National Aeronautics and Space Administration

# Solar Energy for Space Exploration
# Teacher's Guide

**GRADE LEVEL: 6 to 12**
**SUBJECT: Physical Science**

# Solar Energy for Space Exploration

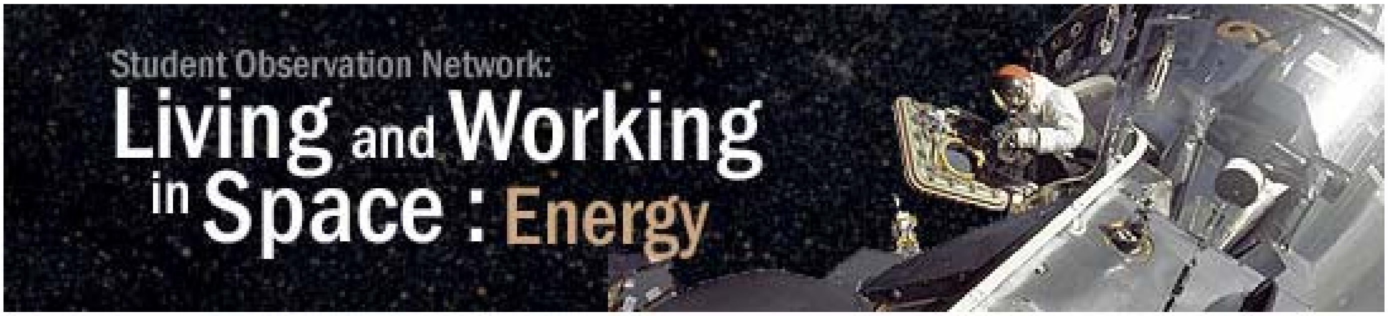
## Table of Contents

Introduction 4
Objectives 4
Unit Overview 5
**1. Introduction: Scenario and Problem 5**
**2. Investigating Solar Cells 5**
**3. Electricity and Power 5**
**4. Solar Power for Your Home 5**
**5. Solar Energy for the Moon and Mars 5**
General Background 6
Preparation and Procedures 8
**1. Introduction: Scenario and Problem 8**
**2. Investigating Solar Cells 8**
Activity 1: Investigating Solar Cells - Journal Assignment 9
Activity 1: Investigating Solar Cells - Investigation A 9
Activity 1: Investigating Solar Cells - Investigation B 11
**3. Electricity and Power 11**
Teacher's Notes 11
Procedures 11
**4. Solar Power for Your Home 12**
Teacher's Notes 12
Procedure 13
Resources 13
Additional Internet Resources 14
**5. Challenge: Solar Energy for Moon and Mars 14**
Teacher's Notes 14
Procedure 14
Design Solution to Problem 15
Math Connections - Solutions 16
**Teacher's Resources** 17
Standards 18
**National Science Education Standards 18**
Grades 5-8 18
Grades 9–12 18
Five Es 20
**Student Assignments** 21
ISS, Moon, Mars, and Beyond 22
**Scenario 22**
**Challenge 22**
**Overview 22**
**Activity 1. Investigating Solar Cells: Journal Assignment 23**
**Activity 1. Investigating Solar Cells: Investigation A 24**
Purpose 24
Materials per Group of Students 24
Procedure 25
Questions 25

# Solar Energy for Space Exploration

## Table of Contents - Continued


**Activity 1. Investigating Solar Cells: Investigation B .......... 26**
Purpose .......... 26
Procedure .......... 26
**Activity 2. Electricity and Power .......... 27**
Procedure .......... 27
**Activity 3. Solar Power for Your Home .......... 28**
Background .......... 28
Procedure .......... 28
Resources .......... 29
Additional Internet Resources .......... 29
**Activity 4. Final Problem: Solar Energy for Moon or Mars .......... 30**
Background .......... 30
Procedure .......... 30
Resources .......... 31
Design Solution to Problem .......... 31
**Student Resources** .......... 32
Interview with a PHALCON (Power, Heating, Articulation, Lighting and Control) .......... 33
Solar Arrays for the International Space Station .......... 36
**Math Connections .......... 38**
Model Space Station: Power Loads and Assembly Sequence .......... 39




## Introduction

How does NASA (National Aeronautics and Space Administration) provide energy to the ISS (International Space Station)? How will NASA provide energy for research habitats on the Moon and Mars? In the 5-E model the NASA exploration context provides an exciting Engagement. During the Exploration and Explanation phases students learn about energy, power, electrical circuits and solar panels. The student investigations and design problems in **Solar Energy for Space Exploration** provide opportunities for Extension and Evaluation of fundamental concepts.

**Solar Energy for Space Exploration** is a problem-based learning activity (PBL). The culminating project requires students to propose and defend a design to provide power to a lunar or Martian research habitat for six explorers. To prepare for this final project, students will investigate the variables that affect the operation of solar panels, learn about energy, power, and circuits, design a solar energy system to meet the power requirements for their own homes, and learn about the solar panels and energy use on the ISS.

While understanding solar cells (or photovoltaic cells) is not included in National Science Education Standards, this short unit provides an exciting context for students to study energy, transfer of energy, electricity, and circuits—understanding of these concepts is required for students in grades five - eight. In addition, the context of providing solar energy for the ISS and for research habitats on the Moon and Mars provides an excellent way to introduce and reinforce the unique position of the Earth in the solar system. For older students, the study of photovoltaics can be an extension and a great way to demonstrate practical applications of many of the standards in Physical Science (Grades 9-12).

## Objectives

1. Given solar cells or panels, students list variables that affect the operation of solar panels and explain how these variables affect the power production of solar panels.
2. Through computer simulations and laboratory investigations with electricity, students create parallel and series circuits, calculate power, and apply this knowledge to solve a theoretical problem on the ISS.
3. By analyzing the power requirements of their own homes, students design a solar system that could supply the power to their home.
4. Using the ISS as a model, students propose and defend a design to provide power for a lunar or Martian research habitat for six explorers.

Mastery of these objectives will depend on classroom expectations. Teachers are encouraged to develop rubrics and levels of mastery consistent with requirements.

## Unit Overview

This unit is structured as a problem-based learning (PBL) activity. There are five student sections to the PBL—an introduction and four activities. For your convenience, a brief description of each section is provided below. Web resources are also shown below. Student handouts are available in the **Student Assignment Pages** and **Student Resources** sections. **Teacher Notes** provide specific information for each activity when necessary and are provided in **Preparation and Procedures** section. The **Teacher Resource** section at the end of the document contains resources for additional information and Standards.

1. Introduction: Scenario and Problem (15 minutes)
   This page provides the challenge for the students.
   - **Solar Energy for Space Exploration –** student handout

2. Investigating Solar Cells (two or three 45-minute periods)
   In this investigation, students will learn about solar cells and what variables affect their operation.
   - **Activity 1: Investigating Solar Cells - Journal Assignment –** student handout
   - **Activity 1: Investigating Solar Cells - Investigation A –** student handout
   - **Activity 1: Investigating Solar Cells - Investigation B –** student handout

3. Electricity and Power (3 –4 weeks)
   Students will do the core concept development and meet core proficiencies in this section. Through computer simulations and laboratory work with electricity, students will learn about electricity, circuits, and power and apply this knowledge to solve a problem on the ISS.
   - **Activity 2: Electricity and Power** – student handout
   - **Electricity and Power in Space -** http://iss.cet.edu/electricity/default.xml

4. Solar Power for Your Home (three to four 45-minute periods)
   Students will analyze the power requirements for their homes and propose designs that will use solar panels to supply all of the energy needs. Work may be done in small groups or individually.
   - **Activity 3: Solar Power for Your Home** – student handout
   - **Surface Meteorology and Solar Energy -** http://eosweb.larc.nasa.gov/sse/
   - **Solar Energy Technologies Program** – http://www1.eere.energy.gov/solar/photovoltaics.html
   - **Roofus' Solar and Efficient Home -** http://www1.eere.energy.gov/kids/roofus/index.html
   - **Solar Power Basics** - http://www.solarelectricpower.org/index.php?page=basics&subpage=pv&display=

5. Solar Energy for the Moon and Mars (two to three 45-minute periods)
   Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS.

Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

- **Activity 4. Final Problem: Solar Energy for Moon or Mars** – student handout
- **Interview with a PHALCON** – student handout
- **Solar Arrays for the International Space Station** – student handout
- **Power to the Station** http://liftoff.msfc.nasa.gov/news/2001/news-stationpower.asp
- **Model Space Station – Power Loads and Assembly Sequence** – student handout
- **The Inconstant Sun** – http://science.nasa.gov/headlines/y2003/17jan_solcon.htm
- **Measuring Solar Radiation** – http://son.nasa.gov/lawis/energy/problem/solar_constant.pdf

## General Background

This section provides general background information. Teacher's Notes provide specific background information for each activity in the **Preparation and Procedures** section.

NASA uses several different technologies for providing energy for space exploration. Each technology meets the requirements for different types of exploration. For space exploration close to the Sun (near the inner planets—Mercury, Venus, Earth, and Mars), solar power with battery backup is often an optimal option. This PBL will explore the use of solar panels as a power source. In the process, students will learn core classroom concepts relating to energy, energy transformation, electricity, and circuits.

For this PBL, it isn't necessary for you or your students to understand the operation of solar cells (photovoltaics). However, you may find the background information on photovoltaics contained in Secondary Solar Energy Teacher Guide and the Secondary Solar Energy Student Guide produced by the NEED (National Energy Education and Development) Project helpful http://www.need.org/curriculum.php.

Solar cell technology is improving rapidly. The solar cells used on the ISS are about 12 percent efficient. Those developed for the Mars Rovers are about 26 percent efficient. Current solar cells have higher efficiency. The students will have to do some research to determine the efficiency. When NASA engineers plan a mission, they have to know all of the specifications for all of the components, and the components have to be space tested. Sizes, electrical characteristics, masses, and connections must be known at the beginning of the planning. Since a mission might take 10 years to plan and construct, equipment might be 10 or more years "outdated." Your students will have to work with the same restrictions. They will be required to use solar cells that are currently available. They will have to research current technology.

A number of variables affect solar cell operation. Students will brainstorm, predict, and test variables in **Activity 1: Investigating Solar Cells**. Let students discover—guide students; do not lecture.

The following background information will help you to guide students more effectively. The critical variables that affect solar cell performance—other than the efficiency of the cell itself—affect the intensity of light on the solar cell. There are several factors that affect intensity:

Blocking - Natural conditions can block solar radiation from reaching the solar cells. Earth's atmosphere can partially block incoming solar radiation. The amount of light reaching Earth above the atmosphere is about 1366 Watts per square meter. When the Sun is directly overhead at the Equator, the intensity of solar radiation reaching Earth's surface is between 800 and 1,000 Watts per square meter. On the Moon and on Mars, solar panels can be blocked by dust. It was expected that the solar panels on the NASA Mars Rovers would become covered with dust and cease to provide energy for the systems. A chance dust devil swept the panels clean. Dust devils occur frequently enough on Mars that Rover panels are kept relatively clean.

Angle - The angle between the Sun and the solar panel is critical. The intensity of light is measured in the Watts (power) per square meter. You can experimentally quantify how the angle changes the intensity. Hold a flashlight directly above a sheet of graph paper. The light source is at 90° to the paper. Count the number of squares illuminated. Keep the flashlight at the same distance from the paper, but tilt the flashlight so that it is at an angle to the paper. This represents a lower Sun angle. Count the squares illuminated again. More squares will be illuminated at the lower angle. The power of the light stays the same, but the area lit increases as the angle gets lower. When the same amount of power is spread over a larger area, the intensity decreases. The 23.5° tilt of the Earth's axis determines the angle of sunlight. The Sun is overhead in June in the Northern Hemisphere at the Tropic of Cancer at 23.5° N. latitude. The Sun is overhead in January in the Southern Hemisphere at the Tropic of Capricorn at 23.5° S. The GEMS (Great Explorations in Math and Science) Guide, *The Real Reasons for the Seasons,* could be used during this lesson to help students to understand how the tilt of the Earth's axis affects the light intensity and the seasons. The axis of Mars is tilted at 25°, so very similar conditions prevail on Mars except the year is longer and each season is longer than Earth's. During the winter on Mars, the Rovers are parked on the slope of a hill to point the solar panels more directly at the Sun. As the International Space Station orbits Earth, the solar panels can be rotated to point more directly at the Sun. At times, the entire space station is pointed in a different direction to improve the angle of the panels and the Sun. For more information see *What are ISS Attitudes?* http://spaceflight.nasa.gov/station/flash/iss_attitude.html.

Distance from the Sun - As you know, the further you are from a light source, the dimmer (less intense) the light is. Students can confirm this experimentally and discover that the intensity (I) of light is inversely proportional to the square of the distance (r) from the light source ($I \propto 1/r^2$). You will need a light bulb, a meter tape measure, and a light intensity probe. In a dark room, measure the intensity of light at 10 cm, 20 cm, 40 cm, and 80 cm from the light. Plot Intensity versus distance. If you plot this curve on a graphing calculator, you can also obtain the equation for the curve.

The intensity decreases because the light spreads out farther away from the source. The Sun emits light energy in all directions. The light of the Sun is spread out over the surface of an imaginary (hollow) sphere with its center at the Sun. The farther the sphere is from the Sun, the bigger the sphere is and the more surface it has (surface area of a sphere = $4\pi r^2$). So, the power (energy per second) emitted by the Sun as light spreads over the surface of this imaginary sphere. Close to the Sun, the sphere is small. There is a lot of power per square meter (Intensity). Farther away, the sphere is big. There is less power per square meter. There is an equation that lets us calculate the intensity of light at a distance from a light source. The equation is:

$$\textbf{Intensity} = \textbf{Power}/(4\pi r^2)$$

But how can you measure the power of the Sun at its source? You can't. However, scientists have measured the intensity of light at Earth, and we know the distance from the Sun to Earth. The intensity of sunlight outside the Earth's atmosphere is 1366 Watts/$m^2$ (It varies from slightly with solar output). The distance (r) from the Sun to Earth is 150,000,000 km (kilometers). If you substitute these values into the equation above and solve for Power, the value for the power of light from the Sun is 384.6 x $10^{24}$ Watts (Joules/second).

Now we can use this value for Power in the equation above and calculate the intensity of light at Mars. The average distance from the Sun to Mars is 227,900,000 km. You can calculate that the intensity of light at Mars is 589.2 W/$m^2$. That is less than half of the intensity at Earth!

But wait! The orbit of Mars is less circular than Earth's orbit. It is more elliptical. At perihelion (closest to the Sun), Mars is 206,600,000 km away from the Sun, and the intensity is calculated to be 717.1 W/$m^2$. At aphelion (farthest from the Sun), Mars is 249,200,000 km away from the Sun, and the intensity drops to 492.9 W/$m^2$.

These differences could be significant to the design of a solar energy system.

You will have to judge whether your students will be able to understand the math involved.

The Planetary Fact Sheet (located at http://nssdc.gsfc.nasa.gov/planetary/planetfact.html) will provide additional information.

## Preparation and Procedures

**1.** Introduction: Scenario and Problem (15 minutes)

- Download, print, and distribute **Solar Energy for Space Exploration.**

**Procedure:**
Have students read the scenario, challenge, and overview. Share with students the time line you have developed for this unit. Students may have procedural questions that can be answered at this time. If you begin this unit at the beginning of class, you will have time for students to complete **Activity 1: Investigating Solar Cells – Journal Assignment**.

**2.** Investigating Solar Cells (two or three 45-minute periods)
There are three parts to this activity: a Journal Assignment, Investigation A, and Investigation B. Each is described below.

## Activity 1: Investigating Solar Cells - Journal Assignment.

See **General Background**.

- Download, print, and distribute **Activity 1: Investigating Solar Cells - Journal Assignment**.

**Procedures**

This writing assignment is designed to get the students to make predictions about the variables that might affect solar panels. Emphasize that you are looking for careful thought. There are a number of variables students might identify. There are no wrong answers. The purpose is to get students engaged in the process of the investigation. They will have opportunities to test their ideas. Following the journal assignment**,** a short class discussion in which students share their ideas may facilitate investigations.

## Activity 1: Investigating Solar Cells - Investigation A

**Materials per Group of Students**

1. solar cell
2. small electric motor
3. 10-inch pie round (25.4 cm stiff cardboard disk
4. plastic wheel that will fit over axle of motor
5. glue
6. black marking pen
7. stopwatch
8. black construction paper
9. red, green, and blue transparency film
10. electrical wire to connect solar cell and motor

**Teacher's Notes**

The experimental design provides a direct connection between energy and work. The solar energy is converted into electrical energy. The electrical energy is transformed into mechanical energy in the motor. As the axle in the motor turns, it turns a disk attached to the axle. The mechanical energy of the motor is transformed into kinetic energy (rotational) of the disk. Students should have studied work and kinetic energy and should be able to understand that the greater the speed of the disk, the greater the kinetic energy the disk will have.

Many physical science supply companies supply solar cells and electric motors. Try to find motors that have low rpm (revolutions per minute). If the motor turns too fast, students won't be able to count the revolutions. If the only motors you can find turn too fast for students to count the revolutions per minute, you can add a 5 kΩ (kilo-ohm) potentiometer in series in the circuit and use the potentiometer as a rheostat (like the rheostats used as light dimmers). Instructions for making this modification can be found at *All About Circuits* http://www.allaboutcircuits.com/vol_6/chpt_3/7.html.

Another option is to use the motor to lift a mass against the force due to gravity. Attach a small pulley wheel to the axle and wind a length of string around the wheel. Attach the other end of the string to a known weight. The motor should pull the weight upward at a constant rate of about 0.5 meters per second. Power is defined as work/time. Work can be calculated using the simplified formula W = force x distance. In this case, the force is the weight of the mass (in N [Newton's]), and the distance is the vertical distance the mass is raised. You will have to experiment with your solar cells and motor to determine the best weight and distance.

You could also measure the power output from the solar cell directly. Power for an electrical circuit is equal to the voltage times the current (P=V x I). The Secondary Solar Energy resource, located in the Teacher Resources section, provides an experimental procedure. This is a more difficult idea for students to understand.

Have students think carefully about the experimental procedure in this investigation. The transparent films also decrease the intensity of light. Does each film decrease the intensity by the same amount? Also, the red film blocks green and blue light very well. Most green films block blue light well, but do not block red light completely. Blue films usually allow some green and red light to pass.

Procedures and questions shown below are provided on the student pages that you can download.

- Download, print, and distribute **Activity 1: Investigating Solar Cells - Investigation A**.

**Procedure**

1. Attach the plastic wheel to the shaft of the motor.
2. Make a small dot on the edge of the cardboard disk.
3. Glue the cardboard circle to the wheel so that it will rotate when the motor is turning.
4. Attach the solar cell to the motor. Follow the teacher's instructions.
5. Place the solar cell and motor in bright sunlight. The motor should cause the cardboard disk to spin. If no spinning occurs, check the connections.
6. Watch the dot on the cardboard disk. Start the stopwatch as the dot gets to the top. Count the number of times the cardboard disk spins in 15 seconds. Multiply this number by four to get the number of revolutions per minute. Record this information.
7. Cover half of the solar cell using the piece of black construction paper. Repeat Step 6.
8. Cover approximately one-fourth of the solar cell with the construction paper. Repeat Step 6.
9. Cover the solar cell with one piece of the red transparency film. Repeat Step 6, and record the data.
10. Repeat Step 9 with each of the different colors of transparency film.

**Questions** (students will answer these questions after doing the investigation)

1. What happened when you covered part of the solar cell with black paper? Why?

2. What is the relationship between the amount of solar cell that is covered and the speed at which the disk turned? Explain.

3. How is the speed of the disk related to the energy provided by the solar cell?

4. How did the colored transparencies affect the solar cells ability to function?

## Activity 1: Investigating Solar Cells - Investigation B

See **Teacher's Notes** for Investigation A.

- Download, print, and distribute **Activity 1: Investigating Solar Cells - Investigation B**.

**Procedures**
Have a variety of materials on hand. You will need all of the materials used in Investigation A. Also provide protractors, metric rulers, and perhaps fine sand or finely ground volcanic rocks used for landscaping as Mars or Moon soil simulant. You may wish to perform a Web search for Mars or Moon soil simulant. The discussion following the journal assignment will alert you to the types of materials you will need. The students are required to design their own experiment, so they may think of other materials to use. You should review their experimental design to ensure safe procedures before they begin. Also, provide your usual lab report format/rubric/documents.

**3.** Electricity and Power (3 –4 weeks)
Students will develop the core concepts and meet core proficiencies in this section. It is recommended that you use **Electricity and Power in Space**, which is located at http://iss.cet.edu/electricity/default.xml. This online program developed by the Classroom of the Future offers an excellent blend of hands-on activities, computer simulations, and a problem-solving context that is standards-based and addresses students' common preconceptions. Through computer simulations and laboratory work with electricity, students will learn about electricity, circuits, and power and apply this knowledge to solve a problem on the ISS. If you choose to do the online activities, you should review the materials required before assigning the activities. The unit requires computers. Students can work in small groups of two to three.

You know the standards you are required to meet. Examine the online unit. If **Electricity and Power in Space** is more or less rigorous than your requirements, you may wish to supplement your own activities. You can adjust requirements in later activities.

- Download, print, and distribute **Activity 2: Electricity and Power**.

## Teacher's Notes

Provided at **Electricity and Power in Space** Web site.

## Procedures

Provided at **Electricity and Power in Space** Web site.

**4.** Solar Power for Your Home (four to five 45-minute periods)
Students will analyze the power requirements for their homes and propose a design that will use solar panels to supply all of their energy needs.

**Teacher's Notes**

The ultimate goal for the "Solar Energy for Space Exploration" activity is to propose a design for a solar energy system that will provide energy for a research habitat for six researchers on the Moon or Mars. But it is easier to start with an environment the students know. Designing a solar energy system for their own homes lets students start with an environment they know well. However, they will still need to examine current electric bills and do additional research. Many homes don't provide all of their energy needs with electricity. It may be necessary to call local appliance providers or estimate electrical requirements. For this challenge, students are required to provide ***all*** of the energy from the solar panels. This is to prepare them for the problems of designing for a lunar or Martian research habitat. NASA will not be able to provide a local power grid on the Moon or Mars for a long time.

Students need to examine peak power demands for their home, and they need to examine peak and low solar energy availability. In cold, northern regions heating demands may peak just when solar availability is lowest. Remember, the task is to provide all energy demands with solar energy. So, even if their current homes are burning wood, pellets, or oil to provide heat during winter months, they must find out how much energy is required and how they can supply the energy with electric appliances. They can research electrical heating systems, and find the average energy usage.

Also, the solar angle can be critical. If the panels are fixed in place, then the season and the angle of the Sun can be critical.

The number of hours of sunlight can be important. Batteries can help to supply energy during the night. Many Earth-bound applications of solar cells use a dual source of electrical energy. Most homes get electrical energy from the local power grid. The local power grid gets electrical energy from coal burning, hydroelectric, or nuclear power plants. Most solar homes receive electricity from the solar panels and are connected to the local power grid. When the solar panels are producing more energy than a home can use, the excess is 'pumped out' to the grid, and the homeowner receives credit. When the home cannot get enough electrical power from the solar panels (at night or during cloudy periods), the local power grid supplies what is needed.

Designing a home solar energy system that supplies all energy needs can be a difficult problem. You need to establish the degree of rigor you will require—and this may affect the amount of time you wish to dedicate to this part of the unit. And, you will need to have some flexibility the first few times you run this activity. Some of your requirements will depend on the depth of the previous activity. If you examined circuits and power requirements and did circuit calculations, you will want students to look at appliances in their houses and their power requirements. If you did not go into much depth in the study of circuits and power, the average monthly usage reflected in electric bills may be sufficient. Realize that this activity may highlight the differences in economic levels in your student population.

This activity also provides an excellent opportunity to have students examine and discuss the sustainability of their practices over long periods of time. Does wood burning or pellet stoves contribute significantly to air pollution? Can we continue to burn oil for heat? Does the cost of solar power create an economic barrier and seriously penalize the poor? Is conservation of energy important?

- Download, print, and distribute **Activity 3: Solar Power for Your Home**.

## Procedure

Designing a home solar energy system requires creative problem solving. There are no definite procedures, but there are some guidelines students may find helpful:

- Find out what you already know.
- Think and talk about in your design groups what you want to learn.
- Do research and record what you learn so you can use it in your design.

The following questions may be helpful in guiding students:

- What are the power requirements for your home?
- Are the power requirements constant, or do they vary during the day and during the year?
- How much solar energy is available where your home is?
- Does the amount of available solar energy change during the day and during the year?
- What can you do if your solar panels produce more energy than your home requires?
- What happens if your solar panels don't provide enough energy for short periods?

## Resources

- Surface Meteorology and Solar Energy (http://eosweb.larc.nasa.gov/sse/)

This NASA site provides you with information about the amount of solar energy available throughout the year where you live. Students will need access to computers. Students must look at the available information and decide what information they need. You will need to become familiar with the site before the activity so you can guide your students depending on the level of rigor you require.

- Click on Meteorology and Solar Energy.
- Get data tables for a particular location either by selecting "Click on a desired map location" or by "Enter latitude and longitude." (It is easier to use this site if you have your latitude and longitude.)
- Register by using student e-mail address and a password the student creates. This is secure and will not lead to unwanted e-mails. You may wish to use your e-mail and a common password for all students.
- If you chose to find your location with a map, click on the image of the globe to center it near your location, and choose zoom levels. You will probably have to center and zoom a few times. If you chose to use latitude and longitude, type in the correct values.
- When you select a location, you will get options for data. Until you know what you need, click Submit. This will give you all of the data.

## Additional Internet Resources

- Solar Energy Technologies Program
  http://www1.eere.energy.gov/solar/photovoltaics.html

- Roofus' Solar and Efficient Home
  http://www1.eere.energy.gov/kids/roofus/index.html

- Solar Power Basics
  http://www.solarelectricpower.org/index.php?page=basics&subpage=pv&display=

## 5. Challenge: Solar Energy for Moon and Mars **(two to three 45-minute periods)**

Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS. Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

## Teacher's Notes

The **General Background** section provides most of the general information you need. Additional background information is provided for you and your students in the files and Web resources in the links below.

- Download, print, and distribute **Activity 4. Final Problem: Solar Energy for Moon or Mars.**
- Download, print, and distribute **Interview with a PHALCON.**
- Download, print, and distribute **Solar Arrays for the International Space Station.**
- **Power to the Station** http://liftoff.msfc.nasa.gov/news/2001/news-stationpower.asp
- **Model Space Station – Power Loads and Assembly Sequence**
- **The Inconstant Sun** http://science.nasa.gov/headlines/y2003/17jan_solcon.htm
- **Measuring Solar Radiation** http://son.nasa.gov/lawis/energy/problem/solar_constant.pdf.

This activity could be made more robust by providing more information about the Moon or Mars. The **Student Observation Network** http://www.nasa.gov/education/son inquiry module, *Living and Working Safely on the Moon*, provides an opportunity for students to learn about the Moon and lunar resources necessary for developing a research habitat on the Moon. The **Mars Student Imaging Project** http://msip.asu.edu/ allows students to discover Mars. **Imagine Mars** http://imaginemars.jpl.nasa.gov/index2.html is a multidisciplinary activity that allows students to think more broadly about developing a community on Mars. **Marsbound** http://marsbound.asu.edu/ is a great game that engages students in developing a mission to explore Mars that can enrich their exploration of **Solar Energy for Space Exploration**.

## Procedure

Designing a solar energy system for the Moon or Mars requires creative problem solving. There are no definite procedures, but there are some guidelines students may find helpful:

- Find out what you already know.
- Think and talk about in your design groups what you want to learn.
- Do research and record what you learn so you can use it in your design.

The following questions may be helpful in guiding students:

- What are the power requirements for your home?
- What are the power requirements for ISS?
- How might the power requirements for six researchers for an extended period of time be different?
- Are the power requirements constant or do they vary during the day and during the year?
- How much solar energy is available where your research habitat is?
- Does the amount of available solar energy change during the day and during the year?
- What can you do if your solar panels produce more energy than your research habitat requires?
- What happens if your solar panels don't provide enough energy for short periods?

## Design Solution to Problem

Students should now have sufficient information to be able to work as a group to design the solar energy system for a research station on the Moon or Mars. The group will have to agree on some assumptions. Make certain that their assumptions are clearly stated and reasonable considering what they know. The emphases should be on careful thinking and not a correct solution. Even scientists and engineers struggle with this problem. The group should be clearly required to support its design with evidence.

If a group of students chooses to design a solution for a research station on Mars, you may want them to consider the decrease in solar energy that reaches Mars because it is farther from the Sun than Earth is.

Provide clear instructions and a rubric to your students about the kind of presentation you want them to make. For example, you may require a written report, a poster presentation, or a PowerPoint presentation.

Answers to math questions at the end of **Solar Arrays for the International Space Station** are provided below.

## Math Connections - Solutions

1. How much power does each solar cell produce?

Information:

- Scientists have measured the intensity of solar radiation at the space station as about 1366 $W/m^2$.
- Each solar cell is about 12 percent efficient. This means each cell can convert about 12 percent of the energy from the Sun that falls on the cell into electric power.
- What is the area of each solar cell? Look in the text above.

***Solution***
***Intensity of solar radiation x area of solar cell x efficiency = 1.05 W***

2. Using the amount of power from each cell, how much power should two arrays produce? How does this answer compare with the information in this article?

Information:

Each array contains 32,800 solar cells.

***Solution***
***Number of cells per array x number of arrays x 1.05 W (answer from #1) = 68,880 W. The value in the text is 64 kilowatts (64,000 W) from two arrays. Some values have been rounded and some efficiency is lost.***

3. What is the efficiency of two arrays? Why might this be different from the efficiency of a solar cell?

Information you need to know:

- What is the intensity of solar radiation at the space station?
- What is the area of an array?
- What is the power output from two arrays?

***Solution***
***Intensity of solar radiation x area of array x two arrays = 1,023,000W***

***Efficiency = power output from two arrays (64,000W) divided by 1,023,000W = about 6 percent***

***The difference arises because a significant part of the array is structural, holding the cells together and giving strength to the whole array. One must always be careful about given information. In this case, students need the total area of the solar cells. The area of a solar panel will include structural material. This really isn't a trick question. Students will often assume that the total surface of their habitat can be covered by solar cells, but some of the area must be dedicated to the structure of the solar panel.***