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Name: ______________________________

Date: ____ / ____ / ____ Class Hour: ____

SOLAR PV:
BALANCE OF SYSTEM EQUIPMENT
and SYSTEM DESIGN

A generation ago many people would have had a hard time determining what they were looking at in the photo above. Today just about everyone recognizes the solar panels in the picture. But ask how they work, and what other equipment--called “Balance of System” equipment--is needed to make them work, and most people are stuck.

There is much more to making a photovoltaic system work than just wiring panels into an electrical service panel and flipping a switch. PV systems need to be carefully designed and installed to meet an owner’s situation and objectives, and often, their budget.

In completing **BALANCE OF SYSTEM EQUIPMENT and SYSTEM DESIGN** you will:

1. **understand how solar PV systems can be engineered to meet different situations and goals.**

2. **learn what Balance of System equipment is needed to make various systems work and what each piece of equipment does.**

3. **produce energy flow diagrams of five PV systems placing equipment in electrical flow order, and showing the interactions between each piece of equipment.**

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.

With that in mind, let's improve your understanding of this unique source of renewable energy by working with these five general types of solar PV system designs!

1. PV Direct:

General Explanation:

Among PV system types, PV Direct is the least expensive, least common, the simplest and least versatile.

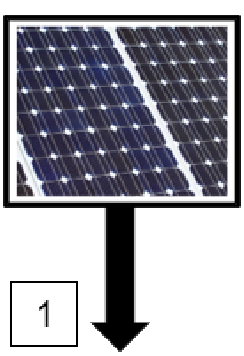
Since solar PV panels produce only direct current (DC) electricity, the appliance being powered must be engineered to run on DC electricity. With no other equipment involved, a PV Direct system may only power an appliance when adequate sunlight strikes a solar panel or array. The system is not connected to the electrical utility grid. It is not connected to battery storage.

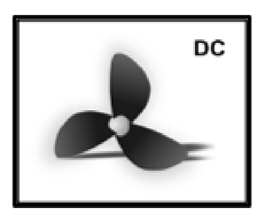
Electricity Flow:

Given adequate sunlight, electricity produced from a **solar panel or array** flows directly to an attached appliance **(electrical load [1])**. Usually the appliance being powered is not plugged in anywhere. Rather the appliance is directly wired into the solar panel or array.

Use the electricity flow narrative to correctly drag and drop the component into the electricity flowchart for this system.

1. PV Direct system.





2. DC Stand-Alone (off-grid system):

General Explanation:

DC Stand-Alone systems are not common in the United States. There is no device in this kind system to convert direct current (DC) electricity produced by the solar PV panels into standard use alternating current (AC) electricity. For this reason, appliances powered by this type of system must be engineered to run on DC electricity.

DC appliances are much harder to find than their more familiar, household current AC counterparts. They are usually more expensive, too. Loads powered through the system must be consistent. Loads must also be carefully matched to the system to avoid overcharging and overdischarging of the batteries, which are also part of a DC stand-alone system. As the name suggests, DC Stand-Alone systems are not connected to the electrical utility grid.

Electricity Flow:

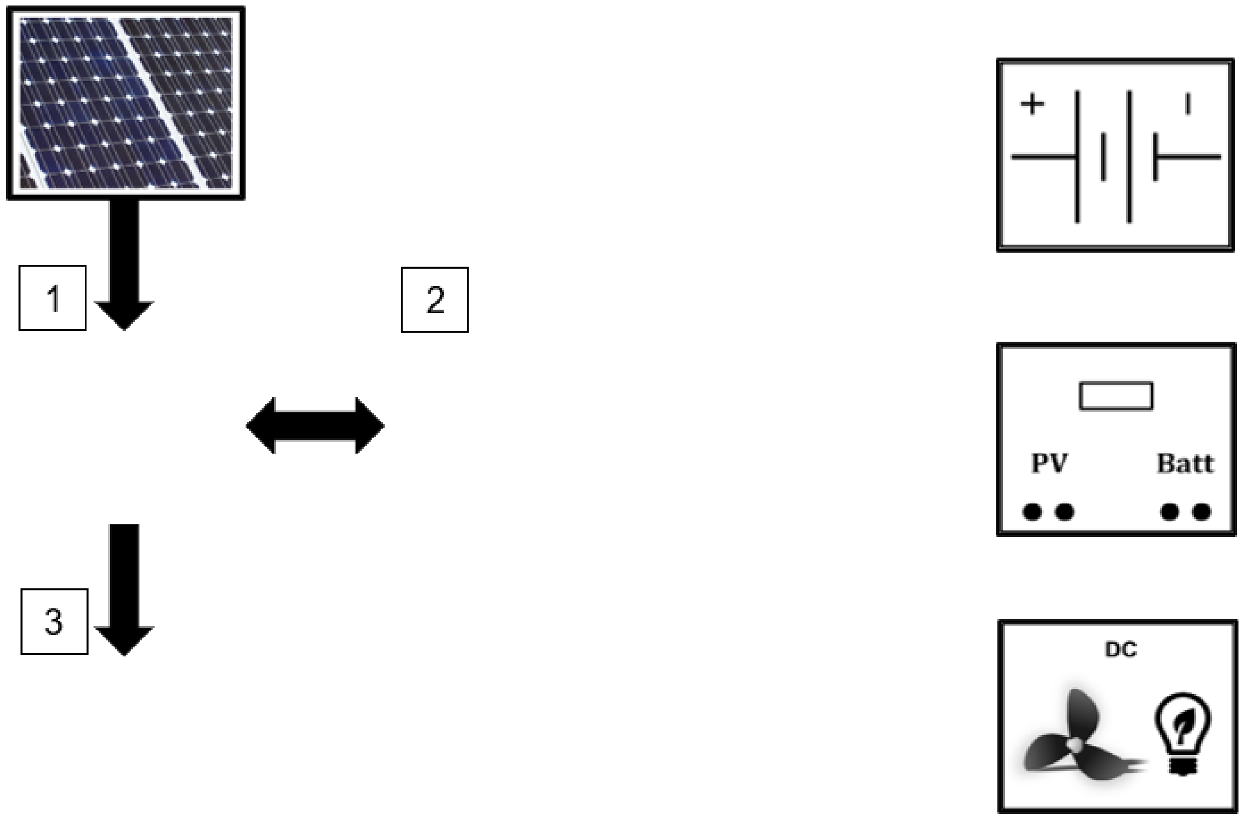
Electricity produced from the **solar panel(s) or array** flows to a **charge controller [1]**. The charge controller moves the electricity to deep-cycle **battery storage [2]** or to the DC load. The charge controller:

- fills batteries with electrical charge when they are low,
- protects batteries from being overcharged, and,
- protects the batteries from being overdischarged.

When adequate sunlight is not available to power the load, stored DC electricity flows out of battery storage. This stored electricity flows back through the charge controller and powers the **DC load [3]** connected to the system.

Use the electricity flow narrative to correctly drag and drop Balance of System and other components on the right into the electricity flow chart for this system.

2. DC Stand-Alone system.



3. AC Stand-Alone (off-grid system):

General Explanation:

As the name suggests, AC Stand-Alone systems are not connected to the electrical utility grid.

AC Stand-Alone systems are more common than DC Stand-Alone Systems. But they are not nearly as popular as PV systems that can interact with the electrical utility grid. Appliances connected to this type of system run on typical household Alternating Current electricity. For this reason, they may power a wider variety of less expensive appliances. Still, the system must be designed to carefully match expected loads. What's more, the addition of an inverter to convert direct current (DC) to alternating current (AC) electricity results in the loss of some energy in the conversion process, as well as additional cost.

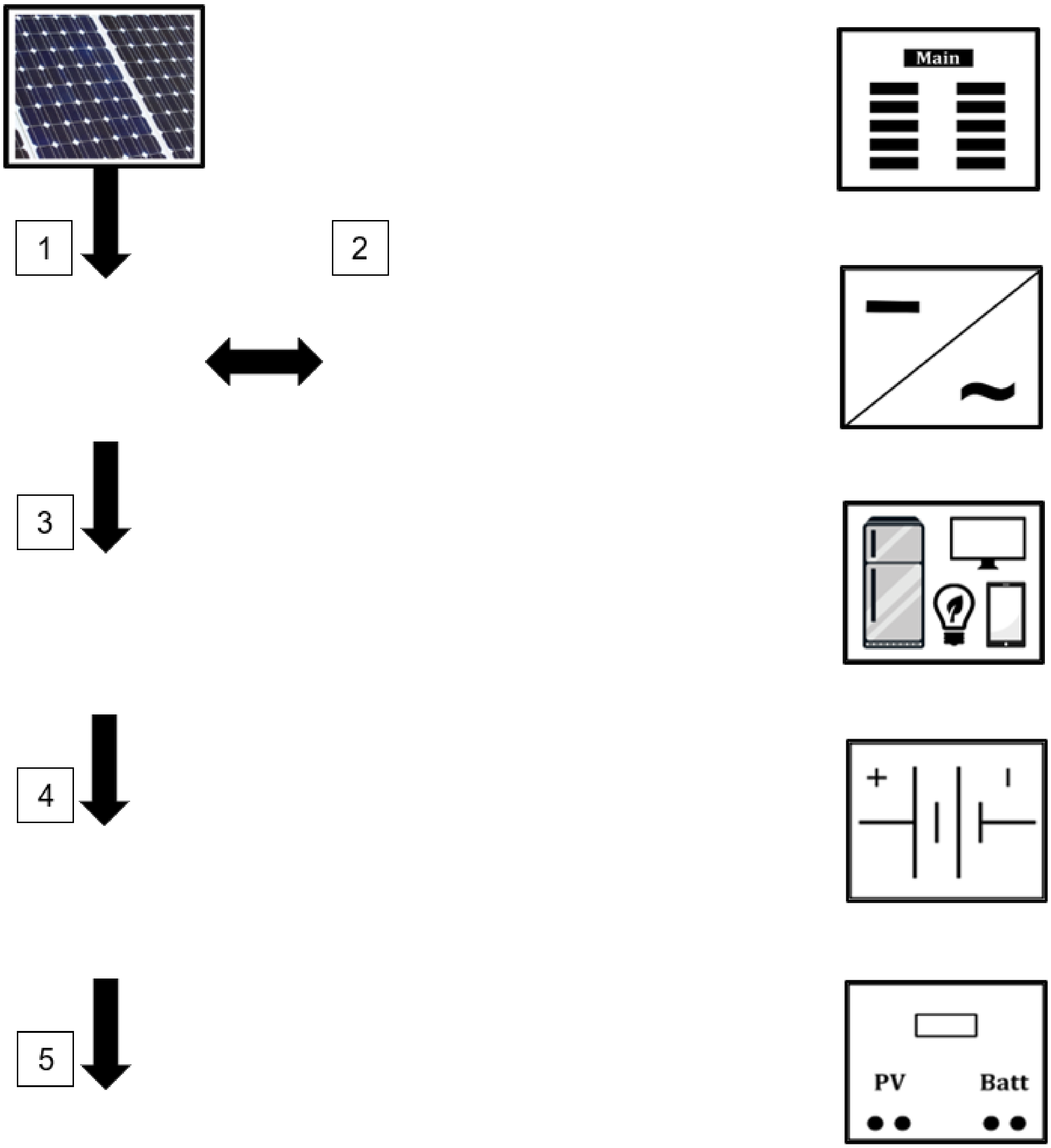
Electricity Flow:

Electricity produced from the **solar array** flows to a **charge controller [1]**, which moves the electricity to deep cycle **battery storage [2]**. The charge controller fills batteries with electrical charge when they are low and protects batteries from being overcharged. When stored electricity is needed to power loads, it flows back through the charge controller. In this situation the charge controller provides overdischarge protection to the batteries.

The electricity needed now flows from the charge controller to an **inverter [3]**. In the inverter, direct current electricity (DC, **—**) coming from the batteries is converted into standard use alternating current electricity (AC, **~**). The inverter makes AC electricity available to a **service panel [4]**, which in turn, serves the appliance **load [5]**.

Use the electricity flow narrative to correctly drag and drop Balance of System and other components on the right into the electricity flow chart for this system.

3. AC Stand-Alone system.



4. Grid-Connected (grid-interactive system):

General Explanation:

Grid-connected systems are far and away the most common and popular solar PV systems installed in America today. As the name suggests, grid-connected systems are connected to the electrical utility grid and interact with it. Grid-connected systems must produce AC electricity since utilities produce, and the electrical grid transports, alternating current electricity. Interaction with the grid is two-way. A grid-connected system may move some or all of the electricity it produces into the grid. At the same time the grid may supply some or all of the electricity the system's owner needs. Ideally the electricity produced and moved into the grid from the system will offset the electricity supplied to the owner from the grid.

A grid-connected system is often favored because it does not require or use battery storage. This makes it simpler and much less expensive to install. Permission and an interconnection agreement are always required to connect to the electrical grid. Local and national safety and technical standards must be properly followed to complete the connection.

Electricity Flow:

Electricity produced from the **solar array** flows to a grid-interactive **inverter [1]**. In the inverter, direct current electricity (DC, **—**) coming from the solar array is converted into standard use alternating current electricity (AC, **~**). The inverter makes AC electricity available to a **service panel [2]**, which in turn, serves the appliance **load [3]**.

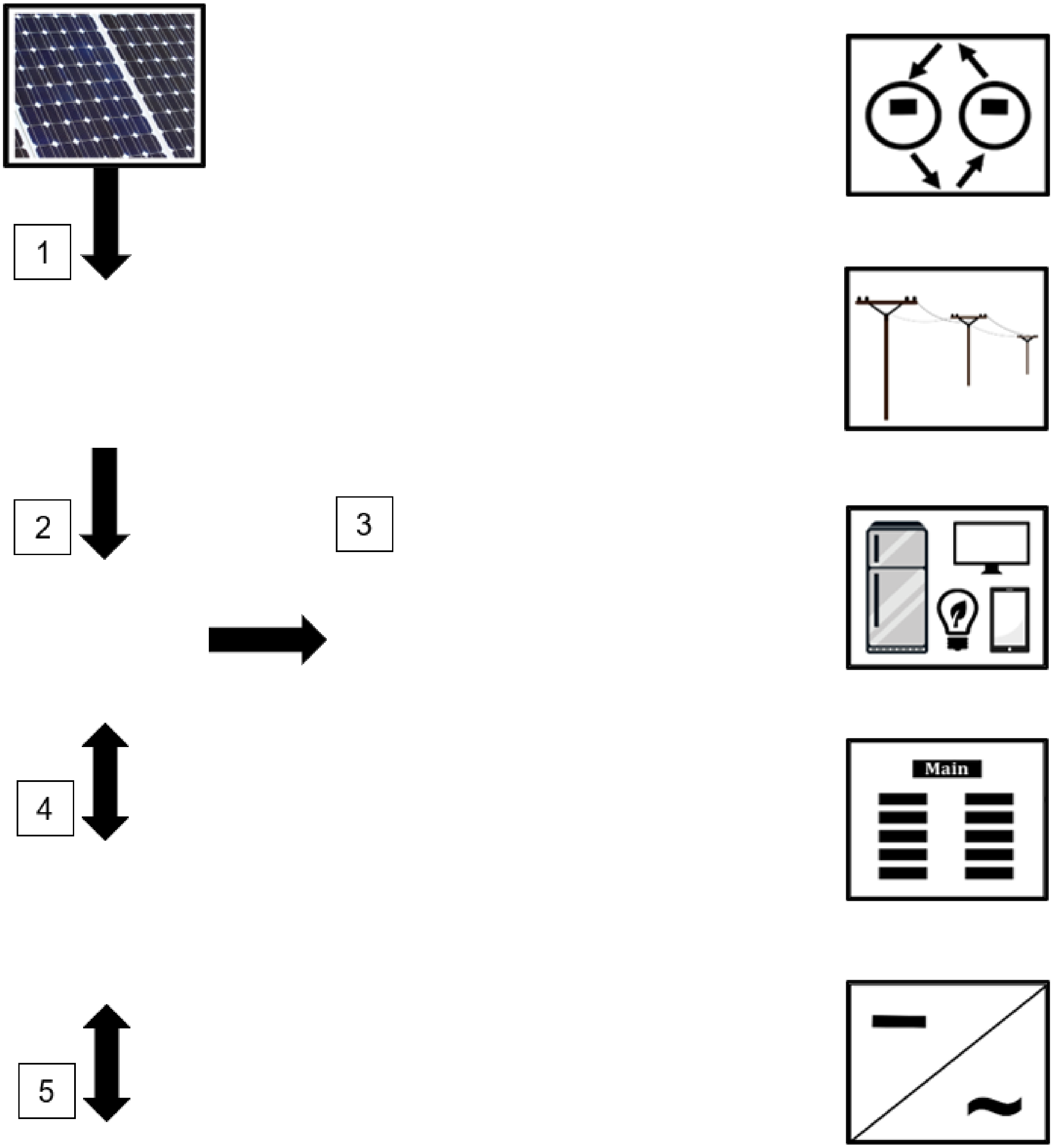
There will be times when more electricity is being produced by the system than is being used. When this happens, the inverter will move its AC electricity out to the grid through the same service panel. Before reaching the electrical grid, the outgoing electricity is metered. This can be done through a single meter that moves two ways (net metering). It can also be done through two meters (**dual metering [4]**) that separately track the electricity flowing out to, and in from the **electric grid [5]**.

The simplicity and convenience of this type of system is demonstrated whenever the electrical load is too large to be served by the PV system. This of course, happens in low and no sunlight situations, and times of unusually high electrical use. At these times the utility electrical grid is readily available to satisfy the owner's electrical needs. Electricity from the electric grid can flow to the service panel, in much the same way it would in a home without solar PV. However, it is net metered or dual metered on its way to the service panel. From the service panel the incoming electricity is available to service all of the owner's appliance loads.

Every grid-connected inverter is programmed to immediately shut down if a power outage occurs. Trying to restore power, line workers are in danger if a grid-connected system directs electricity to power lines they are working on. This type of shut-down is called "anti-islanding."

Use the electricity flow narrative to correctly drag and drop Balance of System and other components on the right into the electricity flow chart for this system.

4. Grid-Connected system.



5. Grid-Tied With Battery Backup:

General Explanation:

Among PV system types, Grid-Tied With Battery Backup is the most expensive and complex. With this type of system, the owner will be able to:

- *Produce and use their own electricity.*
- *Store their own electricity for emergency backup.*
- *Sell electricity into the grid when more electricity is being produced than used.*
- *Buy electricity from the utility grid when more electricity is being used than produced.*

Electricity Flow:

Electricity produced from the **solar array** flows to a **charge controller [1]**. The charge controller moves the electricity to an inverter or to deep cycle **battery storage [2]**. The charge controller fills batteries with electric charge when they are low, protects batteries from being overcharged, and protects the batteries from being overdischarged.

When batteries are fully charged, electricity flows from the charge controller to a grid-interactive **inverter [3]**. In the inverter, direct current electricity (DC, **—**) coming from the solar array is converted into standard use alternating current electricity (AC, **~**). In this type of system, the inverter makes AC electricity available to two electrical service panels.

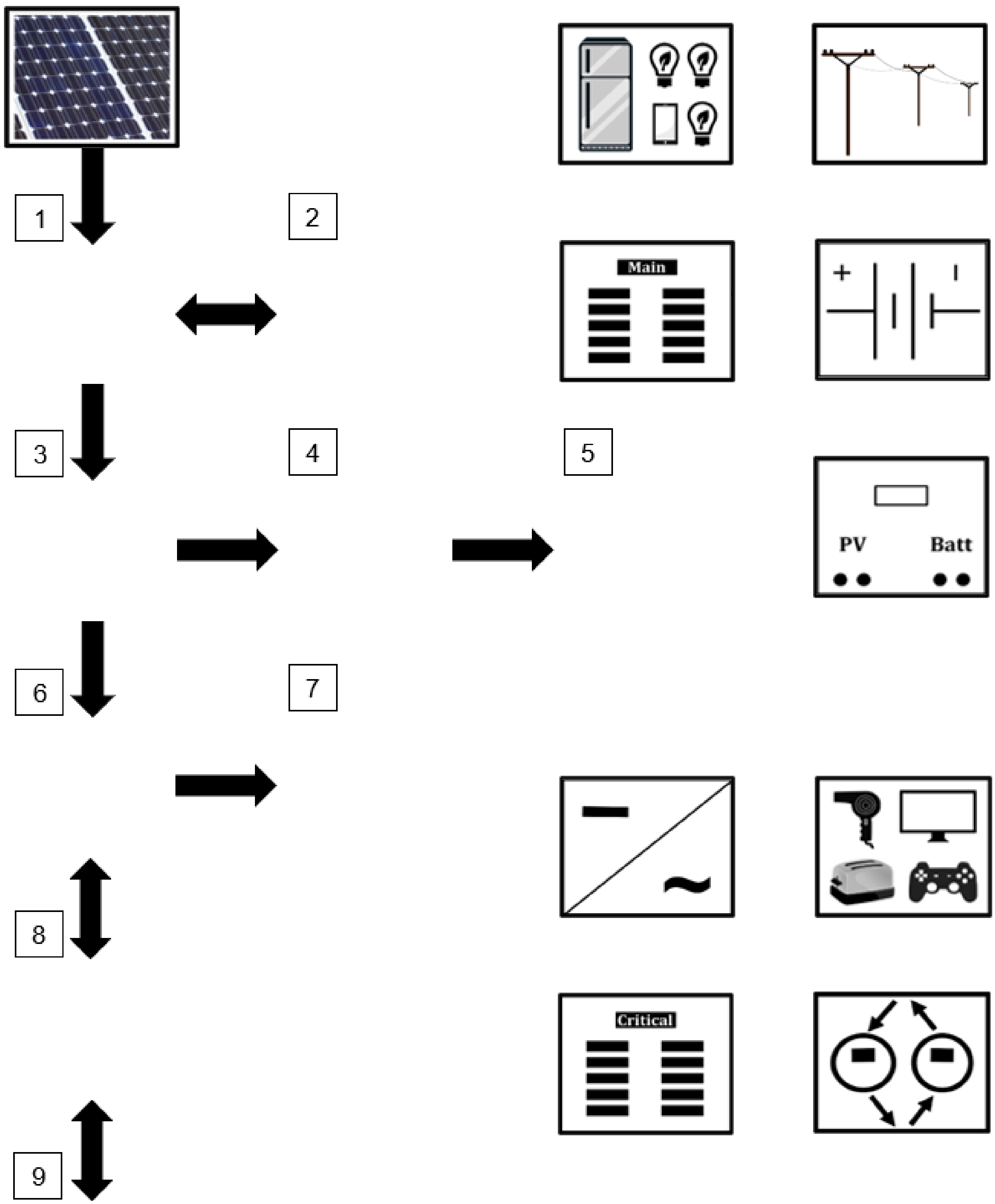
One service panel served by the inverter is the **critical loads service panel [4]**. It provides electrical service to all **critical appliance loads [5]** the owner wants to keep running if the electric grid goes down. The other service panel served by the inverter is the **main service panel [6]**. This panel provides electrical service to **non-critical appliance loads [7]**.

If there's no (or not enough) electricity being produced from the solar array both of these service panels receive electricity from the utility electrical grid. When more than enough electricity is being produced from the array, electricity will flow into the grid. This happens when the batteries are fully charged, and all appliance loads are met from the solar array. When electricity is purchased from or sold into the grid it is metered. This can be done through a single meter that moves two ways (net metering). It can also be done through two meters (**dual metering [8]**) that track the electricity flowing out to, and in from the **electric grid [9]**.

Electricity stored in the batteries can later be used to power critical loads if the electric grid goes down. This is why an owner will go to the expense of setting this system up in the first place--to protect critical loads in the event of a power outage. If the electrical utility goes down, the inverter connection to the main service panel is immediately disconnected. Electricity produced from the array cannot move in to the grid and loads from the main service panel cannot and will not be powered. However, all critical loads are protected and served from battery storage and further energy produced from the array.

Use the electricity flow narrative to correctly drag and drop Balance of System and other components on the right into the electricity flow chart for this system.

5. Grid-Tied With Battery Backup system.



Follow-up Questions

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

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

***Answer**

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

***Answer**

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

***Answer**

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

***Answer**

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.

***Answer**

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

***Answer**