Off the Grid Unit

Lesson 7 : Designing a Solar Phone Charger

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DESCRIPTION: This is the culminating activity for the unit “Off the Grid.” Students will be given some restricted parameters around which to design a solar powered battery operated phone (or other USB device) charger*.* They will charge the AA battery packs that have been using throughout the unit using photovoltaics, and then hook these battery packs into their USB charging device (for a phone, bike light, etc.). This process requires that they combine background knowledge such as voltage and current requirements for their devices they are charging, the function of boost and buck converters, and the correct construction of circuits. *Included at the end of this lesson is a written assessment for the entire unit.*

GRADE LEVEL (S): 7-8 or 9-12

SUBJECT AREA (S): Energy fundamentals, electrical circuits, **efficiency**

ACTIVITY LENGTH: 4-6 hours over one week

LEARNING GOAL (S):

1. Students will be able to design a device that can charge a phone with 4 hours of sun a day.
2. Students will use collected data and be able to support their design – i.e. the data will show that the unit will produce enough energy to charge a phone given it receives 4 hours of sun a day.
3. Students will also be able to calculate **efficiency** from their **power** calculations.
4. Students will be able to compare **efficiencies** of their circuit to others tested in this unit.
5. Students can calculate how much energy 4 hours of sunlight can produce on the solar modules they will use.

NEXT GENERATION SCIENCE STANDARDS:

- HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized

criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

COMMON CORE STATE STANDARDS:

- N-Q 1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- N-Q 2. Define appropriate quantities for the purpose of descriptive modeling.

Materials List

- Solar modules, assorted (3-6 V, 1-3 Watts) (about 2 each per group)
- Buck or boost converter – each group will receive one and they must work with this
- DC Power Plugs, male and female
- Shrink tubing and solder
- Wire strippers
- Battery Packs – depending on the group 2-AA, 3-AA, 4-AA, 6-AA, 8-AA and 10-AA
- (2-10) AA NiMH batteries, depending on the group (Warning: do NOT use Li-ion batteries for this activity!)
- Pelican waterproof case
- USB current/voltage meters
- Cell phone or device that uses a USB plug for charging – students can bring in a USB charging cord for their phone, or instructor can supply any USB charging device. I used LED bike taillights that charge with a USB.

Other Supplies

- Student Journals

Vocabulary

- Multimeter
- Power: $P = VI$
- Efficiency: $e = P_{out}/P_{in}$
- Boost
- Volts
- Amps
- Schematic
- Circuit Diagram
- Amp Hours
- Buck
- DC Power Plugs
- Current
- Voltage
- Solar Module
- Short Circuit

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Student Background

Students participating in this lesson should be familiar with the following:

- **Efficiency**
- **Multimeter use for both current and voltage**
- **Circuit Schematics**
- **Basic wiring**
- **Boost and Buck converters**
- **Battery Holders and configuring for target voltages**

Educator Background

Educators leading this lesson should be familiar with Off the Grid Lesson 4: *Exploring **Buck** and **Boost** Converters*, as well as student concepts above. Other useful background includes:

- Information from other lessons in the OTG Unit to find out about using **DC power plugs** and **ATC fuse** holders to make the systems easy to interchange battery packs, simplify solar charging, and easily measure **current** with a **multimeter** while diminishing the chance of a **short circuit**.
- "Peak sun" is the concept we are using when we talk about the battery having four hours of sunlight. We are going to assume that the sun is shining directly at the solar panel(s) (at 1000 Watts/m^2) for four hours. This is a good yearly average value for Washington. As a teacher, there are many extension activities you can go into and have students research and decide upon the practical number of hours of sunlight they can expect given the time of year and your location, which can add more variety to your culminating projects as each group may design a system for slightly different conditions. This does

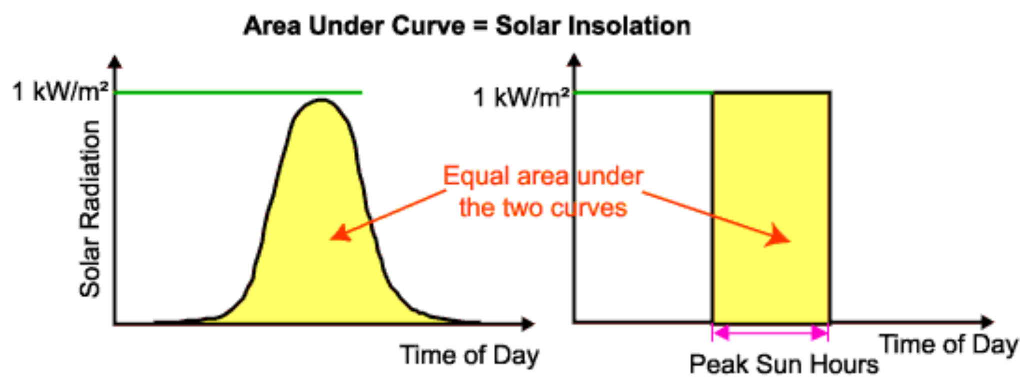

Figure 1. Peak Sun Hour Graph from pveducation.org

not need to be covered in any depth, but if students examined the effects of different angles on efficiency as an extension to Off the Grid Lesson 1, that understanding should be connected to the fact that we are assuming "full sun" for four hours. By all means change that value for your location! A quick google search of "peak sun hours" will yield easy access to your local or regional data.

- If you give students flexibility with the number of hours of charging, you will need to pay attention to their **rate of battery charging:** Charging batteries too fast *can* be dangerous. For the most part, these small experiments will have pretty low rates of

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charging, and we can exceed these values without too much concern. In large-scale systems, a special device called a “charge controller” regulates the rate at which the batteries charge. Batteries charging at too fast of a rate have the potential to have gas build up and the battery could explode. More simplistically, batteries that charge too fast will get too hot, which could cause permanent damage to the battery (explosion or decreased ability to hold a charge). All batteries have a rated value, C, which is measured in Amp-hours. For AA-batteries, they are really measured in milli-Amp-hours (mAh). A good rule of thumb is that a rechargeable battery should charge at a maximum rate of about $C/10$. Example:

- My Duracell rechargeable battery has a capacity of 2650 mAh (a Rayovac AA that I have is 1350 mAh). Essentially, the equation $C/10$ tells me that it should take 10 hours to safely charge the battery, and that safe rate of charging will be $2650\ mAh/10\ h = 265\ mA$, so I will assume that I do not want to charge the battery with any more current than 265 mA (135 mA for the Rayovac). However, it is acceptable to charge at twice that rate, so long as the battery is between 10-80% charged. Additionally, because we are not as concerned about the long-term quality impacts of our discharging, we can err a little on the high side (as a battery that gets a bit too warm will lose its ability to hold a charge faster).
- The solar modules that we used have a maximum current of 300-500 mA, which means that we’ll be charging up to twice as fast as is potentially recommended. This simply means that someone should occasionally check on charge rates of the battery systems and do a “heat test” to ensure that the batteries don’t feel way too hot.
- **Practically**, at that rate of charging, our solar battery charger to be designed for 4 hours of “peak sun,” should not ever fully charge. See Battery Charging Table in the lesson sequence below. Note that if we were to decrease the rate of battery charging by only supplying about 250 mA (by, for instance, adding a second battery pack or a resistor in parallel), then, given our assumptions, we would still (just barely) be able to sustain a fully charge on our phones.
- **If you’re very concerned about charging rates, simply use bigger batteries (C or D). We aren’t concerned about fully charging them, so the greater storage capacity will only help your “safe charging rate” of $\boldsymbol{C/10}$.**

- More on Solar Charging:
  - See Clayton Hudiberg’s Lesson 4: Designing a Solar Charger in his Solar Transportation unit for more details and ideas for solar battery charging. Note that he is using a 12 V battery, and is charging it slowly relative to the battery’s capacity.
  - There’s a great Solar Charging Tutorial created by Voltaic Systems that will guide you through the process if you need additional help, located (as of December 2016) at http://www.voltaicsystems.com/blog/solar-charger-tutorial-part-1/.
  - Information on charging NiMH batteries http://www.powerstream.com/NiMH.htm

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Lesson Details

Planning and Prep

Make sure that half the student teams have **Boost** converters and half of the teams have **Buck** converters. They should already have data on the efficiency of the converters from *Lesson 4: Exploring **Buck** and **Boost** Converters* in the Off the Grid Unit. Make sure to have a variety of battery holders available so students can evaluate what they need and choose it. You will also need a variety of small **solar modules** – from 3 – 6 Volts and 1-3 Watts. Students will also be figuring out their own solar module configuration.

This activity is primarily student driven, and they will need to first design their system on paper, then build it, then test it. The set up in the previous lessons in this unit is very helpful for wiring the circuits and preventing short circuits. The use of male and female **DC power plugs** can also be used for wiring the **Solar Module** to the battery packs, and the **ATC fuse** holders can be used for measuring charging current as well.

Lesson Sequence

Students should be divided into teams of 2-4 per team. Each team will be given a **Boost** of **Buck** converter to design their system around. Using past data for this converter from *Lesson 4: Exploring Boost and Buck Converters*, they will need to find the desired voltage for the input of their converter, the output voltage of it, and the # of AA batteries they will need to create the input **voltage** and the solar charging **voltage**. They should all create Table 1 (below) in their Journal, fill it in, and create a circuit diagram of their **Buck** or **Boost** converter, and also their solar charging circuit. After a teacher check in to make sure they are on the right track with Table 1, and circuit diagrams, they should begin setting up their circuits and wiring their solar modules for charging.

Table 1

Component: Buck or Boost Write which one below	Input Voltage What is the voltage you need or have to supply this converter?	Output Voltage This will be the USB voltage – they should all be the same	# of AA Cells How many cells or batteries will you need to reach input voltage?	Solar Charging Voltage The optimum solar charging Voltage you will need = # of cells x 0.5 V

Students should set up and run their converts to charge an item – phone, camera, bike light, etc. Students should use multimeters to evaluate how much current is leaving the batteries and what the battery voltage is in the Battery Stats Table. They should record this in their Journal and calculate the power the Batteries are supplying. Then they will need some sun to set the modules in and wire them into the battery packs – do not have the Buck and Boost converters hooked up at this point. They will need to measure Charging Current and Voltage of the batteries or panels (they will be the same) in order to calculate Charging Power in the Solar Charging Stats below.

Circuit Diagrams

Create a circuit diagram for your Buck or Boost Converter --- Be sure to label all components and show Battery and Input and output voltages	Create a circuit diagram for your Solar Charger --- Be sure to show Voltages of each module, polarity of the modules and total voltage of the array

Battery Stats Table

Current Leaving Batteries (Amps)	Voltage of Batteries (Volts)	Power Batteries are supplying (Watts)

Solar Charging Stats

Solar Charging Current (Amps)	Voltage of Batteries while charging (Volts)	Power Solar Modules are supplying (Watts)	Weather Condition Full sun, cloudy, rainy, etc.

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Students will next calculate how the solar charging helps extend the battery life and how long it takes for the sun to supply the battery with enough energy to run the USB device for 2 hours – which is usually at least a full charge.

Battery Charging Table

Amp-Hours of AA battery (Check manufacturer label)	Current Leaving Batteries (when powering USB device)	Full Sun Charging Current of Solar Array	Time to Solar charge battery from dead	Each Hour of Solar Charge =? Hours of Powering the USB charger	Approximate Hours to charge USB Device We will use 2 hours as a standard time	Hours of sun needed to supply all Energy to fully charge USB device
Example: 2.5 AmpHr	Example: 1 Amp	Example: .5 Amp	Example: 2.5/.5 = 5 hours	Example: 1/.5 = 2 hours	Example: 2 hours	Example: 2x2 = 4 hours
					2 hours	

Students should fill this table out. The example is meant to help figure out how to calculate the values that go in each box. Explain that this info is what we are after in this lab. The central question is: “With 4 hours of sun a day, how long can we continue to keep our phone charged, assuming we need to charge it at least 2 hours a day?” In the above example it works out that we need 4 hours of sun to get 2 hours of phone charging, so we can keep the phone charged indefinitely (until we get a cloudy day). If they need more than 4 hours of sun, the team should brainstorm about how they might increase the solar charging power in order to reduce the time to 4 hours or less.

Once all teams have completed this part of the lab, they should decide how they could put their system together in some creative way to make it robust and portable and possible protected from the weather. Yogurt containers to Pelican cases can be used to house the batteries and converters.

Students should compare their charging time with others in order to evaluate which system is the most practical – in that it is compact, robust, inexpensive, and gets powered up with the least amount of sun.

Each group should give a short presentation of their data from the above tables, and show the charger they created and justify their design.

Assessment:

Students will be given data and expected to “fill in the blanks” to come up with relative efficiencies of various scenarios.

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Final Assessment for Off the Grid Lab

1. You will be expected to fill in the blanks on both data tables below. Show all your work – with units and make sure your values you come up with have units as well. Fill in the blanks on the Data Table below:

24 V cell phone charger Buck Converter

	Cell Phone side of circuit					24 V side of circuit			
time	Voltage	Current	Power	Efficiency(%)		Voltage	Current	Power	Efficiency(%)
Average values	5.00V	1.00 A				25.0	.30		

Boost Converter

	Cell Phone side of circuit					3 V side of circuit			
Time	Voltage	Current	Power	Efficiency(%)		Voltage	Current	Power	Efficiency(%)
Average Values	5.00V			66.7%		3.0V		3.0W	

2. Evaluate the efficiencies of the Buck and Boost chargers above. You should answer the following:
   a. Which charger is most efficient?
   b. Which charger will charge the phone the fastest given the data above? Assume the same phone is being used in both of the above trials and it is at 50% of charge for both trials.

   Use data to support your arguments. Use complete sentences and write neatly.

3. A car is about 20% efficient in converting the chemical energy in the fuel into kinetic energy of moving the car. Comment on where you think the other 80% of the energy that was in the fuel goes. Since energy cannot be destroyed or created it must be accounted for.

Lesson Extensions

Energy Calculation for Batteries (optional)

Battery Pack Voltage (Total Voltage of your battery pack) (Volts)	Amp Hours for one AA Battery	Calculated Energy = Amp Hrs. x Volts =VoltAmphrs = WattHrs

You can delve into the energy storage of your batteries and energy from the modules for some set time interval and use that to evaluate solar chargers. You will get the same results, but it is a slightly different way of looking at it.

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