POWERUP LESSON 5: SOLAR POWER DESIGN AND BUILD CHALLENGE

PowerUp Lesson Plan Overview

This lesson is one of six lessons developed as a classroom companion to PowerUp, a free, online, educational video game that allows students to experience the excitement and the diversity of modern engineering.

The lessons are designed to be flexible and scalable to meet your students' needs. Facilitation tips, extension activities and resources for learning more can be found in the Teachers' Guide, which is available for download along with each of the lessons. For these resources, as well as to download and play PowerUp for free, go to http://powerupthegame.org.

PowerUp was created by IBM and TryScience/The New York Hall of Science with scientific content and expertise provided by the Tech Museum of Innovation, the Bakken Museum, Idaho National Laboratory and the National Renewable Energy Laboratory.

STUDENT OBJECTIVES

Students will understand that the sun's energy in the earth's system is what drives the wind and water cycles, so ALL of the energy technologies that they have learned about thus far: energy harnessed from renewable wind and hydro power and even energy derived non renewable fossil fuels are, at their origins, examples of SOLAR energy.

Students will understand the differences between two methods of turning solar energy into electricity: photovoltaic technologies and concentrated solar thermal technologies.

Students read articles and look at pictures of large and small scale applications of these technologies, and consider what types of environments are best suited for their use.

Using the Tech Museum of Innovation Design Challenge Learning pedagogy as a framework, students are introduced to the interconnected phases of the design cycle: Investigate, Create, Reflect.

Students are given a design challenge: Design and build a product that concentrates, captures, and holds the sun's thermal energy to do a job.

Students are provided with printed background information including pictures of a number of solar powered products of various designs and scales, and worksheets with hints to help the team work together throughout the design process.

Students work with paper, pens and pencils and a collection of low-cost and recycled materials to conceptualize, construct and test their products. Student document their process by taking notes and drawing sketches and collecting them in a design portfolio.

Teams present their final designs (2D and 3D) to the other groups and reflect on their design process.

CLASS TIME

Period 1

- Solar Energy Discussion (15 minutes)
- Introduction to the Design Cycle (10 minutes)
- Begin Design & Build Challenge (15 minutes)
- Working in teams: Brainstorm, research, plan and sketch solar power designs

Period 2

- Working in teams, Continue Design & Build Challenge (40 minutes)
- Collect Materials
- Work on 2D and 3D designs
- Document process with notes and sketches
- Clean up

Period 3

- Set up 3D prototype in direct sunlight to test
- While testing products, Solar power discussion (20 minutes)
- Observe results, record data (5 minutes)
- Work on 2D and 3D designs – incorporate changes based on test results (10 minutes)
- Clean up (5 minutes)

Period 4

- Design & Build Challenge (15 minutes)
- Complete design portfolio and plan presentation (10 minutes)
- Clean up
- Present 2D and 3D designs. (15 minutes)

MATERIALS

- Research materials for learning more about large and small scale applications of Solar Energy. Some material for research is included in this teacher guide; you may want to supplement it with a collection of your own books, magazines, maps, computers with CD ROMS or internet connection.)
- Student brainstorming guides (included in this teacher guide)
- Binder clips or pocket folders to keep students and groups design portfolios together
- 1 sunny day and access to direct sunlight so that your students can test their devices.

Have students collect as much as possible from home:

- Cardboard boxes, different sizes
- ½ gallon milk or juice carton
- newspapers
- Aluminum pie plates
- manila folder/card stock
- Dark fabric
- Popsicle sticks
- Black construction paper
- Aluminum foil
- Clear plastic (heavy plastic laminate works best)
- Black tempera paint
- Craft glue
- Scissors
- per group – 1 non-mercury thermometer

NATIONAL SCIENCE STANDARDS 9-12

NS.9-12.1 Science as Inquiry

As a result of activities in grades 9-12, all students should develop understanding of:

- Abilities necessary to do scientific inquiry
- Understandings about scientific Inquiry

NS.9-12.2 Physical Science
As a result of activities in grades 9-12, all students should develop understanding of:

- Motions and Forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

NS.9-12.4 Earth and Space Science
As a result of activities in grades 9-12, all students should develop understanding of:

- Energy in the earth system

NS.9-12.5 Science and Technology
As a result of activities in grades 9-12, all students should develop understanding of:

- Abilities of technological design
- Understandings about science and technology

NS.9-12.6 Personal and Social Perspectives
As a result of activities in grades 9-12, all students should develop understanding of:

- Natural resources
- Environmental quality
- Natural and human-induces hazards
- Science and technology in local, national and global challenges

NS.9-12.7 History and Nature of Science
As a result of activities in grades 9-12, all students should develop understanding of:

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

CLASSROOM—GAME CONNECTIONS

When your students log in to PowerUp and play the Solar Mission they will have many opportunities to apply and investigate concepts addressed in this lesson. You may chose to have your students play PowerUp before the lesson, as a primer on photovoltaic technology and concentrating solar power plants and a review of energy concepts or you may assign gameplay for homework after this lesson to reinforce lesson concepts in a highly motivating context.

- **Careful experimentation leads to optimal design.**
  As students repair damaged turbines and generators in the game environment they will receive tailored feedback from an expert Engineer about the efficiency of their design and how much electricity each turbine is generating. If a turbine is not performing well the students must troubleshoot. They will learn through experience that success can be found when one variable at a time is isolated and tested.
- **Solar Energy can be transformed into electricity in two different ways: photovoltaic panels and concentrating solar power.**
  Students will explore and interact with each of these types of technologies as they

complete the game's solar mission. They will need to think critically and apply what they know about concentrating solar power and how it works in a solar cooker, and how it works on a large scale to generate electricity in a solar power tower. They will also apply their knowledge of photovoltaic (pv) technology to charge a solar-powered vehicle and take it for a ride.

PREPARATION

- Review Tips for Project Based Learning Section
- Decide how you will adapt lessons to fit your students' learning needs
- Plan your assessment strategy – adapt rubric as needed (See Rubric in Tips for Project Based Learning Section)
- Gather research materials on large- and small-scale applications of solar power
- Gather materials for building solar power devices
- Make copies of Student Pages (including background information about solar power and brainstorming guide)

FACILITATION

Solar Energy Discussion (15 minutes)

Begin by asking your students for examples of ways solar power is harnessed. They will likely list things that are powered by pv panels or cells, such as satellites in orbit, calculators, watches, battery chargers designed for camping, experimental solar vehicles, solar panels built onto roofs of houses or sides of skyscrapers. Tell them that these are all very good examples. Probe their knowledge of pv technology. How do pv panels work? What happens during the night time when there is no sun? (You may go choose to teach about how pv panels work in detail, or you may not. Resources are available in the background Information section) PV technologies convert solar energy directly into electricity that can power devices directly or can be stored in batteries to be used in a variety of ways at a later time.

Ask your students to think of any OTHER ways, besides pv technologies, solar energy is harnessed for practical needs.

Guide your students in a discussion about concentrated solar technologies which concentrate the thermal energy of the sun to generate electricity or to accomplish another practical task such as cooking food, sterilizing water, or heating a house.

Students have plenty of first-hand experience with the sun's thermal energy, but they may not know that this type of energy is used to create electricity in large power plants. The procedure is very similar as that used in the mechanics of a wind turbine, hydro power turbine and even in a fossil fuel powered plant: in order for energy to be transformed into electricity a generator shaft, must spin and electromagnetic induction must occur. Ask you students how the heat from the sun might be used to make a shaft turn. Concentrated solar energy is used to heat a transfer fluid (usually salt) to extremely high temperatures. The salt heats water into steam which is channeled toward pushes turbine blades, which it pushes with great kinetic energy. This spins the shaft and generates electricity. The hot, molten salt retains the heat of the sun for hours, so electricity can be made even when the sun has set.

Ask your students how sunlight might be concentrated in order to reach the high temperatures necessary for this process? Large arrays of reflective devices called heliostats surround the solar tower. They constantly move, tracking the sun throughout the day so that they always reflect the sun's direct light onto a receiver in the tower. (See picture)

Photo: National Renewable Energy Laboratory

That is one example of how the sun's thermal energy is used to generate electricity – what are some other ways the sun's thermal energy is harnessed to do a practical job? Elicit ideas from your students. (There are some examples of written descriptions, photos and diagrams of such devices included in the Background Information section of this teacher's guide.) Discuss the examples mentioned by students. Do these products/device have any features in common? (Perhaps they use certain colors, materials or shapes to collect as much of the sun's thermal energy as possible? Perhaps they use reflectors to concentrate the sun's energy? Maybe they use insulation to retain the sun's heat.)

Students may point out that solar energy drives the wind and water cycles and is the original energy source behind fossil fuels. This is an important point and a good one to re-emphasize, however, for this Design Challenge your students will be creating products that use thermal energy from direct isolation, rather than another type of renewable energy that originates from solar energy.

Introduction to the Design Cycle (10 minutes)
Explain to your students that for the next few days they will be working in groups on a design challenge. Their challenge is to design and build a device or a scale model of a structure that harnesses the thermal energy of the sun to do a practical task. (You may wish to pre-assign groups or to let the students form their own groups, do what works best for your students.)

Explain that in order to maximize the creativity and the knowledge of every group member the groups will work through cycles of investigate, create, and reflect. Engineers use these same cycles when solving problems and designing products. Explain that each cycle must be documented with sketches, diagrams, lists of ideas, and notes. These will be collected in a design portfolio. Each group will hand in a portfolio; each student is responsible for contributing to it.

The process starts with INVESTIGATE, and ends with REFLECT, but in the middle the process may go back and forth between the three cycles a bunch of times. Students may CREATE a prototype and ask for feedback from another student. As a group they may REFLECT and realize that they didn't take into account a certain constraint, and so the group may want to go back to INVESTIGATE and brainstorm some more ideas, and so on.

Investigate
The design process will begin with investigation, students will:
- identify the problem by reading a newspaper article
- brainstorm ideas and solutions (students will record ideas on handouts, provided)
- research the issues and possible solutions using materials provided and other books and online resources

Create, Re-create
- Select a solution from their brainstorming lists
- Design and construct a prototype
- Test
- Redesign or modify
- Retest

Reflect
- Share solutions
- Reflection and discussion

Period 1
- Begin Design & Build Challenge (10 minutes)
  - Distribute Brainstorming guides (optional - distribute a large binder clip or pocket folder for groups to clip all documentation together)
  - Working in teams, students: Brainstorm, research, plan and sketch hydro designs. Document design process with notes and sketches

Period 2

- Discuss Design Journal (5 minutes)
  - Remind the students that each group’s design journal should include notes from brainstorming sessions, sketches including a final sketch of the solution to be prototyped - with scale indicated, notes on the building process, details of testing, analysis of the trial, problem solving ideas/steps, etc.
  - Remind students that EACH student is responsible for contributing to the group’s journal - there is no assigned “recorder.” Discuss the value of recording all of your ideas – even the ones that don’t pan out and the ones the group does not pursue.

- Continue Design & Build Challenge (30 minutes)
  - Collect Materials
  - Work on 2D and 3D designs
  - Document process with notes and sketches

- Clean up (5 minutes)

Period 3

- Set up 3D prototype in direct sunlight to test (20 minutes)
  - While testing products, students work in groups on 2D designs and prepare for presentation
  - Observe results, record data (5 minutes)
- Work on 2D and 3D designs – incorporate changes based on test results (10 minutes)
- Clean up (5 minutes)

Period 4

- Finishing touches on 3D Design (15 minutes)
- Complete design portfolio and plan presentation (10 minutes)
- Clean up
- Present 2D and 3D designs. (15 minutes)

Student Pages

BACKGROUND INFORMATION

Photovoltaics

Solar cells, also called photovoltaics (PV) by solar cell scientists, convert sunlight directly into electricity. Solar cells are often used to power calculators and watches. They are made of semiconducting materials similar to those used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the *photovoltaic (PV) effect*.

Solar cells are typically combined into modules that hold about 40 cells; about 10 of these modules are mounted in PV *arrays* that can measure up to several meters on a side. These *flat-plate* PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. About 10 to 20 PV arrays can provide enough power for a household; for large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system.

Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Thin film technology has made it possible for solar cells to now double as rooftop shingles, roof tiles, building facades, or the glazing for skylights or atria. The solar cell version of items such as shingles offer the same protection and durability as ordinary asphalt shingles.

Some solar cells are designed to operate with concentrated sunlight. These cells are built into *concentrating collectors* that use a lens to focus the sunlight onto the cells. This approach has both advantages and disadvantages compared with flat-plate PV arrays. The main idea is to use very little of the expensive semiconducting PV material while collecting as much sunlight as possible. But because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the sunniest parts of the country. Some concentrating collectors are designed to be mounted on simple tracking devices, but most require sophisticated tracking devices, which further limit their use to electric utilities, industries, and large buildings.

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. Only sunlight of certain energies will work efficiently to create electricity, and much of it is reflected or absorbed by the material that makes up the cell. Because of this, a typical commercial solar cell has an efficiency of 15%—about one-sixth of the sunlight striking the cell generates electricity. Low efficiencies mean that larger arrays are needed, and that means higher cost. Improving solar cell efficiencies while holding down the cost per cell is an important goal of the PV industry, NREL researchers, and other U.S. Department of Energy (DOE) laboratories, and they have made significant progress. The first solar cells, built in the 1950s, had efficiencies of less than 4%.

From the National Renewable Energy Lab www.nrel.gov/learning/re_photovoltaics.html

Photovoltaic panels power the following:

This household in Stelle, Illinois

Photo: Linda Nellett.

The International Space Station

Photo: NASA

Small electronic devices in these solar-powered pockets

Photo: Russell Neches

This aerodynamic car

Examples of devices that use solar thermal energy, and how they are built:

A woman in Ghana uses a mass-produced solar cooker, called a CooKit.

Photo: Tom Sponheim

Bread bakes in a home-made solar oven.

Photo: Abri le Roux

“Solar cookers come in different shapes and sizes but all share certain design features that allow users to cook food using the sun's heat and light. The basic principles of solar cooker design are:

- **Concentrating sunlight**: Reflective panels catch the sun's rays and bounce them back to a small cooking area. These reflectors collect the suns energy from all around the cooker and intensify it, focusing the light and heat in one area.

- **Converting light to heat**: The insides of solar cookers are often painted black or are constructed with black materials. Black absorbs all of the suns' light and stores it as heat. The color and material of pots used in solar cookers also impact efficiency of solar cooking. Using black pots and pots made of materials that are good conductors of heat results in faster, more efficient cooking.

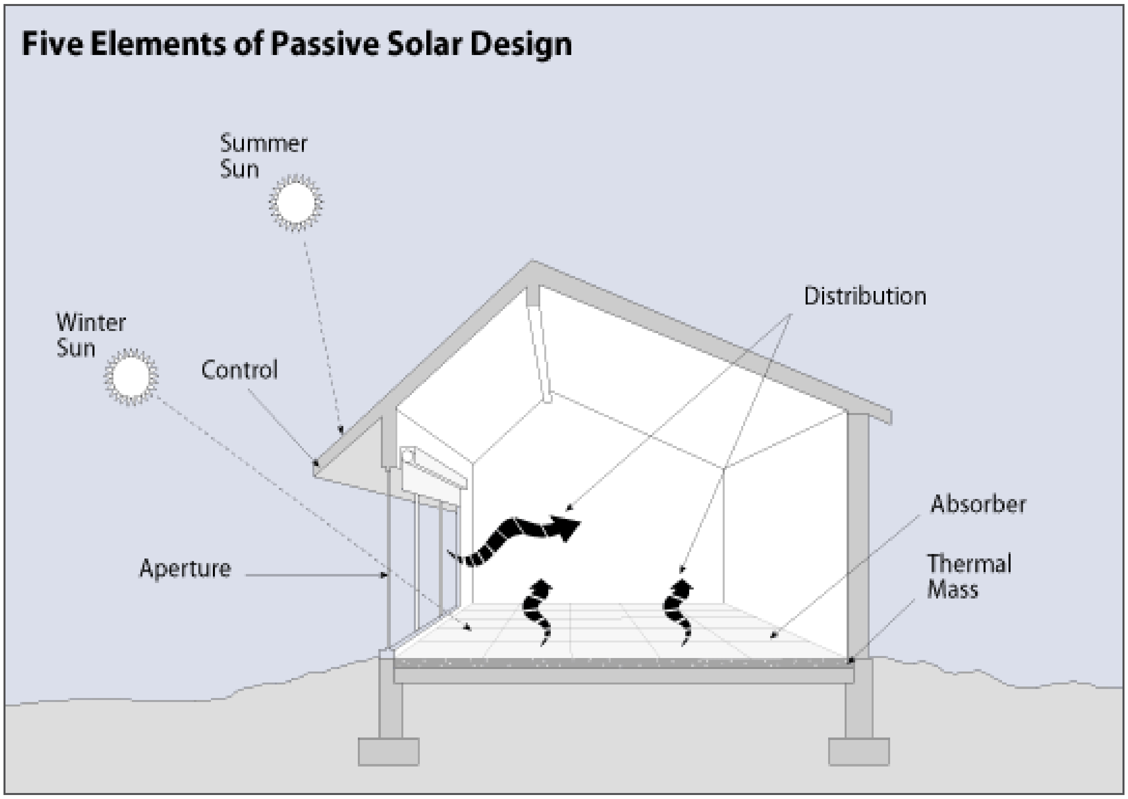
- **Trapping heat**: Once the sun's thermal energy is concentrated on the materials that make up the solar cooker and the pot holding the food the temperature of the air inside the cooking chamber begins to rise. For maximum efficiency, cooler air from the outside must not get in. A clear plastic or glass barrier allows the sun's energy in and prevents hot air from circulating, trapping the heat using the Greenhouse Effect. This makes it solar cookers just as useful on cold and windy days as well as on hot days.”

Designing buildings that rely on solar power for heating uses the same principles as designing a solar cooker. The design must collect solar energy, convert light to heat, store thermal energy and distribute it throughout the space. Are there any other ways these principles could be applied to solve a problem?

Five Elements of Passive Solar Home Design

The following five elements constitute a *complete* passive solar home design. Each performs a separate function, but all five must work together for the design to be successful.

- **Aperture (Collector)**: The large glass (window) area through which sunlight enters the building. Typically, the aperture(s) should face within 30 degrees of true south and should not be shaded by other buildings or trees from 9 a.m. to 3 p.m. each day during the heating season.
- **Absorber:** The hard, darkened surface of the storage element. This surface—which could be that of a masonry wall, floor, or partition (phase change material), or that of a water container—sits in the direct path of sunlight. Sunlight hits the surface and is absorbed as heat.
- **Thermal mass**: The materials that retain or store the heat produced by sunlight. The difference between the absorber and thermal mass, although they often form the same wall or floor, is that the absorber is an exposed surface and thermal mass is the material below or behind that surface.
- **Distribution:** The method by which solar heat circulates from the collection and storage points to different areas of the house. A strictly passive design will use the three natural heat transfer modes—conduction, convection and radiation—exclusively. In some applications, however, fans, ducts, and blowers may help with the distribution of heat through the house.
- **Control:** Roof overhangs can be used to shade the aperture area during summer months. Other elements that control under- and/or overheating include electronic sensing devices, such as a differential thermostat that signals a fan to turn on; operable vents and dampers that allow or restrict heat flow; low-emissivity blinds; and awnings.



Source: U.S. Department of Energy, Energy Efficiency and Renewable Energy Website, www.eere.energy.gov

YOUR DESIGN CHALLENGE

Your group will use its collective imagination and understanding of solar energy and passive solar design to design and build a product prototype that concentrates, captures, and holds the sun's thermal energy to do a job.

Brainstorming Tips:

- No criticism allowed! All ideas are welcome. Do not judge ideas at this stage
- Work for quantity: aim to record 50 different ideas
- Hitch hiking is welcome: try riffing on, modifying and expanding other's ideas
- Silly and outrageous ideas are encouraged: often the zaniest ideas contain some hint that will inspire or help solve a problem
- Use words, pictures, doodles, analogies and diagrams to describe your ideas
- If you get stuck, start another list to come up with the WORST design ideas possible