Solar Transportation

Lesson 3: Can PV technology be a practical technology for charging BEVs?

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DESCRIPTION: In this lesson, students will begin to explore the potential and challenges related to using photovoltaics to supplement the power needed to charge batteries in BEVs. Students will test a variety of wiring options related to series and parallel wiring. Once students have grasped the basics, they will measure the surface area of a passenger vehicle and calculate the approximate power that could be produced by integrated PV modules into the structure of the vehicle. Students will use these calculations to determine each of the following:

- The added mileage between plug-in charges that could be achieved.
- The amount of time required to charge the vehicle using only the PV modules within the structure of the car.
- The PV array size required to match the charge time boasted by Tesla Supercharger Stations.

GRADE LEVEL(S): 10-12

SUBJECT AREA(S): Amperage, Voltage, Electricity, Power, Energy Storage, Battery Charging

ACTIVITY LENGTH: 2 - 3 hours

LEARNING GOAL(S):

1. Students will explore the role of series and parallel wiring as they pertain to voltage and amperage.
2. Students will explore the processes involved with charging batteries and relate these processes to voltage and amperage.
3. Students will test photovoltaic modules to identify voltage and amperage outputs.
4. Students will calculate, using data from field tests, the maximum power that can be produced using photovoltaics within the constraints of a typical passenger vehicle's surface area.
5. Students will calculate charging times using various PV array power ratings.

NEXT GENERATION SCIENCE STANDARDS:

- HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

- HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- 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.
- HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles and energy associated with the relative positions of particles.

COMMON CORE STATE STANDARDS:

- High School Mathematics:
  - BF-F-2: Write arithmetic and geometric sequences both recursively and with an explicit formula, use them to model situations, and translate between the two forms.
  - F-IF-6: Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.

- High School ELA:
  - RST.11-12.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
  - RST.11-12.8: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
  - RST.11-12.9: Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Materials List

- Student Handouts #4 and #5 and #7 (one for each student)
- Student Handout #6 (one per student group)
- (2) SunWind 1.5V, 0.5Amp PV modules for each student group (can be substituted with different solar module)
- (1) multimeter for each student group

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Other Supplies

- Internet access
- Scientific calculators

Vocabulary

Please **bold** the vocabularly words as they appear in the text of this lesson plan.

- Voltage
- Amperage
- Series wiring
- Parallel Wiring
- Power
- Watts/kilowatt
- Amp hour
- Watt hour/Kilowatt hour

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Lesson Details

Planning and Prep

Use the student sheets and set-up photos provided to test the materials before students begin their exploration. The multimeters work great, but sometimes the leads can be finicky. It might be a good idea to have some extra leads on hand in case some of the groups run into problems. Be sure to safeguard against all the ways fuses can be blown as well (switching between current and voltage settings while connected, not turning off the multimeter, etc.). Students will get the best results when the sky is clear, but tests can be run on overcast days without skewing results too much.

Student Background

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

- Climate change and association with transportation
- Carbon cycle
- Renewable vs. non-renewable resources
- The basics of the photovoltaic effect*

*My students completed this lesson in conjunction with a 2-month unit on global energy in their AP Environmental Science class. Students can be successful with this lesson even if they don't really know how photovoltaic panels work.

Educator Background

- If you are not particularly confident teaching the structure and "how it all works" aspects of photovoltaic technology, you can probably learn to do so with a few hours of internet search. The YouTube video (in PowerPoint) you will show the students was also helpful for me as a primer.
    - Intro to Solar Electricity [Solar Schoolhouse] https://youtu.be/ZSviOnud7uY

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- Practice using the photovoltaic modules and multimeter under different conditions to anticipate student areas of confusion or difficulty. Student Handout #6 will help a lot with the set-up of the PV modules and multimeters.
- This lesson is designed for students with little to no background in electrical engineering or solar cell properties. Students will practice using a mathematical model to calculate power (P = IV), but they will not be setting up actual circuits (and therefore calculating actual power). Instead, they will calculate a theoretical maximum power using the highest possible voltage and current measurements for a given photovoltaic module.
- I have created answer keys for the calculations in case you might find them helpful.

Note on "maximum theoretical power":
For this activity, students are not setting up circuits with these photovoltaic modules. When they are measuring voltage, they are measuring the "open circuit" voltage, which gives the maximum possible voltage for a given illumination. When they are measuring current, they are short-circuiting the photovoltaic models. This is similar to short circuiting a battery, except that a photovoltaic module has a maximum current that it will produce whereas a battery can produce a nearly infinite current. For this reason, it is not dangerous to short-circuit these small photovoltaic modules. See Figure 1 for the difference between actual max power and the "theoretical max power" that students will be calculating.

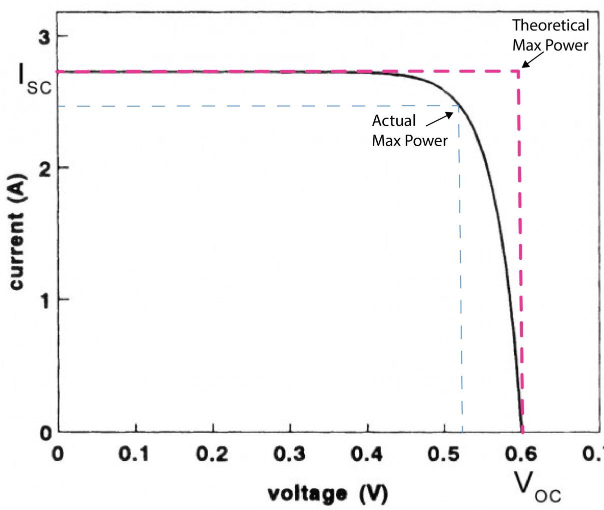

Figure 1 Photovoltaic I-V Curve. Maximum Power Point (Pmpp) identified alongside the value that students will calculate using Voc (Open Circuit Voltage) and Isc (Short Circuit Current). Note that this is for a given irradiance input. Students will be testing and calculating "theoretical max power" at different irradiance levels by altering the angle of the photovoltaic modules.

Lesson sequence (3 days)

Day 1:

<u>Opening (10 - 15 minutes)</u>

Hand out Student Sheet #4. The list of key vocabulary at the top of the student sheet should probably be addressed prior to watching the video. Feel free to employ your own personal methods for introducing new vocabulary.

Before showing PowerPoint, have the students read the prompt and guiding questions as a focus for their note-taking.

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Body (30 minutes)

Have the Photovoltaic and Battery Primer PowerPoint presentation loaded and ready to show the students. The slides are simply an outline and need to be supplemented with further explanation as you go. The YouTube clips are helpful, but optional.

Closing (5-10 minutes)

Have one set of the photovoltaic modules and multimeter ready to quickly review the key concepts regarding series and parallel wiring and to demonstrate how to use the modules. The students will be experimenting with the modules on Day 2.

Day 2:

Opening (10-15 minutes)

Allow 5-7 minutes for students to review their notes from yesterday. Provide 1 copy of Student Handout #5 to each student, and one copy of Student Handout #6 for each group of students. The handouts contain directions for how to use the PV modules and multimeters to experiment with the effects of various lighting conditions, series, and parallel wiring.

Body (30+ minutes)

Have students collect their materials and follow the directions from student handouts.

Conclusion (10-15 minutes)

When students are done collecting data, have a class discussion about their findings.

Day 3:

Opening (10 -15 minutes):

Have the students get organized by first taking out their results from yesterday's investigation. Spend some time reviewing their results and the basics of voltage, amperage, and power. Hand out one copy of Student Handout #7 to each student. Provide some instruction in some of the types of calculations they will be doing.

Body (30-40 minutes):

Students will be working on the calculations during this time. I would encourage them to work together and make frequent progress and accuracy checks. The goal of this lesson is to get everybody "on the same page" with regard to both the limitations and the potential of PV technology as it pertains to meeting the demands of a BEV.

Closing (5 minutes)

Run a quick class discussion of their findings.

Assessment:

I assessed with a small quiz in which the students had to make similar calculations to what they completed on student sheets 5 and 7.

Lesson Extensions

If you have access to Vernier monitoring equipment (A LabQuest, a Variable Load resistor, and an Energy sensor), students can identify the maximum power point for the solar module in its

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optimal position by twisting the variable resistor knob until the calculated power output reports a maximum value. This can also be done with multimeters and either a variable resistor or a set of resistors (start with Vernier's Resistor Board). In this latter case, students will want to record voltage and amperage for a given resistor and then plot results in Excel. They can then add a second plot that shows power using mathematical model P = IV. Note: Googling PV I-V Curve will give a number of examples of the Power-Voltage plot overlayed on an Amperage-Voltage plot.

Students could use the PV modules for water electrolysis and make similar calculations based on the values found for Hydrogen in lesson one. I had originally planned to do this as well, but the project seemed to be getting much too large.

You could also introduce the Tesla Power Wall and have students brainstorm how these could be used to better make use of smaller PV arrays.

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