or "off-grid" system requires the use of batteries. Batteries:

- **are expensive**
- **take up space**
- **need periodic maintenance**
- **increase energy losses (Energy is lost when power is stored in the battery, and energy is lost when power is drawn from the batteries. This can vary greatly among battery types)**
- **may still require a backup electrical generation source**

Essentially a grid-tied system uses the entire electric grid as its virtual battery. Without batteries a grid-tied system:

- **is smaller, simpler, and much less expensive to install**
- **is easier to maintain**
- **is more efficient**
- **does not require a backup electrical generation source**

In general, a grid-tied system allows people to enter the renewable energy generation economy at an affordable price.