NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

Oceans of Energy

An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

This lesson guides student inquiry into the key topic of Energy within the "Why Do We Explore?" theme.

Focus

Ocean energy

Grade Level

7-8 (Physical Science/Earth Science)

Focus Question

What forms of energy are found in the ocean, and how might these be used by humans?

Learning Objectives

- Students will be able to describe forms of energy.
- Students will be able to explain how different forms of energy are used by humans.
- Students will be able to explain at least three ways that energy can be obtained from the ocean.

Materials

- Copies of *Ocean Energy Inquiry Guide*, one for each student group
- Copies of the *Micro-Hydro Electric Generators Construction Guide*, one for each student group
- Materials for constructing Micro-Hydro Electric Generators (For each student group)
  - 1 gal. plastic jug
  - 10 plastic spoons
  - 1 cork, 1.5 – 2 inches diameter
  - 300 ft enameled magnet wire, 24 gauge (Allied Electronics Part Number 214-3578 or equivalent)
  - Wooden dowel, 1/4-inch diameter, 10 inches long
  - Foamcore, approximately 9 inches x 12 inches
  - 4 - Ceramic or rare earth magnets (Radio Shack Part Number 64-1883 or equivalent)
  - clear vinyl tubing, 1/4-inch inside diameter, 4 inches long
  - 4- brass paper fasteners, 1 inch long
  - Safety glasses, 1 pair for each student
- Tools and Supplies that may be shared among student groups
  - Inexpensive multimeter (Radio Shack Part Number 22-810 or or equivalent)
  - 2 - Jumper cables (Radio Shack Part Number 278-1157 or equivalent)
  - Electric drill with 1/4-inch drill bit
  - Scissors
  - Vinyl electrical tape
  - Ruler
  - Awl, icepick, or 3-1/2 inch nail
  - Hot glue gun
  - Glue sticks
  - White glue
  - Utility knife
  - Pencil sharpener
  - Felt tip marker
  - Magnetic compass
  - Wire cutters
  - Gloves

Mention of commercial names does not imply endorsement by NOAA.

Audiovisual Materials

- (Optional) Images of ocean energy technologies (see Learning Procedure Step 1,) or computer projector

Teaching Time

Two or three 45-minute class periods, plus time for student research and hands-on inquiry

Seating Arrangement

Five groups of two to four students

Maximum Number of Students

32

Key Words and Concepts

Energy
Salinity gradient energy
Wave energy
Tidal energy
Current energy
Thermal energy
Solar energy
Wind energy
Geothermal
OTEC
Methane hydrates


Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Background Information

The ocean is Earth's largest collector and storage system for solar energy, as well as the environment that receives a great deal of the heat energy produced by the Earth itself. The energy contained in Earth's ocean is enormous; a small fraction could power the world. Yet, humans presently use almost none of this energy.

Ocean energy exists in several forms, including heat energy, mechanical (motion) energy, and chemical energy. Methane hydrates, discussed in the *Why Do We Explore Leader's Guide*, are one example of an abundant potential energy source that is virtually untapped. Hydrothermal vents and undersea volcanoes are manifestations of geothermal energy that may also have significant potential for human use. Because Earth's ocean is 95% unexplored, there are almost certainly yet-to-be-discovered areas that are particularly promising as sites for harvesting one or more forms of ocean energy. The mission of the NOAA Ship *Okeanos Explorer* is not specifically targeted toward developing

Iceworms (*Hesiocaeca methanicola*) infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald. *http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg*

ocean energy, but the ship's voyages of exploration will gather new information including undiscovered geologic formations, temperature gradients, currents, and geothermal processes that will contribute directly to efforts to enhance our use of ocean energy resources. Appendix 1 provides an overview of ocean energy resources and some of the technologies being developed to harvest them.

This lesson guides student inquiries into various forms of ocean energy and some of the technologies used to capture this energy for human use.

Learning Procedure

1. To prepare for this lesson:
   - If you have not previously done so, review introductory information on the NOAA Ship *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html. You may also want to consider having students complete some or all of the Initial Inquiry Lesson, *To Boldly Go…* (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf).
   - Review the Learning Procedure steps, procedures on the *Ocean Energy Inquiry Guide*, and information in Appendix 1.
   - Assemble materials, tools, and supplies for the Micro-Hydro Generator Construction activity. Depending upon your students' manual dexterity and level of maturity, you may want to do some of the cutting and drilling in advance.
   - You may want to download images of various ocean energy technologies from the Web sites cited in Appendix 1, or bookmark these sites if you are using a computer projection system.
2. Provide each student group with a copy of the *Ocean Energy Inquiry Guide*, and have them complete Questions 1 and 2 (you may want to assign this as homework in a prior class). Briefly discuss the definition of energy as the ability to do work. Be sure students understand that this definition includes stored (potential) energy as well as working (kinetic) energy. Briefly discuss the various forms of energy. Students may have encountered some variation in terms and descriptions depending upon their specific research sources. For example, the term "mechanical energy" is sometimes confined to potential energy of objects under tension, while the kinetic energy of objects in motion is described as "motion energy." Key points include:
   - ***Thermal Energy (Heat)*** – kinetic energy of vibration and

movement of atoms and molecules within substances; increasing thermal energy causes atoms and molecules to move and collide more rapidly

- ***Radiant Energy (including Light, Radio Waves, Microwaves, and X-rays)*** – kinetic energy of electromagnetic waves; some definitions refer to radiant energy as the kinetic energy of a stream of photons, since some properties of electromagnetic waves resemble properties of particles; according to quantum field theory, both definitions are correct

- ***Mechanical Energy*** – potential energy stored in objects by tension, such as compressed springs and stretched rubber bands; kinetic energy in the force moving objects and substances

- ***Electrical Energy*** – kinetic energy of electrons moving through a conductor

- ***Chemical Energy*** – potential energy stored in the bonds of atoms and molecules

- ***Nuclear Energy*** – potential energy stored in the nucleus of an atom

- ***Gravitational Energy*** – potential energy stored in an object that may be accelerated by a gravitational force; if an object is raised above Earth's surface it may be accelerated by Earth's gravity; gravitational energy increases with increasing height and/or mass of the object

- ***Sound Energy*** – kinetic energy moving through a substance (such as air or water) in waves causing the substance to vibrate

Be sure students understand that our experience with energy frequently involves conversions between these forms. For example, when we use electrical energy in a battery, that energy results from a conversion of chemical energy in the components of the battery to electrical energy of electrons moving through a circuit. Similarly, when we feel heat from the sun, we are experiencing a conversion of electromagnetic energy from the sun to thermal energy in the atoms and molecules of our bodies. In the latter example, there actually are additional conversions involved in our "feeling" the heat: the thermal energy in our bodies is converted to chemical energy in nerves that causes a series of chemical reactions that eventually cause our brain to perceive the heat.

You may also want to remind students about the First and Second Laws of Thermodynamics:

First: Energy can be changed from one form to another, but cannot be created or destroyed.

Second: Converting one form of energy into another form always involves a loss of useable energy.

Make sure students understand that the electricity we use is a secondary source of energy (sometimes referred to as an "energy carrier"). Since we are not presently able to capture and control natural sources of electricity (e.g., lightning), we have to use another energy source to make electricity. The chemical energy of coal and petroleum fuels, the mechanical energy of moving water or wind, and the nuclear energy of radioactive materials are common primary energy sources that are converted into electrical energy. The reason for doing this is that it is is much easier to move electricity than it is to move coal, wind, or nuclear fuels. Point out that the problem of how to capture, control, and distribute energy from a given source is a key issue in developing new energy sources for human activities. Hydrogen is another energy carrier that is being considered for storing and transporting excess energy produced from offshore ocean energy sources such as wind, solar, and waves (http://ocsenergy.anl.gov/guide/hydrogen/index.cfm).

3. Briefly discuss the mission of NOAA Ship *Okeanos Explorer*, highlighting the fact that 95% of Earth's ocean is unexplored, and the potential importance of ocean exploration to major issues facing our society. Brainstorm various sources of energy that may be found on and in the ocean, and record these on a list that is visible to the students. Ideally, the list will eventually include:
   - Salinity Gradient (Osmotic) Energy
   - Wave Energy
   - Tidal Energy
   - Current Energy
   - Thermal Energy
   - Solar Energy

Wind Energy
Hybrids
Methane Hydrates

It is not very likely that students will mention all of these; that's okay, just leave unmentioned sources off the list for now. For each energy source on their list, have students discuss how the energy might be captured, controlled, and distributed in a useful form. In many cases, this will involve converting the energy to electricity. Briefly review the basic process through which most electricity is produced:

The fundamental principle underlying electricity generators was discovered in 1831 by Michael Faraday: When a magnet is moved inside a coil of wire, an electrical current flows in the wire. The basic parts of a generator are a series of insulated coils of wire arranged to form a stationary cylinder, a magnet that rotates inside the cylinder, and a source of energy (because electricity is a SECONDARY energy source) to rotate the magnet. Steam turbines, internal-combustion engines, gas combustion turbines, water turbines, and wind turbines are the most common devices used to rotate the magnets in electricity generators. Steam turbine power plants powered by coal and nuclear energy produce about 70% of the electricity used in the United States. These plants are about 35% efficient, which means that for every 100 units of primary energy are consumed by the generator, only 35 units are converted to useable electricity.

Assign one or more ocean energy sources from the complete list (above) to each student group. Provide each group with a copy of the *Ocean Energy Inquiry Guide*. You may also want to provide some of the references cited in Step 1, or allow students to discover them on their own—a Web search on "ocean energy" will produce most of these and millions of others (no kidding!). Have students complete the remaining questions on the *Inquiry Guide*, as well as the Micro-Hydro Electric Generator activity.

Note: Students may also mention biomass as a potential form of ocean energy. Marine algae have been cultivated for centuries as food, and a variety of projects have been proposed that use seaweed as a feedstock for biofuels and electricity generation (biopower). Only a few small-scale projects have actually been implemented, and biomass is not normally included in discussions of ocean energy. Even so, marine biomass may prove to be important on a local scale, and you may want to add this to the list for students' inquiry.

4. Have each student group present the results of their inquiries, then lead a discussion of which ocean energy technologies appear to be most promising. Students should realize that energy storage and distribution are major issues for all of these technologies. Ask students whether there are other types of "energy carriers" that may be useful in addition to electricity and hydrogen. If a hint is needed, suggest considering the various forms of energy discussed in Step 2; could one or more of these provide an alternative energy carrier? A land-based example is using wind power to pump water into an elevated reservoir, so that it can be released in a controlled way through an electricity-generating turbine when electricity is needed.

The BRIDGE Connection

http://www2.vims.edu/bridge/DATA.cfm?Bridge_Location=archive1005.html – An activity guide: Waves – An Alternative Energy Source

The "Me" Connection

Have students write a brief essay describing how they might use alternative energy resources to significantly reduce their personal consumption of energy derived from fossil fuels.

Connections to Other Subjects

English/Language Arts, Mathematics, Social Studies

Assessment

Students' responses to *Inquiry Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html.
2. Visit http://www.re-energy.ca for additional hands-on renewable energy projects.
3. Visit http://www.simplemotor.com/, a site originally established by an 11th grade student to share his investigations into easy-to-build electric motors.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward grades 7-8)

Friendly Volcanoes
http://oceanexplorer.noaa.gov/explorations/04fire/background/edu/media/RoF.friendlyvol.pdf
(5 pages, 380k) (Submarine Ring of Fire 2004 Expedition)

Focus: Ecological impacts of volcanism in the Mariana Islands (Life Science/Earth Science)

In this lesson, students will be able to describe at least three beneficial impacts of volcanic activity on marine ecosystems and will be able to explain the overall tectonic processes that cause volcanic activity along the Mariana Arc.

How Does Your Magma Grow?
http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_magma.pdf
(6 pages, 224k) (from the 2005 GalAPAGos: Where Ridge Meets Hotspot Expedition)

Focus: Hot spots and midocean ridges (Physical Science)

In this lesson, students will identify types of plate boundaries associated with movement of the Earth's tectonic plates, compare and contrast volcanic activity associated with spreading centers and hot spots, describe processes which resulted in the formation of the Galapagos Islands, and describe processes that produce hydrothermal vents.

It's Going to Blow Up!
http://oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_explosive.pdf
(10 pages, 337Kb) (from the New Zealand American Submarine Ring of Fire 2005 expedition)

Focus: Volcanism on the Pacific Ring of Fire (Earth Science)

In this lesson, students will be able to describe the processes that produce the "Submarine Ring of Fire," explain the factors that contribute to explosive volcanic eruptions, identify at least three benefits that humans derive from volcanism, describe the primary risks posed by volcanic activity in the United States, and will be able to identify the volcano within the continental U.S. that is considered most dangerous.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration Program

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

http://tonto.eia.doe.gov/kids/index.cfm – "Energy Kids" Web page from the U.S. Department of Energy, Energy Information Administration

http://tonto.eia.doe.gov/kids/energy.cfm?page=Plans – Lesson Plans from the Energy Information Administration's "Energy Kids" Web page

http://www.eia.doe.gov/kids/energyexplained/sources/electricity.html – Electricity basics from the Energy Information Administration's "Energy Kids" Web page

http://www.energyquest.ca.gov/index.html – Energy Quest Web site from the California Energy Commission; includes lesson plans, links to resources, and 20 short and very readable essays on energy and related topics

http://oceanenergy.epri.com/ – Ocean Energy Web page from the Electric Power Research Institute

Appleyard, D. 2009. Ocean Energy Developments. *Renewable Energy World Magazine*. 12(4) http://www.renewableenergyworld.com/rea/news/article/2009/09/ocean-energy-developments

http://www.masstech.org/renewableenergy/k-12/k12.htm – K-12 teaching resources from the Massachusetts Technology Collaborative's Renewable Energy Trust

http://www.re-energy.ca/ – Web site for Re-Energy.ca, a renewable energy education project of the Pembina Institute; a renewable energy project kit that includes working models for a wind turbine, biogas generator, solar car, solar oven, and water-powered generator; includes background information, hands-on activities, resources and links on renewable energy and sustainable energy technologies

http://www.builditsolar.com/Projects/Educational/educational.htm – Web page with links to simple renewable energy projects

http://www.eu-oea.com/ – Web site for the European Ocean Energy Association

http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm – Web site for the National Methane Hydrate R&D Program

http://graysharboroceanenergy.com/Documents/Offshore%20Renewable%20Technology%202008%20-%20Musial.pdf – Slide presentation on "Wave, Wind and Tidal Technologies and Future Trends" by Walt Musial, National Renewable Energy Laboratory (NREL)

http://ocsenergy.anl.gov/guide/index.cfm – Introduction to ocean energy resources, from the Minerals Management Service Outer Continental Shelf Environmental Impact Statement Web site

http://ocsenergy.anl.gov/documents/docs/OCS_EIS_WhitePaper_Wave.pdf – Technology White Paper on Wave Energy Potential on the U.S. Outer Continental Shelf

http://ocsenergy.anl.gov/documents/docs/NREL_Scoping_6_06_2006_web.pdf – NREL Scoping Meeting Presentation: Renewable Energy Technologies for Use on the Outer Continental Shelf

http://ocsenergy.anl.gov/guide/hydrogen/index.cfm – Web page on hydrogen generation as an energy carrier for ocean energy technologies

http://www.oceanenergycouncil.com/ – Web site for the Ocean Energy Council

Verne, J. 1870. Twenty Thousand Leagues Under the Sea.

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard B: Physical Science

- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

Content Standard D: Earth and Space Science

- Structure of the Earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments
- Risks and benefits
- Science and technology in society

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept a. The ocean is the dominant physical feature on our planet Earth—covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.

Fundamental Concept c. Throughout the ocean there is one interconnected circulation system powered by wind, tides, the force of the Earth's rotation (Coriolis effect), the Sun, and water density differences. The shape of ocean basins and adjacent land masses influence the path of circulation.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 3.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept b. The ocean absorbs much of the solar radiation reaching Earth. The ocean loses heat by evaporation. This heat loss drives atmospheric circulation when, after it is released into the atmosphere as water vapor, it condenses and forms rain.

Condensation of water evaporated from warm seas provides the energy for hurricanes and cyclones.

Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Essential Principle 7.
The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education setting.
Please send your comments to: oceanexeducation@noaa.gov

For More Information

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Acknowledgments

This lesson plan was produced by Mel Goodwin, PhD, The Harmony Project, Charleston, SC for the National Oceanic and Atmospheric Administration. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov

Ocean Energy Inquiry Guide

Background Research

1. What is the definition of energy?

2. List and briefly describe eight different forms of energy.

3. Your teacher will assign your group one or more ocean energy resources to investigate. Your research should include:

   Assigned energy resource:

   - Identification of the type of energy involved (radiant, mechanical, etc.);

   - A description of technologies that can be used to capture energy from this resource;

Ocean Energy Inquiry Guide - Page 2

- Information about installations that are proposed or are actually using these technologies to obtain energy; and

- Identification of major problems or obstacles to obtaining useful energy from this resource.

4. What kind of information might be obtained by the NOAA Ship *Okeanos Explorer* from unexplored areas in Earth's ocean that could enhance understanding and potential development of this ocean energy resource?

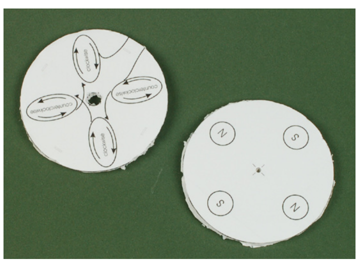
Micro-Hydro Electric Generator Construction Guide

Construction Procedure

Read ALL of the directions before beginning construction.

When a magnet is moved inside a coil of wire, an electrical current flows in the wire. The basic parts of a generator are a series of insulated coils of wire, one or more magnets, and a source of energy to rotate the coils or the magnets. The generator you are about to build consists of four coils that remain stationary (called the stator), four magnets that rotate around the coils (called the rotor), and a paddle wheel that can capture the energy of falling water.

Step 1



1. Glue the patterns for the rotor and stator (found on Page 22)onto a piece of foamcore. When the glue has dried, use a utility knife to cut the rotor and stator disks from the foamcore sheet. Wear gloves when using the utility knife, and be careful! Use a cutting board, piece of scrap wood or several sheets of cardboard as a cutting surface.

Step 2

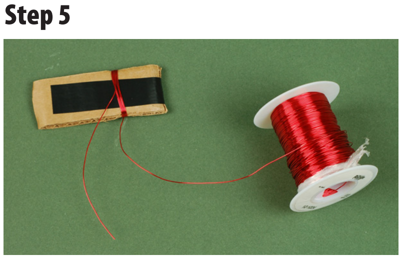
2. Use an awl, icepick, or 3 1/2 inch nail to punch a small hole through the center of the rotor disk as indicated on the pattern. Use the utility knife to make a hole approximately 1/2-inch diameter in the center of the stator disk. Cut four slits through the disk as indicated.

Step 3

Assemble the Stator

3. Make a form for winding your coils by cutting a 1 1/4 inch x 3 1/4 inch piece of cardboard, folding it in half, and taping the ends together with electrical tape. This form is called a jig.

Step 5

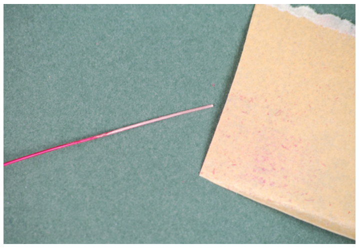


4. Cut eight pieces of electrical tape about 3 inches long, and set them aside.

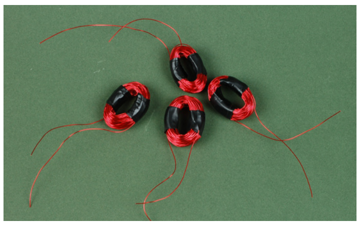
5. Leaving a lead of about 3 inches, begin winding the first coil on the cardboard form. Wrap 200 turns, keeping the turns close together to form a tight coil.

Micro-Hydro Electric Generator Construction Guide - Page 2

Step 7



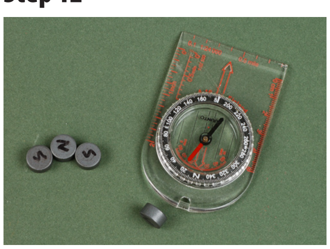
Steps 6 & 8



Step 9

Step 10

Step 12



Step 13

6. Slip the coil off the jig and secure the wraps with two pieces of electrical tape. Be sure you have leads about 3 inches long at both ends of the coil.

7. Use a small piece of sandpaper to remove about 3/4-inch of the enamel insulation from the ends of both leads.

8. Repeat Steps 5 through 7 to make three more coils.

9. Lay the coils on the stator disk in the position shown on the pattern. Arrange the coils so that their windings alternate between clockwise and counterclockwise. THIS IS VERY IMPORTANT! When you are sure you have arranged the coils correctly, connect adjacent coils be twisting the bared ends of the leads together. Be sure to leave two leads unconnected as shown on the pattern and in the photograph. Cover the twisted connections with short pieces of electrical tape.

10. Check your connections by setting your multimeter to measure resistance (ohms) and connecting the leads of the multimeter to the two free ends of the stator coil assembly. If your connections are good, the resistance should be very low (about 10 ohms or less). If the resistance is very large, two or more of the connections are not good, probably because the enamel insulation was not completely removed from the ends of the wires. Note that this test does not check whether you have correctly arranged the coils with alternating clockwise-counterclockwise windings.

11. Glue the coils to the stator disk in the positions indicated on the pattern. Lift the coils one by one, put a large glob of glue onto the disk where the coil touches, and press the coil into place. Let the glue solidify before gluing the next coil.

Assemble the Rotor

12. Use a magnetic compass to determine the north and south pole of each magnet. Mark the polarity on the appropriate faces of each magnet.

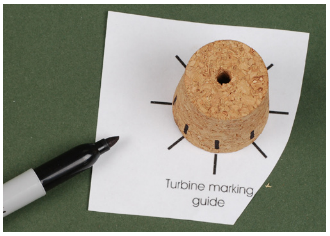
13. Attach the magnets to the rotor disk as indicated on the pattern. Put a small glob of glue onto the pattern, then press the magnet into place. Be sure you have alternating north and south poles facing up.

Assemble the Paddle Wheel

14. Put a blunt point onto the ends of the wooden dowel with a pencil sharpener.

Micro-Hydro Electric Generator Construction Guide - Page 3

Steps 15 & 16



15. Drill a 1/4-inch hole in the exact center of the cork. Be careful when using the electric drill! Wear eye protection and gloves. Be sure the cork is firmly clamped or held in a vise.

16. Center the wide end of the cork on the Marking Guide on the pattern page, and mark eight cutting points on the cork with a pencil or pen.

Step 17

17. Place the wide end of the cork flat on a cutting surface, and use the utility knife to make shallow slits where the ends of the spoons will be inserted. Be careful! Wear gloves!

18. Use wire cutters to cut the handles off of eight plastic spoons. Leave about 3/8-inch of the handle attached to the bowl of each spoon.

Step 18

19. Insert the spoons into the slits in the cork. Push one spoon into each slit first, to slightly widen the slits. Then assemble the paddle wheel by pushing each spoon as far as it will go into each slit. Adjust the spoons as necessary so that they are evenly spaced and stick out of the cork at the same angle. When you are satisfied with the arrangement of the spoons, glue each one into place with some hot glue.

Step 19

Assemble the Generator

20. Cut the bottom off of the plastic jug. Hold your paddle wheel inside the jug to determine how it needs to be oriented so that it can spin freely when attached to the dowel. If your jug has a handle on the side, this may interfere with the paddle wheel rotation unless it is properly oriented.

21. Use a ruler to find the center of the two sides that will support the dowel. Mark the center with a felt tip marker, being sure to allow enough space inside the container for the paddle wheel to rotate freely.

Steps 20, 21 & 22

22. Drill a 1/4-inch hole through each of the marked points. Be careful! Wear eye protection and gloves.

23. Test-fit the dowel through the holes. If it seems to stick, slightly enlarge the holes with the drill or utility knife.

24. Place the stator assembly on the outside of the container so that the stator's center hole is over the hole in the container. Push an awl, icepick, or nail through the slits in the stator disk to mark their location on the container. If the side of the container slopes away from one of the slits, that is okay; three attachment points are enough to hold the stator in position.

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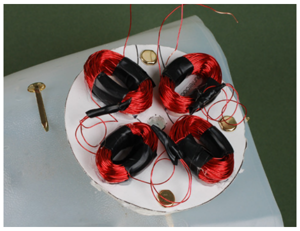
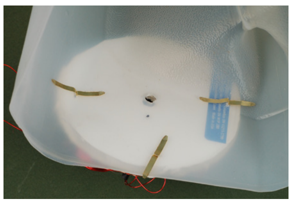
25. Use the utility knife to make four small slits on the side of the container to match the slits on the stator disk. Be careful! Wear gloves.

26. Attach the stator disk to the container with brass paper fasteners. Bend the tabs of the fasteners flat against the inside of the container.

Step 26a



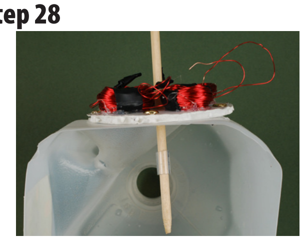
Step 26b



27. Cut four pieces of vinyl tubing, each about 1/2-inch long.

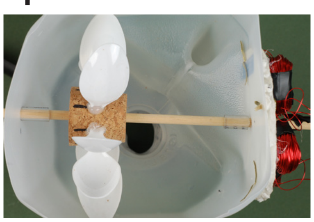
28. Slide one piece of vinyl tubing onto the dowel, about 3 inches. Push the other end of the dowel through the hole in the stator, and slide another piece of vinyl tubing onto the dowel from inside the container.

Step 28



29. Position the paddle wheel inside the container and slide the cork onto the dowel. Slide a third piece of vinyl tubing onto the dowel, then push it through the hole in the side of the container. Slide the fourth piece of vinyl tubing onto the dowel from outside the container. You may have to adjust the various pieces of vinyl tubing during these steps.

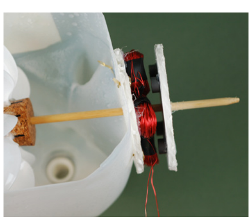
Step 29



30. Spin the shaft to be sure it turns without binding and so that the paddle wheel does not hit the sides of the container as it spins. Adjust the pieces of vinyl tubing to hold the shaft in the correct position.

31. Slide the rotor disk onto the dowel so that the magnets face the stator coils and are about 1/4-inch or less from the coils. Adjust the rotor so that it spins without wobbling and without having any of the magnets hit the coils. Use hot glue to hold the rotor in the appropriate position on the dowel.

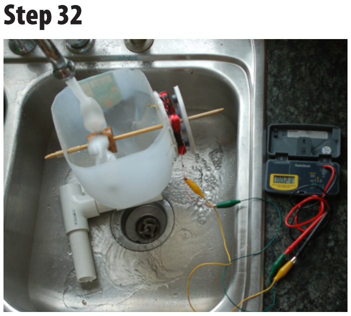
Step31



Test Your Generator!

32. Place your assembled generator under a faucet so the water will hit the spoons and turn on the water. The rotor should spin rapidly. Set your multimeter to measure AC volts, and connect the leads of the multimeter to the two free ends of the stator coil assembly. Measure the voltage produced by your generator.

Step 32



(PVC pipe apparatus used to support generator for the photograph)

How It Works

When a coil of wire moves through a magnetic field, an electric current is produced in the coil. If you hold the coil in your right hand with your fingers curled around it, so that your fingers point in the direction of the magnetic field, your thumb will point in the direction of conventional current flow. This is called the Right Hand Thumb Rule.

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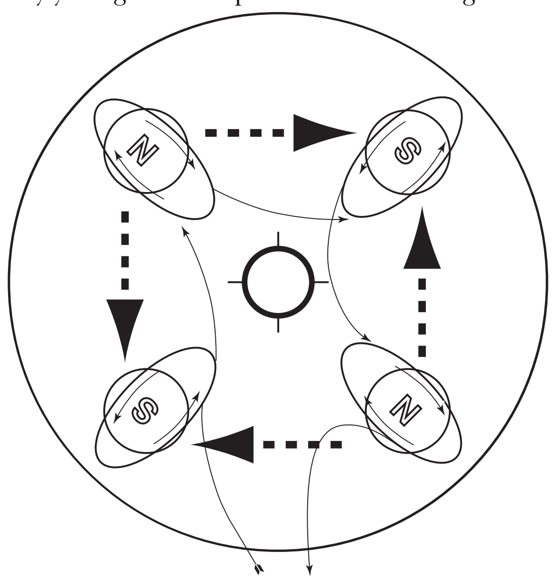
Notes:

1. The direction of a magnetic field is from north pole to south pole.
2. Conventional current flow is related to Benjamin Franklin's theory of electricity, which was that it flow from positive to negative. We now know that electric current is the flow of electrons, which move from negative to positive. So conventional current flow is the opposite of the actual direction in which electrons move, which is called electron flow.

Referring to Figure 1, when the magnets of the rotor are positioned on top of the coils of the stator, conventional current flow through the coils is as indicated by the arrows. Notice that the direction of conventional current flow is opposite in adjacent coils, which is why you had to orient the stator coils with alternating clockwise and counterclockwise winding. When the rotor spins one-quarter turn to the position indicated in Figure 2, current flow through the coils is reversed, which is why your generator produces alternating current.

Figure 1



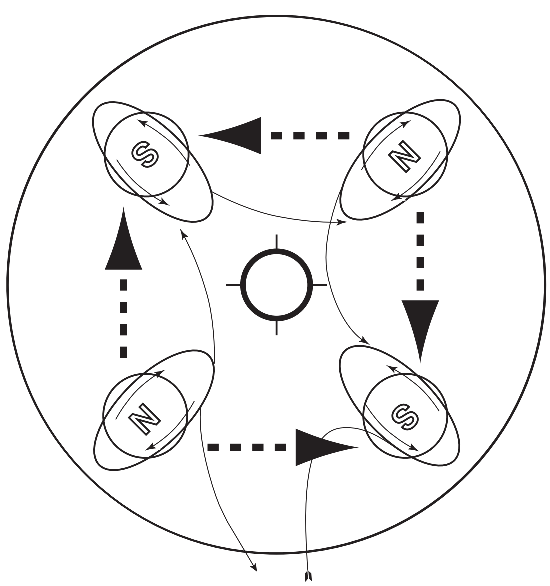


Figure 2

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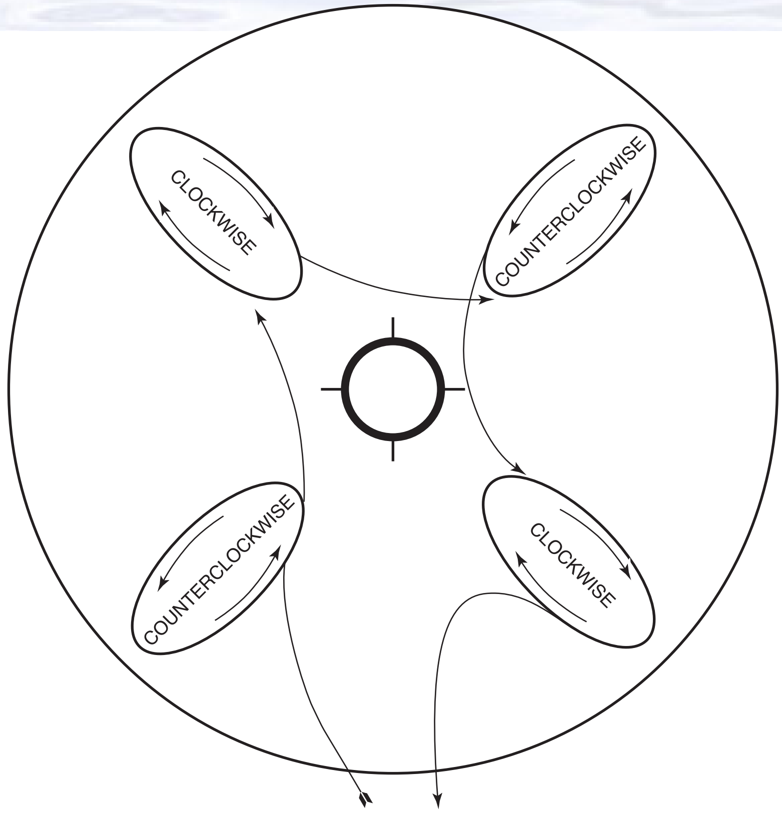
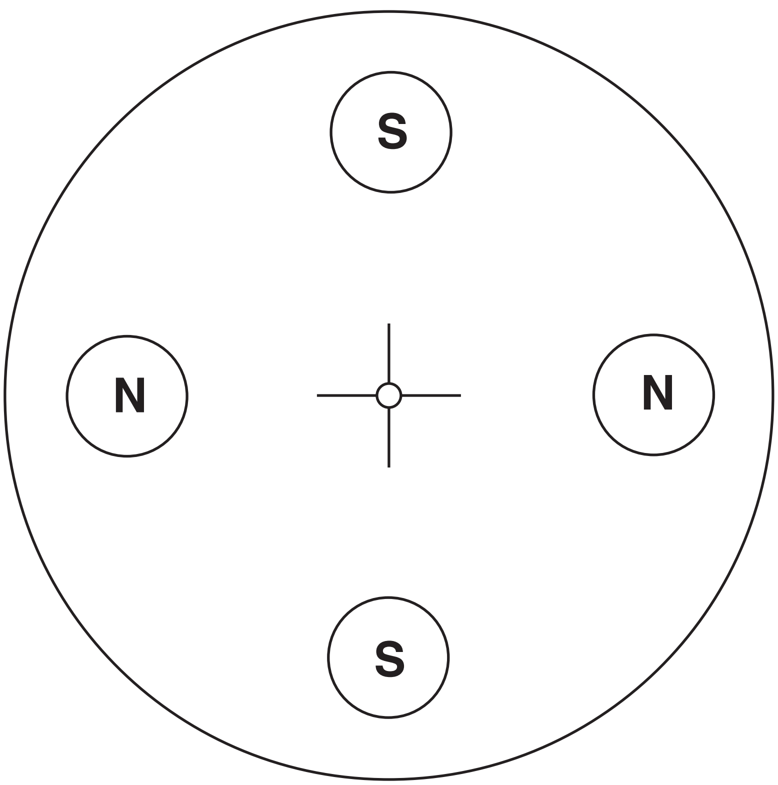
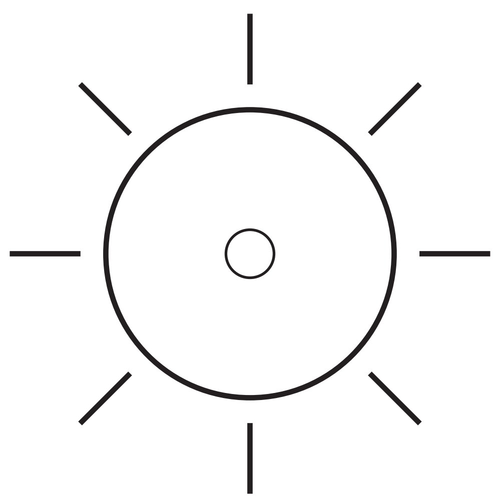


Stator Pattern



Rotor Pattern



Marking Guide

Appendix 1 – Ocean Energy Overview

Earth's ocean contains enormous energy resources in its waters, in the adjacent atmosphere, and in the mantle and crust beneath the sea floor. Ocean energy resources include non-renewable sources such as oil and gas, as well as renewable sources, such as the energy of offshore winds, waves, and ocean currents. With the exception of oil and gas, ocean energy resources have not been extensively utilized in the United States, primarily because many of the technologies are not well-developed, nor have they been economically competitive with fossil fuels and nuclear power.

Underutilized ocean energy resources, though, are receiving increasing attention as technologies improve, prices of traditional energy sources continue to increase, and political considerations become more problematic. The following overview includes energy sources that are already being used in commercial-scale projects, as well as sources for which harvest technologies are still in the early stages of development.

Note: "Ocean energy" is sometimes used as a term that includes only forms of RENEWABLE energy that may be derived from the sea. The following discussion also includes non-renewable methane hydrates, because of the enormous quantity of energy that is potentially available from these substances, and the widespread occurrence of methane hydrates in deep sea environments.

Salinity Gradient (Osmotic) Energy

When fresh water and salt water are separated by a semipermeable membrane, water will move through the membrane into the salt solution (only water molecules can pass through a semipermeable membrane). This water movement is driven by a force called osmotic pressure, which is defined as the pressure that would have to be applied to the salt water solution to prevent the influx of water through the semipermeable membrane. Influx of fresh water will increase the volume of the salt water. If the salt water is in a closed container, the volume cannot increase because water is essentially incompressible, and the pressure in the container will rise until it equals the osmotic pressure. If the pressure in the container is released, it can be used to drive a turbine to generate electricity. This method for utilizing salinity gradient energy is called Pressure Retarded Osmosis.

Reverse Electrodialysis is another salinity gradient technique that uses a series of anion and cation exchange membranes (negatively charged ions can pass through anion exchange membranes; positively charged ions can pass through cation exchange membranes). When fresh water and salt water are separated by an anion exchange membrane, negatively charged ions will move

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from the salt water into the fresh water until the concentration on both sides of the membrane are equal. Similarly, when fresh water and salt water are separated by an cation exchange membrane, positively charged ions will move from the salt water into the fresh water until the concentration on both sides of the membrane are equal. A reverse electrodialysis cell is essentially a salt battery with alternating containers of fresh water and salt water separated by an alternating series of anion and cation exchange membranes. If electrodes are placed at opposite ends of the cell and connected to an electric circuit, a voltage will be produced in the circuit.

Development of salinity gradient energy technology is still in its infancy, though the potential energy is large in locations where rivers mix with salt water.

Waves

Enormous amounts of kinetic energy exists in the moving waves of the ocean. In fact, waves have the highest energy density of any renewable resource. Wave-power is particularly rich in areas along the western coasts of Scotland, northern Canada, southern Africa, Australia, and the northwestern coasts of the United States. Devices to capture wave energy are designed to extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface caused by waves. Most of these devices being tested at commercial scales use one of the following technologies:

- Terminator devices are oriented perpendicular to the direction of wave travel and are analogous to a piston moving inside a cylinder. An Oscillating Water Column is a type of terminator in which water enters through a subsurface opening into a chamber with air trapped above it. Wave action causes the column of water to move up and down in the chamber, forcing the air though an opening to rotate a turbine. Another type of terminator, called an Overtopping Device, consists of an enclosed reservoir that is filled by overtopping waves. Water collected in the reservoir is released back into the ocean through an outlet system that uses the energy of the falling water to rotate a turbine.
- Point absorbers are floating structures with components that move relative to each other due to wave action (for example, a floating piston inside a fixed cylinder). The motion of the components is used to drive electromechanical or hydraulic energy converters (you can see an animation of one type of point absorber at http://www.finavera.com/en/wavetech/aquabuoymovie).
- Attenuators are segmented floating structures oriented parallel to the direction of the waves. As waves pass under the attenuator, the connections between segments flex and this flexing motion is transmitted to hydraulic pistons that drive electric generators inside the segments.

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You can see illustrations and animations of these devices at http://ocsenergy.anl.gov/guide/wave/index.cfm.

Tidal Energy

Humans have been using the energy of ocean tides since at least the eighth century AD. The basic principle is to build a dam across an estuary or small tidal stream so that water is trapped behind the dam when the tide rises. Then when the tide falls, the trapped water can be released to that it turns a water wheel that can do work such as mill grains or turn a turbine to generate electricity. A tidal range of at least 16 - 24 feet is needed for economical electricity generation, which limits the number of locations where it is feasible to capture tidal energy in this way. One such location is the La Rance River estuary on the northern coast of France, where a tidal energy generating station has been in operation since 1966. Smaller stations have been established in Nova Scotia, Canada and Murmansk, Russia.

An alternative approach for capturing tidal energy is to place turbines in offshore tidal streams. The technology is similar to that used for capturing energy from ocean currents.

Current Energy

Ocean currents, such as the Gulf Stream, Florida Straits Current, and California Current, are driven by wind, solar heating, and density variations of large ocean water masses. These currents are relatively constant and flow in one direction only, while the velocity of tidal currents closer to shore varies constantly and their direction changes several times each day. Ocean currents contain an enormous amount of energy; for example, it has been estimated that all of Florida's electrical needs could be met by capturing less than 1% of the available energy in the Gulf Stream.

Technology to capture ocean current energy is presently in the early stages of development, and there are no commercial scale turbines producing electricity for regular distribution. Experimental projects include submerged water turbines similar to wind turbines, as well as doughnut-shaped turbines with blades resembling those seen in jet engines (see http://ocsenergy.anl.gov/guide/current/index.cfm for illustrations).

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Thermal Energy

> I owe all to the ocean; it produces electricity, and electricity gives heat, light, motion, and, in a word, life to the Nautilus.
> — Jules Verne, 1870

Captain Nemo's explanation of engineering aboard the *Nautilus* in *20,000 Leagues Under the Sea* provides the first documented reference to the use of ocean temperature differences to produce electricity. A decade later, French Engineer Jacques D'Arsonval suggested the possibility of using ocean temperature differences to produce electricity.

This idea is based on the fact that Earth's ocean covers slightly more than 70 percent of the Earth's surface, making the ocean Earth's largest collector and storage system for solar energy. On an average day, 60 million square kilometers (23 million square miles) of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil (in 2008, the world daily consumption of oil is estimated to have been 84.5 million barrels). So, harvesting even a very small fraction of the radiant energy absorbed by Earth's ocean could have a significant impact on human energy needs.

Ocean Thermal Energy Conversion (OTEC) is a technology to convert solar radiation absorbed by the ocean into electric power. The basis for this concept is surface ocean waters receive most solar radiation and are consequently warmer than deeper waters. Where the temperature difference between surface water and deep water is about 20°C (36°F), an OTEC system can produce a significant amount of power.

D'Arsonval's original idea was to pump warm seawater through a heat exchanger to vaporize a fluid with a low boiling point (such as ammonia), and then use the expanding vapor to turn an electricity-generating turbine. Cold seawater would be pumped through a second heat exchanger to condense the vapor back into a liquid, which would be recycled through the system. This type of OTEC is called a closed-cycle system. Pilot-scale closed-cycle OTEC systems have been successful in producing electric power.

Open-cycle OTEC systems use warm seawater that boils when it is placed in a low-pressure container. The expanding steam drives an electricity-generating turbine. Cold seawater is used to condense the steam back to water. This water is almost pure fresh water, since the salt is left behind in the low-pressure container when the seawater boils. Experimental open-cycle OTEC plants have also successfully produced electric power, in some cases with energy conversion efficiencies as high as 97%.

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Hybrid OTEC systems combine some features of both closed-cycle and open-cycle systems: Warm seawater enters a vacuum chamber where it is evaporated into steam (similar to the open-cycle evaporation process) that is used to vaporize a low-boiling-point fluid (as in closed-cycle system) that drives a turbine to produce electricity.

Another type of thermal energy comes from the earth itself. This geothermal energy is produced in Earth's core by the decay of radioactive particles. Earth's core consists of an inner mass of solid iron and an outer core of melted rock called magma. The outer core is surrounded by Earth' s crust, which is 3 - 5 miles thick under the oceans and 15 - 35 miles thick under the continents. Volcanoes occur where magma comes close to the surface of the crust. In some areas, water enters cracks in the crust, comes close to hot magma, and turns into boiling hot water or steam. The heated water may emerge at the surface of Earth's crust as a hot spring, or may erupt into the air as a geyser. Geothermally heated water has been used for centuries to heat buildings, for bathing, and for cooking, and more recently to generate electricity.

Most geothermal activity in the world occurs along the boundaries of tectonic plates encircling the Pacific Ocean, in an area called the Ring of Fire. This area has been the subject of Ocean Explorer expeditions from 2002 through 2007, which documented numerous underwater volcanoes, hydrothermal vent fields and other geothermal features, many of which were unexplored prior to these expeditions. Technology for capturing geothermal energy from these sources is in the early stages of development, but pilot projects are planned or underway in several locations including the Azores, Northern Mariana Islands, and Cascades Mountains of the Pacific Northwest; and at least one system has been proposed to directly harvest energy from deep-sea hydrothermal vents.

Solar

Energy from the sun is the primary energy source for all photosynthetic ecosystems, and also drives winds, waves, and deep ocean currents. In fact, energy from wind, waves, currents, and OTEC could be considered as indirect forms of solar energy (similarly, tidal current energy could be considered as an indirect form of gravitational energy, since tidal currents are driven by gravitational forces between Earth, its moon, and the sun). Solar energy technologies that are presently used in land-based installations may also be developed for offshore use.

Concentrating Solar Power (CSP) technology concentrates the sun's rays to produce steam to drive turbines or other devices to generate electricity. In the United States, CSP plants have been operating reliably for more than 15 years. CSP installations typically are one of three types:

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- Trough systems consist of long mirrors that are curved to form parabolas with oil-filled pipes running along the long axis of the mirror at the focal point of the parabola. The mirrors focus sunlight onto the pipes and heat the oil up to 750°F. The hot oil is used to make steam that drives a steam turbine to produce electricity.
- Power towers (also called central receivers) have many large, flat mirrors that track the sun and focus its rays onto a receiver that is on top of a tall tower. The concentrated sunlight heats a fluid, which is used to make steam or is stored for later use (this allows electricity to be produced even if the sun is not shining). Some power towers use molten salt as the fluid and heat the salt to over 1,000°F.
- Dish/engine systems use mirrored parabolic dishes (similar to a television satellite dish but about 10 times larger) to track the sun's path and focus sunlight onto a receiver, which is mounted at the focal point of the parabola. The receiver heats hydrogen or helium gas contained in thin tubes that are connected to cylinders of an engine similar to an internal combustion engine. Heated gas expands inside the cylinders and drives pistons connected to a crankshaft. The crankshaft is connected to an electric generator.

Solar photonic technologies absorb solar photons and convert part of the energy to electricity (as in a photovoltaic cell) or store part of the energy in a chemical reaction (as in the conversion of water to hydrogen and oxygen). A photovoltaic (PV) cell transfers the energy of photons to electrons in the atoms that make up the cell. The energized electrons escape from these atoms and move from the PV cell into an electrical circuit. Concentrated PV (CPV) systems use mirrors or lenses and track the sun to keep light focused on the PV cells.

The appropriate solar technology for offshore applications depends in part on the intended use of the energy to be generated. CSP technologies may be more appropriate for generating and delivering electricity to shore, while photonic technology may be more appropriate for generating electricity that will be used "on-site" and to supply energy for activities such as hydrogen production or desalinization.

You can see illustrations and animations of CSP and solar photonic devices at http://ocsenergy.anl.gov/guide/solar/index.cfm.

Wind

For many centuries, humans have harnessed wind power to do various types of work, from pushing ships through the ocean, to pumping water, to processing agricultural products. More recently, wind has been used to produce electricity. Most wind turbines (wind turbines produce electricity; windmills

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grind grain or pump water) have been located on land, but offshore wind turbines are being used in a number of countries, including Denmark and the United Kingdom where large offshore wind facilities have been installed to take advantage of consistent winds. Offshore winds tend to flow at higher speeds than onshore winds, which means that offshore wind turbines have the potential to produce more electricity than land-based installations.

Commercial-scale offshore wind facilities in the United States are located in waters that are much deeper than European waters where commercial wind facilities are currently sited. As a result, offshore wind turbines are larger and more complex than shore-based turbines, with features that include strengthened support towers to withstand with wind and wave forces, built-in service cranes, automatic greasing systems, pre-heating and cooling systems to maintain gear oil temperature within a narrow temperature range, and lightning protection systems.

Hybrids

There is growing interest in combining several ocean energy sources in installations called Hybrids. One of the problems with wind power, for example, is that the wind doesn't always blow at velocities needed to generate electricity (above 12 to 14 miles per hour), but is so strong at other times that turbines have to be shut down to avoid damage. Combining wind turbines with other energy sources can provide more consistent electricity output. Waves, currents, and OTEC have been proposed as potential energy sources for hybrid installations. Recent examples include:

- Eclipse Energy's Ormonde Project in the Irish Sea, which will produce energy from 30 wind turbines as well as from nearby gas fields; and
- Outer Banks Ocean Energy Corporation, which was formally chartered in September 2009 to generate electrical power from wind, wave and current resources approximately 25 miles off the coast of North Carolina.

Methane Hydrates

Methane hydrate is a type of clathrate, in which molecules of frozen water form an open lattice that encloses molecules of methane without actually forming chemical bonds between the two compounds. Methane is produced in many environments by a group of Archaea known as methanogenic Archaeobacteria. These Archaeobacteria obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. Methane

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is a fossil fuel that could be used in many of the same ways that other fossil fuels (e.g., coal and petroleum) are used (and with the same environmental impacts). According to the U.S. Department of Energy, the recoverable U.S. domestic natural gas resource is roughly 2,300 trillion cubic feet (Tcf). In the case of methane hydrates, the potentially-recoverable domestic resource base could be on the order of 5,000 Tcf.

Interest in methane hydrates has intensified in recent years due to the fact that the United States is relying more and more on the use of natural gas to achieve economic and environmental goals and there are increasing concerns about the long-term availability of our natural gas supply. Since 2000, the National Methane Hydrate R&D Program (conducted by the U.S. Department of Energy's National Energy Technology Laboratory) has supported a wide range of projects to assess the feasibility of developing methane hydrates deposits as new source of natural gas. Key activities include efforts to ensure the safety of deep-water oil and gas exploration and production operations that require drilling through marine hydrate deposits; developing knowledge and technology to allow commercial production of methane from hydrate deposits on Alaska's North Slope by the year 2015; and a joint project with Minerals Management Service and NOAA to establish a permanent monitoring station on the Gulf of Mexico seafloor to monitor the stability of methane hydrates. See http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/projects/DOEProjects/DOE-Project_toc.html for other methane hydrate R&D projects.