Geothermal Energy:

A Geothermal Teacher Guide for Grades 9-12

Grades: 9-12

Topic: Geothermal Energy

Owner: Geothermal Education Office, Tiburon, California

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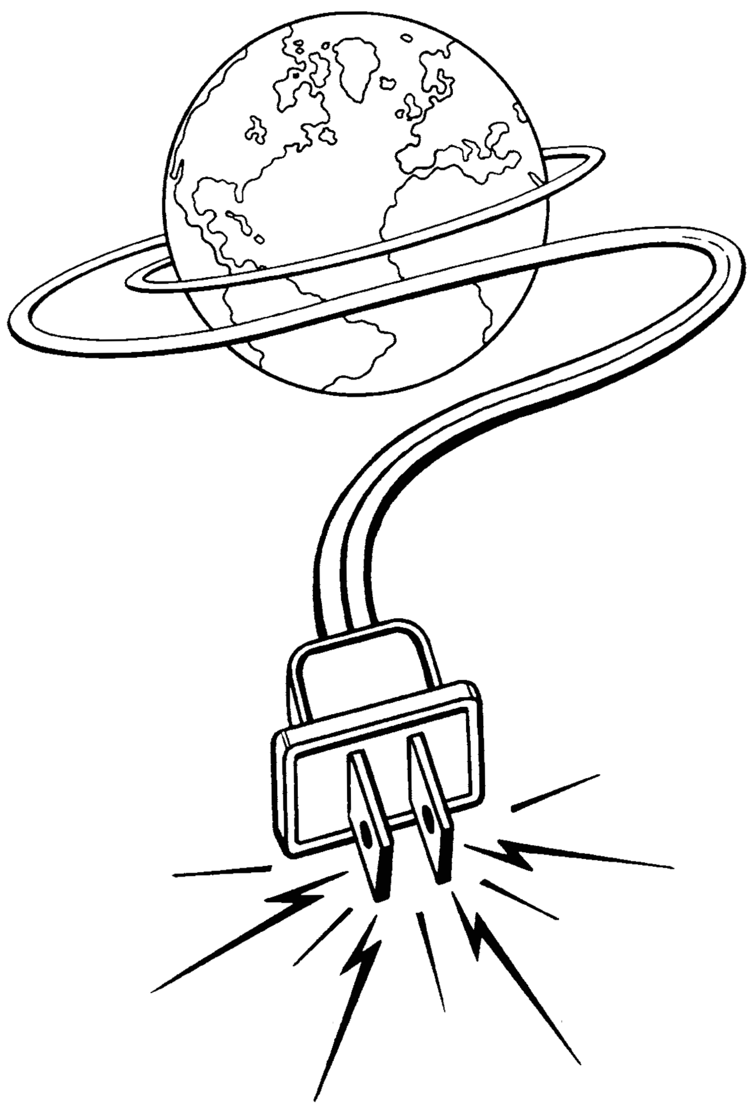
GEOTHERMAL ENERGY

A GEOTHERMAL TEACHER GUIDE FOR GRADES 9 – 12

For teachers of Ancient and Western Civilization, World and U.S. History, U.S. Government, Geology, Earth Science, Environmental Science, and Physical Science



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

THIS GUIDE provides teachers with background information, references, links to multimedia resources and activity suggestions to teach high school students about geothermal energy. It is not intended to be a self-contained textbook. The activities contained herein presume library and Internet access. Students will learn by doing, by researching and by completing interactive projects with classmates.

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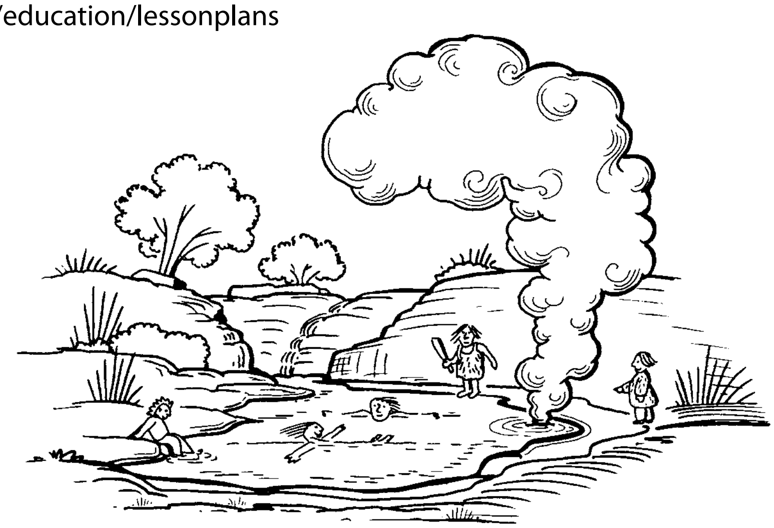
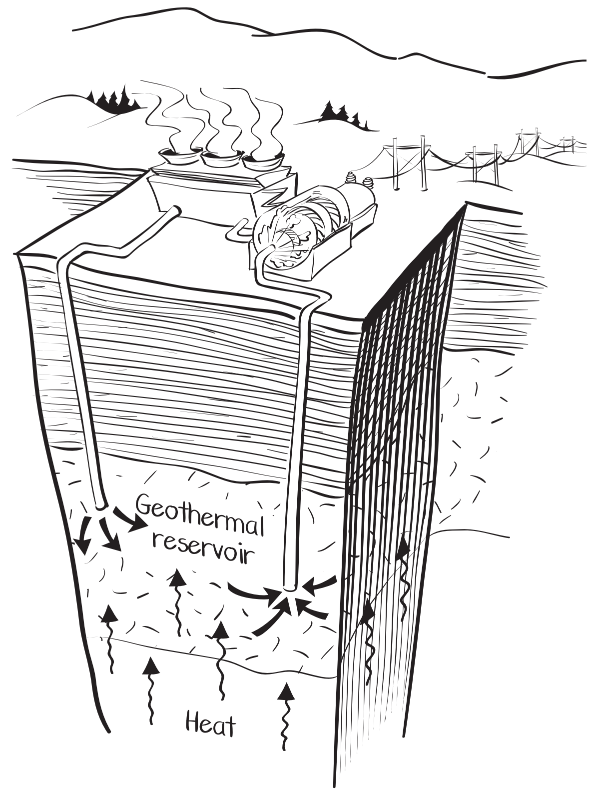


GEOTHERMAL ENERGY

A GEOTHERMAL TEACHER GUIDE FOR GRADES 9 – 12

OVERVIEW



Unit I: GEOTHERMAL FOOTPRINTS OVER TIME

Ancient Civilization, Western Civilization, World History, U.S. History

Unit II: GEOTHERMAL POWER FOR ELECTRICITY GENERATION

Earth Science, Physical Science, Geology, Environmental Science

Unit III: GEOTHERMAL ENERGY AND PUBLIC POLICY

U.S. History, U.S. Government, Environmental Science

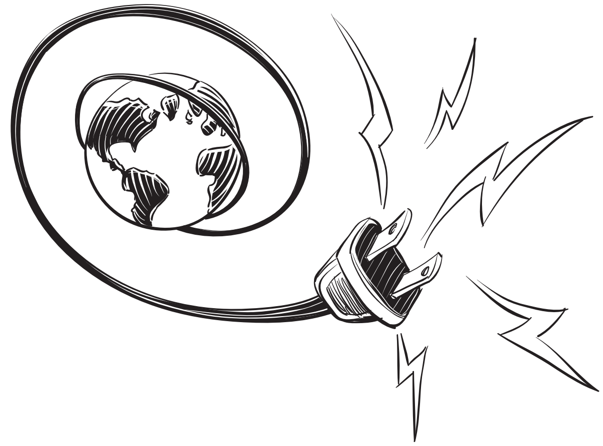
This three-part teacher guide encourages a multi-disciplinary approach to many issues and topics related to geothermal power development, including the scientific fundamentals as well as the social, economic, environmental and political aspects. Though some of the lessons are based very loosely on an actual site — here given the name Rock Station — the Rock Station situation is not unique. Many regions — local, state, and federal — are grappling with the science and policy issues associated with building new renewable energy power plants and the implications of finding alternatives to the growth model of fossil fuels. Driven by concerns of climate change, fuel supply, national security, and environmental and human health, people are learning to address the tradeoffs between geothermal and other energy sources as they explore the complexities in making this transition.

Earth contains and produces heat (*geo = earth, thermal = heat*), which is evident on or near its surface in many places. For over a thousand years human populations have utilized this earth heat directly (that is, in non-electric applications) in a number of ways. Beginning in the last century, near-surface geothermal emerged, additionally, as an important renewable energy resource for electricity generation. Recent technological research and development, as well as economic and political trends, now offer the potential of geothermal being an even more significant component of our rapidly developing energy future. Enhanced Geothermal Systems, often referred to as EGS technology, is a promising example.

This Geothermal Energy Teacher Guide is comprised of three sets of lesson plans and activities for grades 9-12. It was developed with funding from the U.S. Department of Energy (DOE), with assistance from the National Renewable Energy Laboratory (NREL). The guide was developed to be part of the DOE's Office of Energy Efficiency & Renewable Energy (EERE) webpage on Energy Education & Workforce Development (eere.energy.gov/education/lessonplans/). This website is in pursuit of developing the nation's capacity to educate the much larger renewable energy workforce that will be required in the near future.

One goal of this guide is to develop interest and capabilities in geothermal energy at the high school level, which will predispose and encourage more students to pursue this field in school and as a career. Students will gain an understanding of the existence, past use, and future potential of geothermal energy as a resource, both naturally occurring hydrothermal and Enhanced Geothermal Systems (EGS).

A second goal of this guide is to increase student energy literacy by investigating geothermal as an important part of our country's energy mix and by helping students develop skills they can use to address the many issues, technical and non-technical, scientific and political, involved in energy transformation and power generation. Students will engage in a way that simulates the issues, the debate and the choices they might address as residents of a community weighing the alternative of continued reliance on nonrenewable power and the development of geothermal energy.



These goals are addressed in three distinct but related units. The first unit focuses on understanding the geothermal energy inherent in Earth's structure and the history of human relationship with that energy. The second unit focuses on understanding the uses of geothermal energy, mainly in generating electricity. The third unit involves students in the design of government policy around the potential of geothermal energy production as it moves through the democratic process. It pushes students to understand the potential of geothermal in meeting local and national needs of the future.

Written by Randy Baker, Erik Schmitz, and Joan Wegner with contributions by Doug Purinton. Mr. Baker, Mr. Schmitz and Ms. Wegner are high school teachers in Marin County, California. Mr. Purinton is a high school science teacher in Spartanburg, South Carolina.

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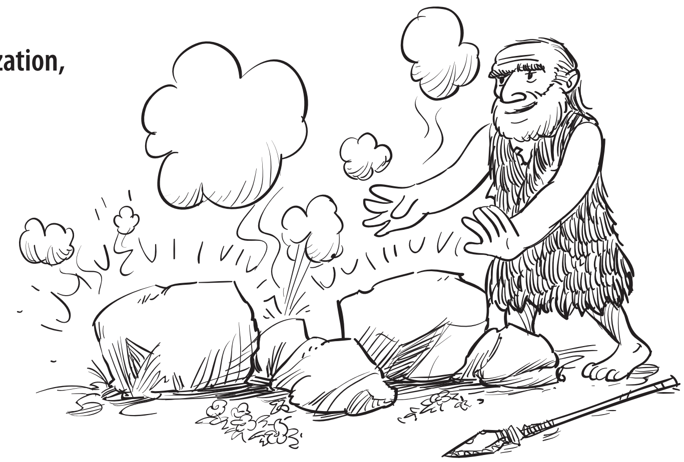
And thank you also to Joel Renner (ret.), Idaho National Laboratory, for his good advice.

Unit I
GEOTHERMAL ENERGY:
GEOTHERMAL FOOTPRINTS OVER TIME

Subjects:
Ancient Civilization, Western Civilization, World History, U.S. History



UNIT OVERVIEW

THE OBJECTIVE OF THIS UNIT is to introduce the concept of geothermal energy to students of World History, Ancient Civilization or Western Civilization. Each lesson is designed to enhance students' understanding of how geothermal energy can potentially impact their lives today from studying its use in the past.

Lesson 1, ***Geothermal Discoveries in the Prehistoric World,*** introduces the concept of geothermal energy and its use in the past, beginning with prehistory. Students will produce a timeline with key events in geothermal history, which will strengthen their understanding of how the use of geothermal energy has evolved. Students will work together to write a grant proposal, which will demonstrate their knowledge of the roles geography and science play in geothermal energy.

Lesson 2, ***Roman Bath Houses,*** allows students to study geothermal energy as it was used by Romans for their bath houses. Students will prepare a group project that enables them to design a creative advertising campaign to promote the uses of geothermal energy during Roman times.

Lesson 3, ***Electricity and Geothermal Energy,*** is designed for students to study geothermal energy in comparison to other forms of energy used during the Industrial Revolution. Students will be able to explain through oral and written components advantages of using geothermal energy over other forms of energy. In this project, students will demonstrate their understanding of the different forms of energy.

Unit I - Lesson 1: GEOTHERMAL DISCOVERIES IN THE PREHISTORIC WORLD

Objectives

Students will be able to:

- Understand how geothermal energy differs from other energy sources.
- Demonstrate understanding of geothermal energy and many of its uses.
- Provide specific means of finding geothermal sites.
- Demonstrate understanding of some costs and benefits of geothermal energy.
- Construct an accurate timeline and draw detailed maps.

Time

Four class periods

Background

Slideshow at http://www.geothermal.marin.org/GEOpresentation/

Geothermal chapter from *Energy for Keeps*, free download from http://www.geothermal.marin.org/edmatl.html

Materials

Library and/or Internet access
Maps

LESSON PROCEDURES

Engage:

Activator: K-W-L (Know–Want to Know–What You Learned)

Ask students to explain what they know about geothermal energy in relation to prehistory, archaeology, anthropology, and geology. Next, ask what they might *want* to know about the topics. After the conclusion of the unit, students will fill in what they have learned from the class lessons. This method of topic introduction encourages students to feel more motivated and take a more active role in their learning. *10-15 minutes.*

After assessing the students' current knowledge of geothermal energy, teachers will introduce the major concepts of geothermal energy. Teachers will present the major facts of geothermal energy: What is it? Who has used it in the past? Who uses it today? How is it used? When has it been used? Where do you find geothermal sites?

Teachers may present the information in a lecture format or in conjunction with the Geothermal Education Office slide show, "Geothermal Energy," available at www.geothermal.marin.org.

Explore:

Discovery Activity: Determining Sites of Geothermal Energy

Teachers would set up classroom in six stations. Each station should have a poster representing a continent. Teachers (or a few service-minded students) will prepare these ahead of time, indicating as clues on each continent, geologic features (i.e., mountains, geysers, fertile farmland, volcanoes, valleys). Students must use these clues to determine if a site would likely have geothermal energy and be able to defend their conclusions.

Explore (optional):

Timeline: In this activity, students will learn how to chart dates properly. Students will trace geothermal energy activity from 10,000 B.C. to the present day. The students will choose 15-20 events (e.g., earthquakes, volcanic eruptions, historic use of hot springs, other examples of geothermal use or activity) that have taken place in Asia, Africa, the Middle East, Europe or the Americas.

Demonstrate how to construct a timeline.

Ask students to accurately put the following dates in chronological order.

1 million B.C.

707 B.C.

250,058 B.C.

305,017 B.C.

10,007 B.C.

4161 B.C.

58 B.C.

Explore:

This activity is the lead-in to student handout for Archeological Dig Grant Proposal

Activator: Gallery Walk (see http://serc.carleton.edu/introgeo/gallerywalk/what.html)

Students will walk around the room and write down what is significant about prehistoric times, anthropology, archaeology, and geology in relation to these questions:

- What are the characteristics of prehistoric times? What sets this period of time apart from historic eras?
- How can archaeology be used to learn more about prehistoric and historic times?
- How can anthropology be used to learn more about prehistoric and historic times?
- How can the field of geology aid an archaeological dig?

Teachers will prepare four posters, each titled with one of the above questions on it. Students walk around the room in groups and address each question, being careful not to repeat any information already stated on the poster.
(10-15 minutes)

Class discussion about posters: Students will discuss what they have learned about geothermal energy.
(10 minutes)

After the discussion, distribute student handout, "Archeological Dig Grant Proposal." Discuss "Proposal" assignment and answer any questions.
(15-20 minutes)

Explain:

Teachers may want to review the major concepts of geothermal energy.

- What is geothermal energy?
- Where do we find it on Earth's surface?
- What has it been used for in the past (prehistoric times)?
- How is geothermal energy being used today?
- A good time to discuss: What are the benefits and potential benefits of geothermal energy use?
  (20-30 minutes)

Extend, as part of "Proposal" assignment (Day 3):

It is recommended that students have at least one day of research in the library.

Cartography: Students will draw an accurate map to scale of their expected areas of exploration.

Written Research: Students will research and write about prehistoric excavation sites to determine a site for their work.

Evaluate (Day 4):

Oral Presentations: Students will present their proposals including relevancy of geothermal energy use at the dig site. See "Criteria for Success" at bottom of student handout.

GEOTHERMAL ENERGY: GEOTHERMAL FOOTPRINTS OVER TIME

Archaeological Dig Grant Proposal

Instructions: As a young graduate student, you have always dreamed of applying your knowledge of prehistoric life to an archaeological dig. You want to complete your Masters thesis by completing an archaeological dig, but know that any dig is incredibly expensive. So you are writing a grant proposal for three archaeological digs — Africa, the Middle East, and Asia.

In the process of writing your grant proposal, you are trying to come up with a fresh angle to present to the grant committee. What will your dig uncover that is new and significant? Recently you have delved into the history of geothermal energy and realized that this is an area in which you can conduct research to see the advantages and challenges of using geothermal energy throughout prehistory. How did prehistoric people use geothermal energy? Your group of archaeologists and anthropologists want to study the lives of how prehistoric people and the earliest civilizations utilized geothermal energy as a resource.

Your group is requesting money from Dr. Caraluggio, a famous archaeologist, to fund your expeditions/digs. In your written proposal, you must include the following information:

- Where do you intend to stage your expeditions? Why did you choose these sites? What evidence does your group have to conclude that you will find anything significant? Where is the location on the globe (Ring of Fire, plate tectonics, subduction, spreading centers and hot spots)? What surface features did you look at to determine location (volcanoes, geysers, mineral deposits, hot springs, fumaroles)?
- How would prehistoric people have used their resources?
- What groups of people do you hope to study? When did these people live? How will you date your findings?
- What artifacts or fossils does your group hope to find?
- How will you research and explain the significance of your findings?

In addition to your written grant proposal, each group will have to present its grant proposal to a panel of expert archaeologists and anthropologists. The presentation should include:

- Summary of your proposal, prediction of location, use and evidence
- Hand-drawn maps detailing and explaining reason for location of your proposed digs
- Timeline

- Examples of items you hope to find (evidence); what your evidence looks like; did the evidence meet your predicted hypothesis?

Criteria for Success

Grades will be assessed based on how well your completed summary, posters, and presentation meet the following criteria.

A = Student work shows a sophisticated understanding of the subject matter involved. The summary, posters, and presentation are expertly insightful, going beyond the typical facts. There is evidence of critical thinking involved in the completion of the project and original thought.

B = Student work shows a good understanding of the subject matter involved. The elements of the project involved an advanced degree of difficulty. There is some evidence of critical thinking and original thought.

C = Student work shows an adequate understanding of the issues involved. Work reveals some control of the elements. There is less demonstration of critical thinking or original thought.

D = Student work shows a limited understanding of the concepts. The elements of the project demonstrate little critical thinking or original thought.

F = Student work is incomplete. There is no understanding of the concepts.

National Social Studies Standards Correlations for Lesson 1

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme I: History

Teachers who are licensed to teach history should process the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of history.

- Enable learners to analyze and explain how groups, societies, and cultures address human needs and concerns.
- Guide learners in constructing reasoned judgments about specific cultural responses to human issues.
- Have learners explain and apply ideas, theories, and modes of inquiry drawn from anthropology and sociology in the examination of persistent issues and social problems.
- Help learners apply big concepts, such as time, chronology causality, change, conflict, and complexity to explain, analyze and show connections among pattern of historical change and continuity.
- Guide learners in using such processes of critical historical inquiry to reconstruct and interpret the past, such as using a variety of sources, and checking their credibility, validating and weighing evidence for claims, searching for causality and distinguishing between events and developments that are significant and those that are inconsequential.
- Enable learners to use, interpret, and distinguish various representations of Earth such as maps, globes, and photographs, and to use appropriate geographic tools.
- Encourage learners to construct, use and refine maps and mental maps, calculate distance, scale, area, and density, and organize information about people, places, regions, and environments in a spatial context.
- Provide opportunities for learners to examine, interpret, and analyze interactions of human beings and their physical environments and observe and analyze social and economic effect of environmental changes, both positive and negative.
- Challenge learners to consider, compare and evaluate existing uses of resources and land in communities, regions, countries of the world.
- Direct learners to explore ways in which Earth's physical features have influenced and been influenced by physical and human geographic features.
- Help learners understand the concepts of role, status, and social class and use them in describing the connection and interactions of individuals, groups, and institutions in society.
- Assist learners in utilizing chronological thinking so that they can distinguish between past, present, and future; can place historical narratives in the proper chronological framework; can interpret data presented in time lines, and can compare alternative models for periodization.
- Challenge learners to examine how the forces of cooperation and conflict among people influence the division and control of Earth's surface.
- Help learners see how human actions modify the physical environment.
- Enable learners to analyze how physical systems affect human systems.
- Help learners to apply geography to interpret the past and present and plan for the future.

continued

National Social Studies Standards Correlations for Lesson 1 (continued)

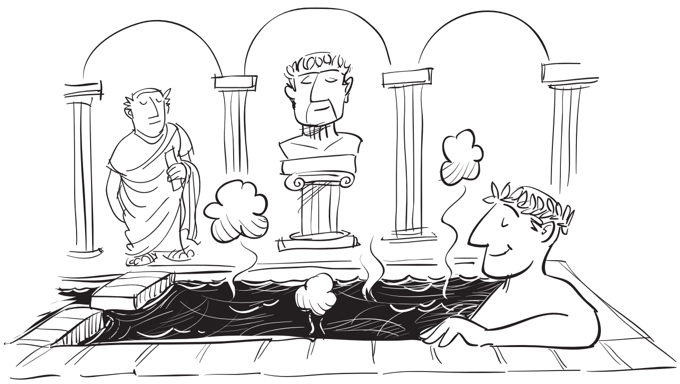
National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme I: Geography

Teachers who are licensed to teach geography at all levels should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of geography.

- Guide learners in the use of maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective.
- Assist learners to analyze the spatial information about people, places, and environments in a spatial context.

Unit I - Lesson 2: ROMAN BATHHOUSES



Objectives

Students will be able to:

- Demonstrate their understanding of geothermal energy use in the context of Roman times.
- Understand how the Romans used geothermal energy for bathhouses.

Time

Four class periods

Background

Slideshow at http://www.geothermal.marin.org/GEOpresentation/

Geothermal chapter from *Energy for Keeps*, free download from http://www.geothermal.marin.org/edmatl.html, or see Supplemental Information at end of this document.

Materials

Library and/or Internet access

LESSON PROCEDURES

Engage/Explore (Day 1):

Word Splash: In a journal entry, each student will write speculative statements about how each word/term in the following list is associated with geothermal energy. (*10-15 minutes.)*

heat
baths
social interactions
rich resources
earth
under-floor heating
Romans
commercial
environmentally sound
social classes

Explain (Day 2):

Lecture/Discussion on Roman society, including the political and social importance of Roman bathhouses. *(30-40 minutes)* Cover the following topics/questions at whatever level of detail works for the group:

- What is a bathhouse?
- How was a bathhouse constructed?
- Where would bathhouses be constructed? Why?
- Who frequented bathhouses? Why?
- Explain the important political and social relevance of the bathhouse.
- How was heat achieved at the bathhouse? (Was it always geothermal?)

Distribute handout, "Roman Bath Advertising Campaign." Introduce Project/Advertising Campaign and answer student questions.

Extend (Day 3):

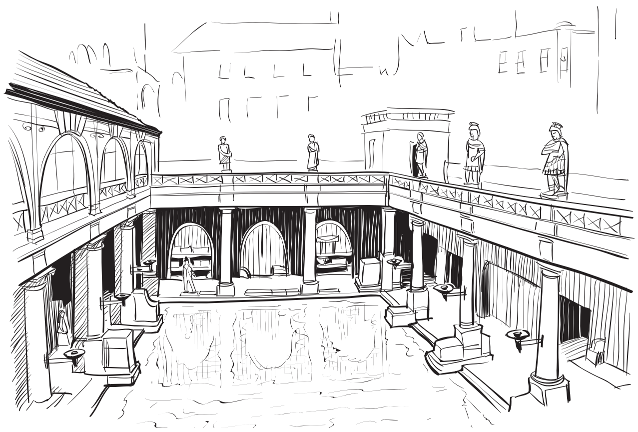
It is recommended that students be provided with library research time to work on this project.

Evaluate (Day 4):

Advertising campaign presentations. See "Criteria for Success" at bottom of student handout.

GEOTHERMAL ENERGY: GEOTHERMAL FOOTPRINTS OVER TIME

Roman Bath Advertising Campaign



Instructions: You will be creating an advertising campaign for your new Roman bath in Bath, Somerset, England. It is the first century A.D. While on a military campaign in England, you uncover the potential for a bathhouse in this new Roman territory. You are a young Roman engineer who wants to construct a new Roman bathhouse with deluxe heated floors. The construction will be a costly project. You and your fellow engineers will design this advertising campaign to attract the emperor and his council of advisers to invest in the bathhouse.

You want to have a thorough campaign that would explain the cost benefits and other benefits of using geothermal energy to heat the bathhouse, the appeal of the bathhouse, and the possible clientele to use the bathhouse. In an effort to explain the process of getting heated floors, you hire a group of Roman scientists to develop hands-on demonstrations of practical uses of geothermal energy.

Components of the Campaign

Power point/ Keynote Presentation of campaign's critical points

Must be 15-30 slides, and might include the following information:

- Ancient civilization's use of geothermal energy before the Romans
- Roman use of geothermal energy
- Cost benefits of using geothermal energy for heat
- Practical uses of first hand accounts of Romans using bathhouses
- Design of known bathhouses (use examples of known bathhouses)
- Process of determining the location of the bathhouses
- Use of scientific method in determining location
- Clientele (explain who would use the bathhouses)
- Role social class played in the bathhouse

Oral Presentation

You will be expected to explain and review your campaign, with your colleagues, to the emperor and his council of advisers. At the end of the presentation the emperor will decide if your campaign warrants a contract.

Criteria for Success

Grades will be assessed based on how well your completed summary, posters, and presentation meet the following criteria.

A = Student work demonstrates a sophisticated understanding of the subject matter involved. The written work and presentation are expertly insightful, going beyond the typical facts. There is evidence of critical thinking involved in the completion of the project and original thought.

B = Student work shows a good understanding of the subject matter involved. The elements of the project involved an advanced degree of difficulty. There is some evidence of critical thinking and original thought.

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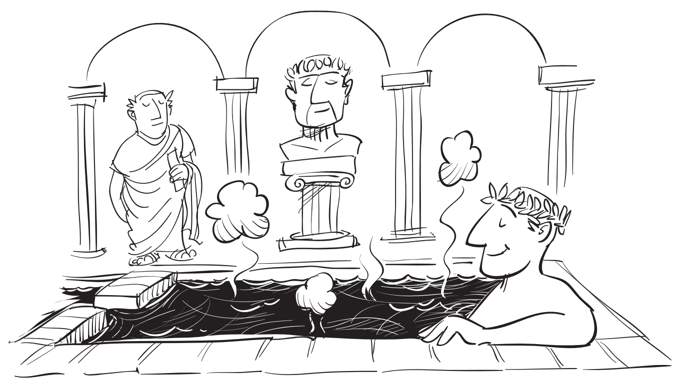


National Social Studies Standards Correlations for Lesson 2

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme I: History

Teachers who are licensed to teach history should process the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of history.

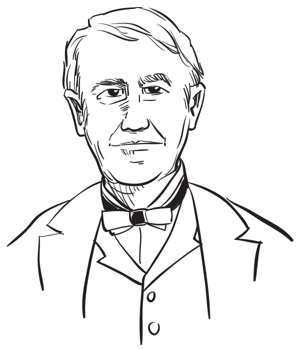
- Enable learners to analyze and explain how groups, societies, and cultures address human needs and concerns.
- Guide learners in constructing reasoned judgments about specific cultural responses to human issues.
- Guide learners in using such processes of critical historical inquiry to reconstruct and interpret the past, such as using a variety of sources, and checking their credibility, validating and weighing evidence for claims, searching for causality and distinguishing between events and developments that are significant and those that are inconsequential.
- Enable learners to use, interpret, and distinguish various representations of Earth such as maps, globes, and photographs, and to use appropriate geographic tools.
- Encourage learners to construct, use and refine maps and mental maps, calculate distance, scale, area, and density, and organize information about people, places, regions, and environments in a spatial context.
- Provide opportunities for learners to examine, interpret, and analyze interactions of human beings and their physical environments and observe and analyze social and economic effect of environmental changes, both positive and negative.
- Challenge learners to consider, compare and evaluate existing uses of resources and land in communities, regions, countries of the world.
- Direct learners to explore ways in which Earth's physical features have influenced and been influenced by physical and human geographic features.
- Help learners understand the concepts of role, status, and social class and use them in describing the connection and interactions of individuals, groups, and institutions in society.
- Help learners see how human actions modify the physical environment.
- Help learners to apply geography to interpret the past and present and plan for the future.

Theme I: Geography

Teachers who are licensed to teach geography at all levels should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of geography.

- Guide learners in the use of maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective.
- Assist learners to analyze the spatial information about people, places, and environments in a spatial context.

Unit I - Lesson 3: ELECTRICITY AND GEOTHERMAL ENERGY



Thomas Edison

James Watt

Objectives

Students will be able to:

- Evaluate the significance of some major electricity-related accomplishments from the Industrial Revolution to today's scientists working to offer geothermal energy as a friendly alternative to fossil fuel-based energy.

Time

Four class periods

Background

Slideshow at http://www.geothermal.marin.org/GEOpresentation/

Geothermal chapter from *Energy for Keeps*, free download from http://www.geothermal.marin.org/edmatl.html, or see Supplemental Information at end of this document.

Materials

Library, Internet

LESSON PROCEDURES

Engage (Day 1):

Activator: Journal entry. Describe your life without electricity *(5-8 minutes)*

Discuss the journal entries *(10 minutes)*

Explore/Engage (Day 1):

Lecture on James Watt and Thomas Edison (marking their places in the Industrial Revolution)

- What was the significance of the steam engine?
- How was life changed by the steam engine?
- How can technology be used to improve people's lives?
- Were all people immediately accepting of this new technology? Why/Why not?
- Introduce concept of renewable energy, then introduce geothermal as one of the renewable sources of power for electricity: show Slideshow from www.geothermal.marin.org so students have understanding of the basics:
- What is geothermal energy?
- How can we access geothermal energy?
- How do we generate electricity from geothermal energy?
- What are benefits of geothermal energy and other renewable energy use?

Explore (Day 2, option):

Discuss the historical evolution of how people have used geothermal energy for electricity.

Explore/Explain (Day 2/3):

Distribute handout, "Electricity and Geothermal Energy." Introduce activity:

Discuss the contributions of Edison and Watts to the Industrial Revolution.

Divide students into groups of three. You are a modern day scientist working on bringing geothermal energy to widespread use. Compare and contrast your impact with those of Watts and Edison. You and your partners will take on one of the three roles (today's scientist, Watts, Edison) and explain the impact of his work in a dialogue.

The dialogue must include:

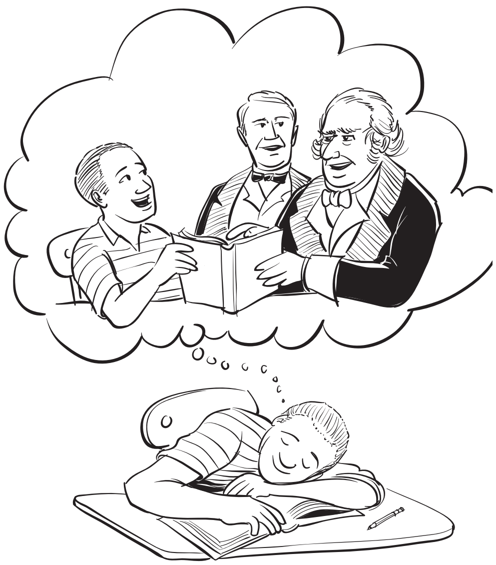
- Thirty lines of dialogue
- An explanation of how electricity is generated (by both fossil fuels and by geothermal energy)
- The environmental effects of energy use for power generation

Evaluate (Day 4):

Students' theoretical discussion with Watts and Edison, as described on student handout for this lesson. See "Criteria for Success" at bottom of student handout.

GEOTHERMAL ENERGY: GEOTHERMAL FOOTPRINTS OVER TIME

James Watts, Thomas Edison and Geothermal Energy



Instructions: The year: the present. You are Dr. __________ (your name), an engineer who is conducting tests for possible geothermal sites. While preparing a presentation to prospective investors, you prepare a firsthand demonstration of geothermal energy, a written report on the benefits and potential challenges of geothermal energy, including the potential of a newer geothermal technology, called Engineered Geothermal Systems (EGS).

In the course of your research and preparation, you realize that the challenges you face in convincing your potential investors and the public at large is similar to what James Watt and Thomas Edison faced during the Industrial Revolution.

Consumed by work, you fall asleep at your desk. You have a vivid dream in which you discuss your project with Watt and Edison. The three of you discuss the similarities and differences between electricity generated from steam made by burning fossil fuels or wood vs. geothermal steam. You discuss the following:

- How and when was each form of energy first used to generate electricity?
- What are the benefits and costs of each one to the environment?

Upon waking up, you realize the vivid dream will aid you in completing your presentation to prospective investors.

Criteria for Success

A = Student work demonstrates a sophisticated understanding of the subject matter involved. The written work and presentation are expertly insightful, going beyond the typical facts. There is evidence of critical thinking involved in the completion of the project and original thought.

B = Student work shows a good understanding of the subject matter involved. The elements of the project involved an advanced degree of difficulty. There is some evidence of critical thinking and original thought.

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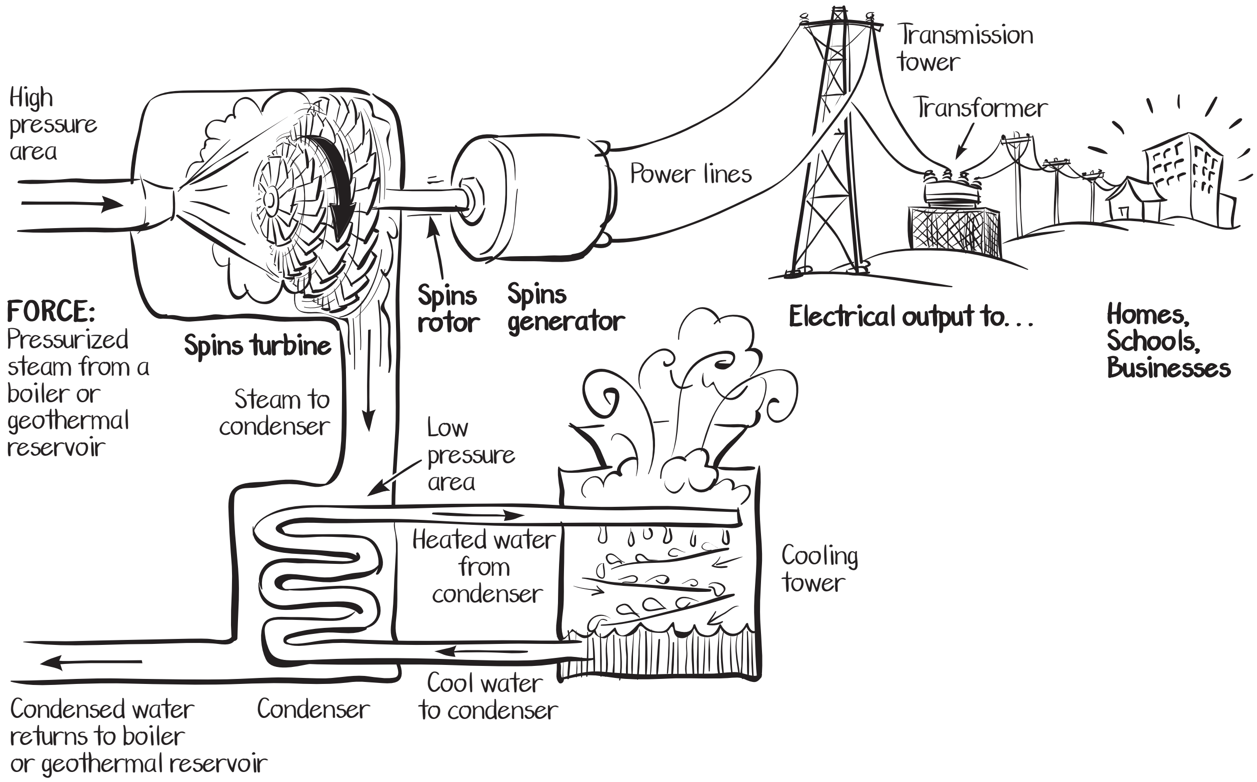


How a Steam-driven Power Plant Works

National Social Studies Standards Correlations for Lesson 3

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme I: History

Teachers who are licensed to teach history should process the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of history.

- Enable learners to analyze and explain how groups, societies, and cultures address human needs and concerns.
- Guide learners in constructing reasoned judgments about specific cultural responses to human issues.
- Guide learners in using such processes of critical historical inquiry to reconstruct and interpret the past, such as using a variety of sources, and checking their credibility, validating and weighing evidence for claims, searching for causality and distinguishing between events and developments that are significant and those that are inconsequential.
- Provide opportunities for learners to examine, interpret, and analyze interactions of human beings and their physical environments and observe and analyze social and economic effect of environmental changes, both positive and negative.
- Challenge learners to consider, compare and evaluate existing uses of resources and land in communities, regions, countries of the world.
- Help learners see how human actions modify the physical environment.
- Help learners to apply geography to interpret the past and present and plan for the future.

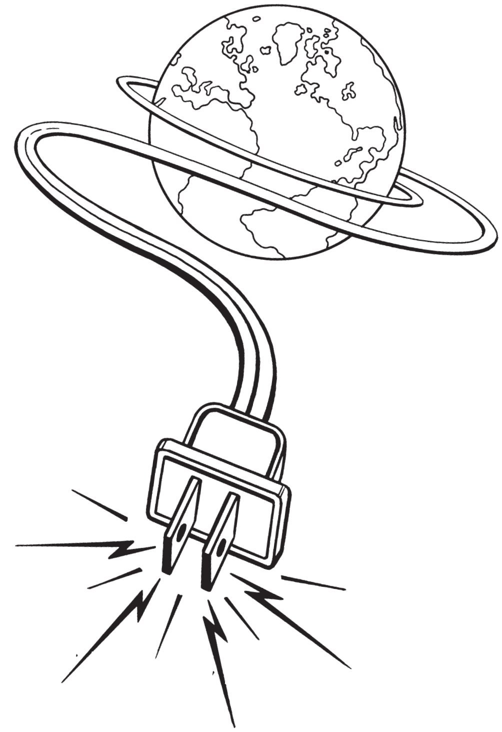
Theme I: Geography

Teachers who are licensed to teach geography at all levels should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of geography.

- Guide learners in the use of maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective.
- Assist learners to analyze the spatial information about people, places, and environments in a spatial context.

Unit II
GEOTHERMAL ENERGY: ELECTRICITY AND OTHER USES

Subjects:
Earth Science, Physical Science, Geology, Environmental Science



UNIT OVERVIEW

THIS UNIT INTRODUCES GEOTHERMAL ENERGY as a resource for generating electricity and for other uses. It is composed of six lessons. Correlations to National Science Standards for all six lessons begins on page 56.

Abundance of Earth's Heat

Lesson 1, *Earth's Heat,* investigates the creation and distribution of this geothermal enegy resource introducing the concept of a *geothermal reservoir*. It begins with an overview of Earth's structure, and the heat within. Students identify and describe heat as an important component of the structure and behavior of planet Earth, create a scaled model of the planet, and map its heat both by depth and on Earth's surface. The Big Idea here is that heat is abundant in the earth, and differs by location.

Benefits of Earth's Heat

Lesson 2, *Geothermal Reservoirs,* and **Lesson 3, *Getting the Heat Out,*** investigate and compare the uses humans have found for this resource, as well as ways that heat is transmitted to us. The lessons allow students to apply some of what they learned from Lesson 1 through researched presentations on the variety of geothermal energy applications to a classroom audience. An interdisciplinary connection can be made here with Unit I of this curriculum, which explores earlier human experience with geothermal energy.

Converting Earth's Heat to Electricity

Lesson 4, *Energy Conversion,* and **Lesson 5, *Modeling and Testing a Turbine,*** investigate one major benefit of geothermal energy: the generation of electricity. The importance of energy capture and conversion to electricity are investigated and applied, including the promise of emerging technologies in the field of geothermal energy. Students can see the potential for this resource in an exciting future that addresses both energy supply and environmental challenges. The goal is to move citizens towards a more sustainable energy future. As such, it is also a jumping off point for Unit III of this curriculum, which pursues the policy-making aspect of this emerging issue in civics and government.

Discovering Uses for Earth's Near-Surface Temperature

Lesson 6, *Heating and Cooling Buildings with Geothermal Heat Pumps,* investigates another benefit of geothermal energy: capturing geothermal energy to heat and cool buildings — without the need for a geothermal reservoir. Earth has an inexhaustible supply of renewable thermal energy just a few feet underground or underwater; temperatures even very close to the surface remain fairly moderate at 45°-55°F (7°-13°C), year-round. Students will compare traditional fossil fuel systems to the geothermal heat pump systems and will see the value of this environmentally clean and renewable source of energy that can be used as a major contributor to the energy industry and to energy conservation.

Background

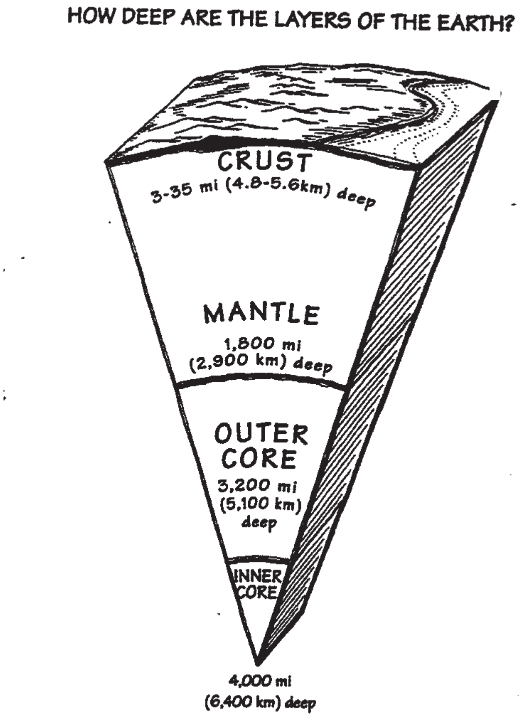
Earth's heat (geothermal) originated at the formation of the solar system 4,500 million years ago. As extraterrestrial bodies collided they created friction, which combined with the compressing force of gravity to form a hot planet (geosphere). The heat is sustained by ongoing radioactive decay within the geosphere. The heat played a major role in the creation of life on the planet, and has since played a role in the evolution of life over 3,700 million years. As humans evolved they recognized and used the heat.

More recently, Earth's heat has been recognized as a source of useful energy, which we refer to as geothermal energy. In the last century we learned to use this heat to generate electricity, an integral component of modern society. As fossil fuel resources begin to approach the limits of their lifespan, renewable alternatives garner increased attention. The connection of these fossil fuels to human-caused climate change intensifies the interest in renewable sources of energy, including geothermal. Unlocking or enhancing the potential of these energy resources, through technology and engineering, is a worthwhile goal that is rapidly gaining steam.

Background Resources

There are many excellent resources that provide background, activities and images for the topics covered in Unit II. See the Resources section at the end of this unit, the Supplemental Information at the end of this curriculum, and the files in the folder entitled *Additional Resources_GeoUnits I, II, III* at eere.energy.gov/education/lessonplans/.

Unit II - Lesson 1: ABUNDANCE OF EARTH'S HEAT



Objectives

Students will be able to:

- Construct an accurately scaled visual model of the earth, which visualizes and summarizes basic behavior of Earth's heat, including convection currents, geothermal reservoirs, and surface patterns
- Use metric units in a scientific illustration and in conversion problems

Time

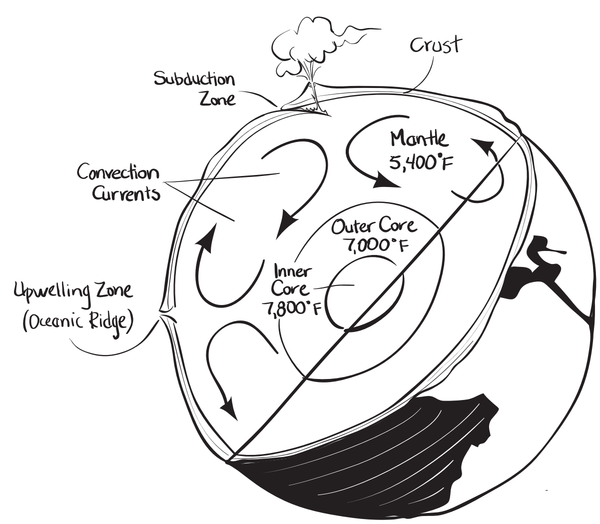
Two or three class periods (depending on time spent independently as homework)

Background

Teacher should become familiar with the origin and structure of Earth, and basics of geothermal energy. Allow perhaps two hours, using any of the following:

- Slideshow and video from Geothermal Education Office website, geothermal.marin.org
- Video Supplement (PDF file) in "Additional Resources" folder at www.eere.energy.gov/education/lessonplans
- Geo-energy.org (see Geothermal 101 PDF file)
- Chapter on Geothermal Energy from *Energy for Keeps*, in Resources section of this curriculum

When the earth formed over 4,500 million years ago, heat from the friction of all the impact collisions that formed the early planet were enough to melt the space dust and rocks. To feel the heat of friction, tell students to slap their hands together and rub them back and forth repeatedly, then quickly place their palms on their cheeks to feel the heat. In the case of the earth, the result of all this heat was a molten ball of rock in space. Like any hot object, it began to cool. And, like a slow cooking thick stew, a thin film on its outer surface cooled first. The result was a ball of rock in space, with a thin crust of solid rock on its outer surface surrounding a hot molten interior.



That's what we are standing on today. We live on a hot ball of rock with a thin cool solid crust. In this activity, students create an accurately scaled diagram of the earth, using metric measurements of temperature and distance. As a result, students gain an awareness of the energy potential of geothermal resources.

Materials

A hard-boiled egg and an apple
Ruler
Graph paper, blank paper, or poster board
Colored pens/pencils
Library or Internet access

LESSON PROCEDURES

Engage:

Lead a brief discussion of modeling the earth using either a hard-boiled egg with a cracked shell, or an apple. Identify the analogy of crust, mantle, and core, pointing out the thin skin of the crust in comparison to the more substantial mantle and core of the sphere. Now, imagine the core of the apple or the yolk of the egg at many thousands of degrees (hot enough to melt rock), and brainstorm what that would do to the skin or the shell. This is our Earth, on heat, and we're standing on it! Discuss crust as insulator. *15 minutes.*

Explore:

Show students the glitter in water on a hot plate to illustrate convection currents as movement of heated material inside the mantle of the earth. Ask students to first describe and sketch their observations, then explain why convection currents happen. Help students see that these convection currents occur inside the earth, and that the inside of the earth is hot, which is the energy that drives these currents.

Quiz students on units of measure and conversions to illustrate the difficulty in converting in the system we currently use: How many teaspoons in a gallon, how many inches in a mile, how many ounces in a ton, at what temperature does water freeze and boil, etc. Students should recognize that factors of conversion are not easy. By comparison, metrics are all divisible by 10s, a simple move of a decimal point.

For metric practice, as well as perspective and background information on geothermal energy, pass out **Student Handout 1,** *How Geothermal Energy Measures Up.*

Explore:

Pass out **Student Handout 2,** *Creating a Scale Model of the Earth.*

Students construct a data table to record layers, distances/thicknesses, and temperatures of Earth, including crust, mantle, and core, at a minimum.

Students research these data, either in a textbook, encyclopedia, or online, depending on teacher preference. Basic data can be shared with students, if they're not to do their own research:

- Crust: 3-35 miles (4.8-56 km) thick
- Mantle: down to 1800 miles (2,900 km) deep; about 5,400°F (3,000°C)
- Outer Core: down to 3,200 miles (5,100 km) deep; about 7,000°F (3,900°C)
- Inner Core: down to 4,000 miles (6,400 km) deep (the center of the earth!); about 7,800°F (4,300°C)

Depending on student background and teacher comfort, students can collect more detailed information, including types of crust (oceanic and continental), lithosphere and asthenosphere, upper and lower mantle.

Students should be instructed to convert all measurements into metric units: miles to kilometers (km) for distance, and degrees Fahrenheit (F) to degrees Celsius (C) for temperature. Data table columns should be headed with the appropriate labels and correct metric units.

Students convert distances in kilometers so that scaled distances in centimeters will fit on their scaled model diagram.

Explain:

Students create on graph paper (or printer paper or poster board) a scaled diagram of the layers of the earth (geosphere), labeling each section collected in their research. They may also include the oceans (hydrosphere), which have an average depth of about 2.5 miles (4 km), air (atmosphere), which extends 4-11 miles (7-17 km) from Earth's surface, and even where in this diagram life exists (biosphere). Color-coding is encouraged for clarity.

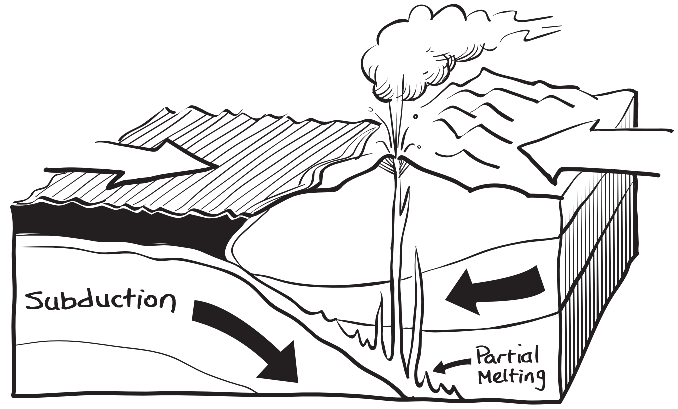
Include in the diagram: location of a geothermal reservoir, a plate boundary and a convection current. These are important components for understanding geothermal energy as a resource.

Extend:

Students can research temperature gradient graphs (heat increases with depth, but not always the same gradient), and perhaps create graphs based on data collected from different sites. See U.S. maps with temperatures color-coded at three depths (students can use these to graph temp gradients at different locations) in the Supplemental Information section of this curriculum.

Students can also recognize there are patterns of concentrated features where Earth's surface temperature is higher, explained by the theory of plate tectonics:

- Tectonic plate boundaries of subduction zones and spreading centers
- Hot spots (Hawaii, Iceland, Yellowstone)
- Crustal Extension in western U.S. between Pacific and North American plates



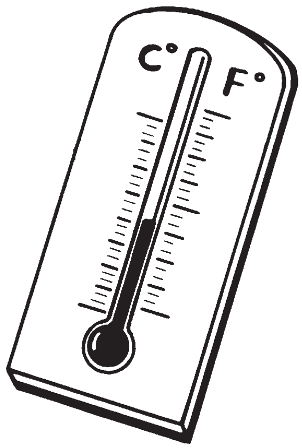
Magma can reach the earth's surface, or near the surface, where the crust is "fractured" or thinned, such as at plate boundaries.

Evaluate:

Students should share their creations in a gallery walk (see http://serc.carleton.edu/introgeo/gallerywalk/what.html), allowing for interaction and greater understanding by comparing with other model diagrams. Students can self-evaluate based on criteria.

Student diagrams can be evaluated on clarity of labeling, correctness of scale, detail of information included, and usefulness of descriptions of layers. The possibility of using these posters for community education as a guideline. Depending on abilities and background of student population, attention in a grading rubric can be paid to the surface features that give evidence of Earth's heat. Also, research into the temperature gradient near the surface can be considered. See maps in "Supplemental Information" at the end of this document.

ABUNDANCE OF EARTH'S HEAT
How Geothermal Energy Measures Up



Instructions: Since geothermal energy is a global resource, it is used — and therefore measured — by people all over the world. Although many in the United States learn and use a system called Customary Measures, the system of measurements used by scientists (as well as non-scientists) globally, is the metric system. Since it is a decimal system based on multiples of tens, it is much easier to use, and is not difficult to learn.

To get you started, or as a reminder:

To measure length: Instead of inches, feet or miles, the metric system uses meters, centimeters and kilometers.

To measure temperature: Instead of degrees Fahrenheit, the metric system uses degrees Celsius.

For practice, answer the following questions about geothermal energy. Show your work in a way that others can understand how you got your answers.

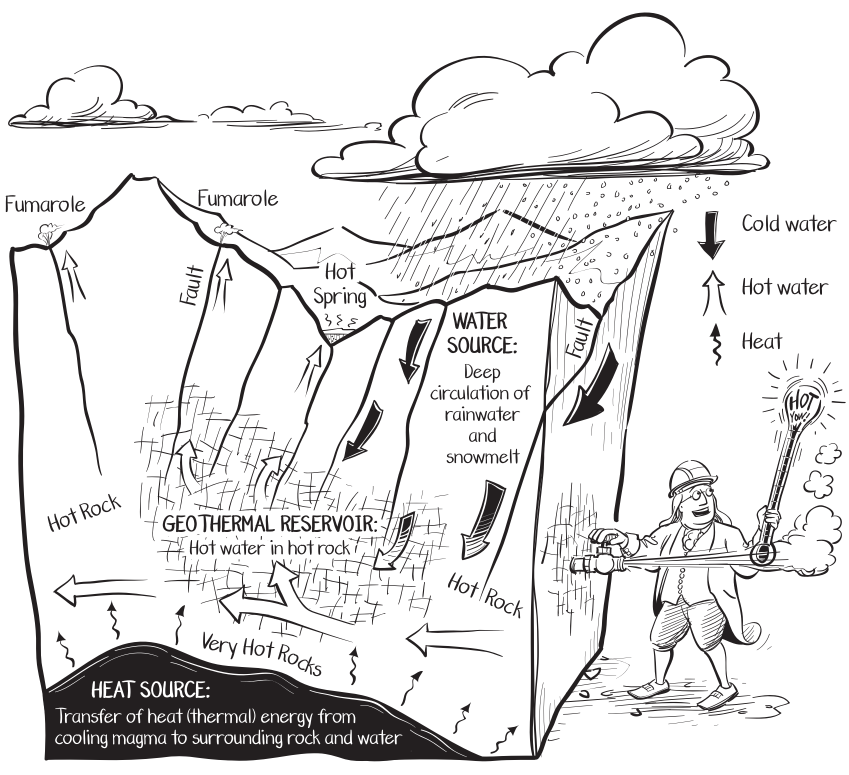
1. Magma is hot molten or partially molten rock the temperature of which can exceed 1,000 degrees Fahrenheit. Convert this to Celsius.
2. The hot rock heats water, which can be trapped below impermeable rock formations to form "geothermal reservoirs." These can be found from 200 to 14,000 feet below the earth's surface. What would these depths be, using the metric system? Would you convert to centimeters, meters or kilometers, and why?
3. For every 100 meters below the surface of the earth, the temperature of the rock increases about 3 degrees Celsius. Convert this to feet and degrees Fahrenheit.
4. Geothermal reservoirs can reach temperatures of over 300 degrees Celsius. What is this in Fahrenheit? By comparison, what is the temperature of boiling water? When this water comes up to the surface through cracks in the earth's surface, it's called a geyser or hot spring, and can be used for heating pools, warming buildings for people or maintaining greenhouses for plants.
5. Soda Lake geothermal power plant produces 12 MW of power. Write this number three different ways, using different metric prefixes. How many average American homes can this plant supply with electricity (requires research)?
6. Draw, to scale, a thermometer that could measure the heat of different areas in the earth, temperatures we experience in our daily lives (boiling and freezing water, body temperature, warm day, room temperature), and other temperatures of interest for reference (the sun, for example, and the coldest place on Earth or the temperature nitrogen gas turns into a liquid).

Identify those points on the thermometer. Draw metric measurements on one side, and the equivalent Fahrenheit numbers on the other.

- Lava (1,500°-2,000°F, 820°-1100°C), core, mantle, crust, boiling water, body temperature, room temperature, freezing temperature of water
- Aquaculture: 70°-90°F (21°-32°C)
- Balneology and Communal Bathing: 80°-105°F (27°-41°C)
- Agriculture and Greenhouses: 80°-200°F (27°-93°C)
- Home and Building Heating: 80°-250°F (27°-121°C)
- Industry: 200°-300°F (93°-149°C)
- Generating electricity: reservoirs from 165°F (74°C) up to 700°F (371°C)

Bonus Question: Flash steam power plant versus binary system power plant: what considerations do engineers have when deciding which type of geothermal power plant to build?

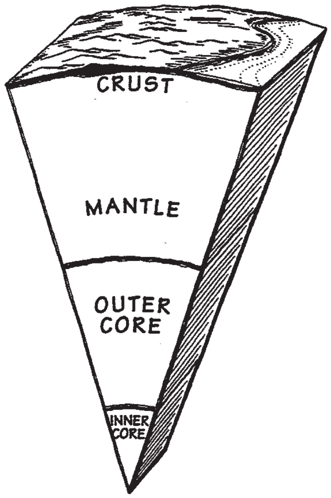
Research the temperatures needed for generating electricity using geothermal energy. Careful, there's a lot more to this than you might think! Where would such a power plant need to be located?



A geothermal reservoir is a large underground area of hot permeable rock saturated with hot water and steam.

ABUNDANCE OF EARTH'S HEAT

Illustrating the Heat of the Earth: A Scale Model



How deep are Earth's layers?

When the earth formed over 4,500 million years ago, heat from the friction of all the impact collisions that formed the early planet were enough to melt the space dust and rocks. To feel the heat of friction, slap your hands together and rub them back and forth repeatedly, then quickly place your palms on your face to feel the heat. In the case of the earth, the result of all this heat was a molten ball of rock in space. Like any hot object, it began to cool. And, like a slow cooking thick stew, a thin film on the outer surface cooled first. The result was a ball of molten rock in space, with a thin solid 'crust' on its outer surface.

In fact, that's what we are standing on today. We live on a hot ball of rock with a thin, cool (in most places, anyway!) solid crust. In this activity, you're going to create an accurately scaled model diagram of the earth, using metric measurements of temperature and distance.

You will need:

Graph paper, blank paper, or poster board

Ruler

Pencil and eraser

Calculator

Colored pencils

Library or Internet access

How hot are Earth's layers?

Procedure

1. Create a data table in your journal/notes/binder paper.

- It should include four columns: name of Earth's layer, thickness/distance (in kilometers), temperature (in degrees Celsius), and other facts of interest (state of matter, composition, pressure, magnetism, etc).
- Make sure to include geothermal reservoirs and convection currents as part of your data table. These two are important for understanding our use of geothermal energy.
- The number of rows (entries) must include crust, mantle, outer core, and inner core. You could divide your data further to include other layers as well. Check with your teacher for how detailed your scale model is going to be.

2. Based on your research, fill in your data table. Make sure your data are metric!

3. Determine scale:

- Find the distance from the surface of the earth to its center in km.
- Identify how large you want your model to be, in cm. A good idea would be a round number slightly smaller than the size of your paper.
- Divide total kilometers by desired centimeters to determine your scale. This will give you a scale of km per cm for your scaled-down model drawing of the earth.

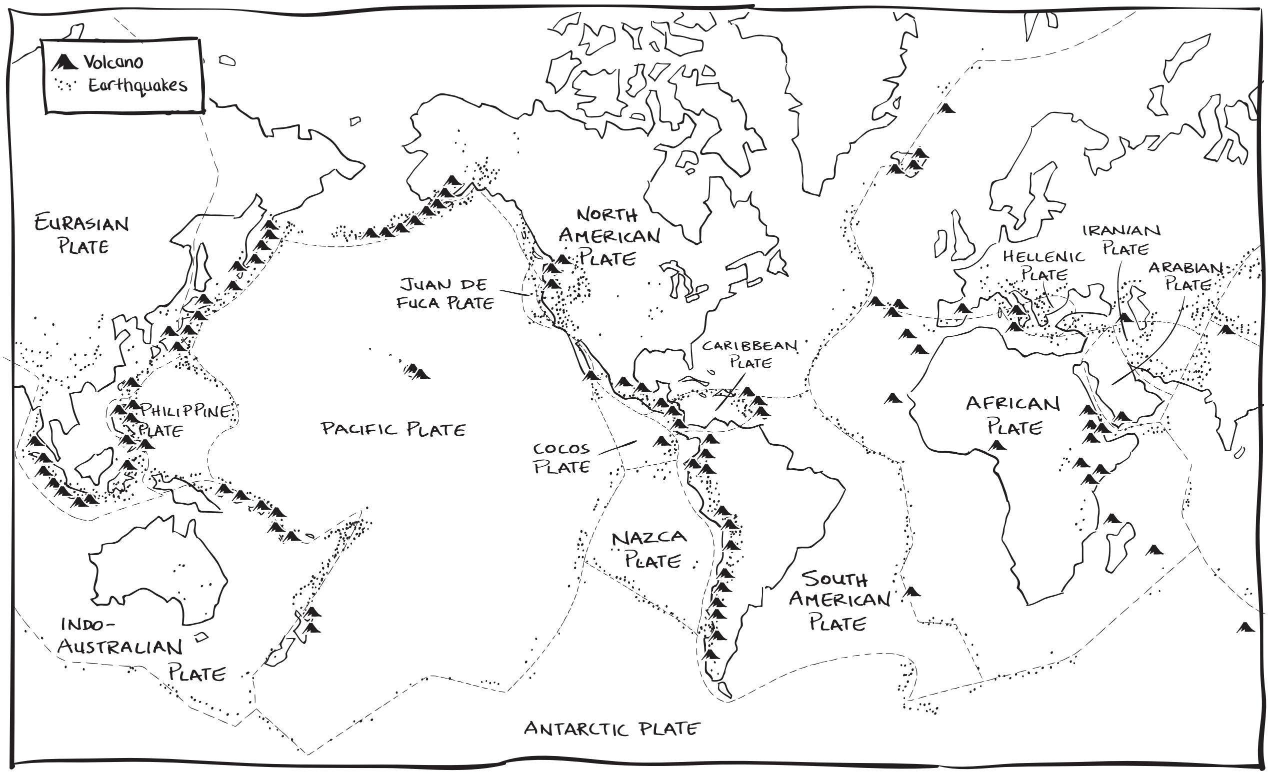
4. Now, use these data from your table to construct a scale model of the earth.

- Use a ruler to clearly and accurately draw the model Earth.
- Clearly label all parts of your model, using your data table as a guide.
- Include convection currents, and use colors and/or labels to illustrate how they carry heat within the earth (from… to…).
- Include a geothermal reservoir in your diagram as well.

Review Questions

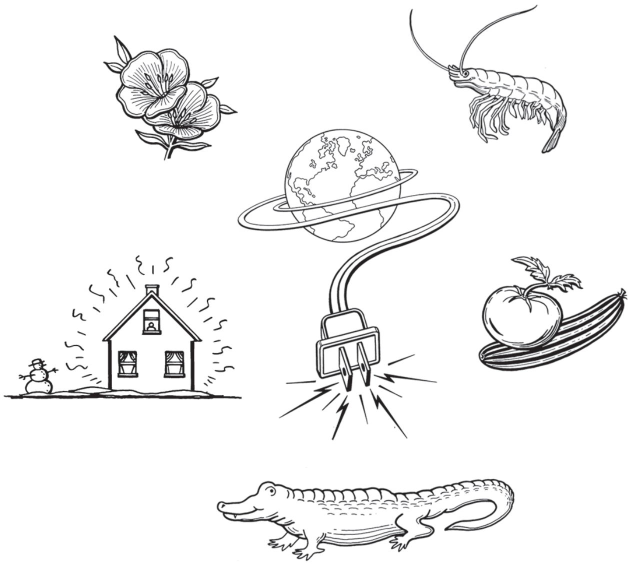
Answer the following questions on separate paper. Some are thought provoking; some may require a bit more research.

1. Where is the earth the hottest? Coolest? Why is it this way? What layer do we live on?
2. How many layers make up the earth? Why is there not one easy answer for this question?
3. How is the earth like an apple or an egg, and how is it not?
4. Why do we use these food models? What are their limitations?
5. What are the pieces of the earth's crust called? How are they different than our food-based models of apple or egg?
6. How are these pieces of crust able to move? Use convection currents in the earth's upper mantle to help you explain.
7. Geothermal reservoirs are areas of heated water located in the earth, relatively close to the surface. What heats these areas? Where does the heat go?
8. What is the "Ring of Fire"? Why is there so much geothermal activity there? Do you live near the Ring of Fire? Where is the nearest geothermal activity to your home?
9. Describe any patterns of Earth's heat, revealed by your research and illustrated on your Earth model, that you discovered during this project.
10. What implications do your findings have for human use of geothermal energy as a resource?



This map shows the edges of the tectonic plates that form the Pacific "Ring of Fire." The edges of the continents that surround the Ring of Fire are prone to earthquakes and volcanoes and have some of the best geothermal resources in the world. This includes the western part of North, Central and South America; New Zealand; Indonesia; the Philippines; Japan; and Kamchatka (eastern Russia). Some of the other prime geothermal locations include Iceland, Italy, the Rift Valley of Africa, and Hawaii.

Unit II - Lesson 2: BENEFITS OF EARTH'S HEAT



Objectives

Students will be able to:

- Research and present a clear overview of one use of geothermal energy.
- Categorize uses of geothermal energy.
- Identify and describe the three necessary components of a geothermal reservoir.
- Identify a variety of uses for geothermal resources, depending on temperature, including three types of geothermal power plants.

Time

Two class periods

Materials

Poster of graph showing uses of Earth's heat (Geothermal Education Office)

Internet access

LESSON PROCEDURES

Engage:

Show students the video of geothermal energy uses, from the GEO website.

Lead a brief discussion of what students already knew, and what they didn't, about the benefits and uses of geothermal energy.

Explore:

Demonstrate the basics of heat transfer. Have students place their palms flat on various surfaces and compare how cold they feel. Styrofoam and metal are two materials that work very well for this exploration. Also, place thermometers (postcard type is preferred, but regular will work as well). Help the students notice that all the materials are the same temperature (room temp!), although what they feel is very different. Ask them to propose explanations for this.

Explain:

Your skin detects the difference between your body and your outside skin temperature. When your skin cools down, your body tells you what you're touching is cold. An object that feels cold must be colder than your hand, and it must carry your body heat *away* so that your skin cools down. Both the metal and the Styrofoam start off colder than your body. They do not *feel* equally cold, however, because they carry heat away from your hand at different *rates*. Styrofoam is a poor conductor of heat, called an insulator. When students' hands touch the Styrofoam, heat flows from the hand to the Styrofoam and warms the Styrofoam surface. Since the heat is not quickly conducted away, the surface of the Styrofoam *feels* warm to the hand. Therefore, little or no heat leaves students' hands. There was no difference between the inside of the body and the outside, so the Styrofoam feels warm.

The metal, in contrast, carries heat away quickly. Metal is a good conductor of heat. Heat flows from students' hands into the metal and then is conducted rapidly away into the bulk of the metal, leaving the metal surface and the skin surface relatively cool. That's why the metal feels cool. Heat is conducted from one material to another. We feel it in our skin, but it can also be measured on the earth, and it's important for how we are able to capture and use the heat we call geothermal energy.

Explore:

Distribute the **Student Handout,** *Poster of geothermal energy uses.*

Let students pick a topic, or assign (teacher preference), for brief research topic.

Students research their assigned temperature range or topic, using online or print resources, noting information on their handout.

Teacher may specify reference categories for research (government, private, non-profit, newspaper, periodical, educational research institution, etc).

Explain:

Students present research findings, using visuals either in PowerPoint/Keynote, poster or other.

Extend:

Other students record information from each presentation on poster handout, as well as extra binder paper as necessary.

Teacher should help students to make connections, and highlight important ideas from the student presentations, so students can record them on their own notes.

Evaluate:

There are different options for assessment:

Student presentations can be assessed on many aspects, depending on teacher preference, but may include communicated level of understanding, specific examples and locations of use, clarity of connection to Earth's geology, historical use (as appropriate), convincing the audience of the value of the resource, projected future use, detailed content, ability to answer questions, etc.

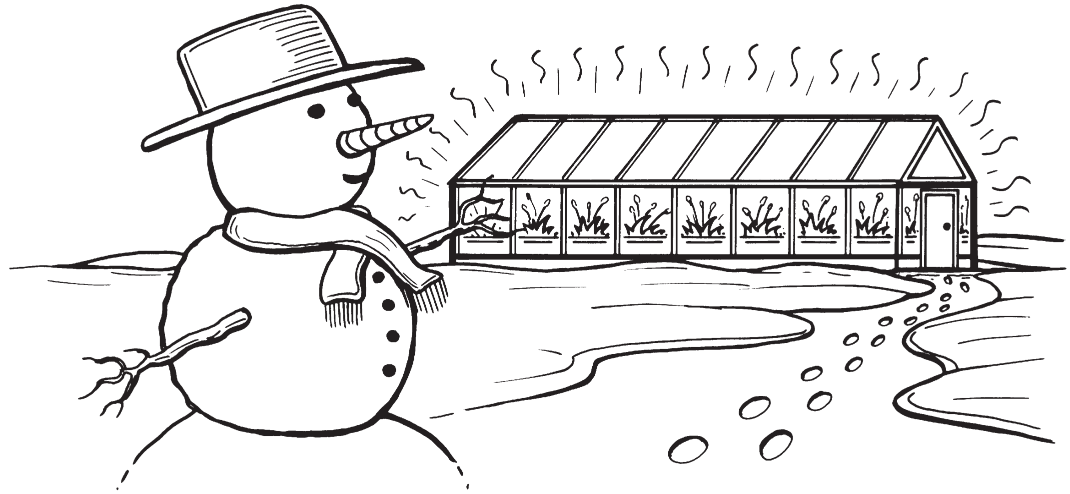
Student can create a written proposal explaining why their community should invest in geothermal energy, based on its history, current variety of uses, and its future potential.

Students can create a chart to compare uses of geothermal energy, based on temperature, history, and location.

Students can create a list prioritizing different uses of geothermal energy, with justification for their list.

BENEFITS OF EARTH'S HEAT

Earth's Heat: Many Temperatures, Many Benefits



Geothermal energy has many uses, depending on the temperature of the water. In this activity, you get to be the expert on one of these uses and to prepare a short presentation about it.

You will need:

Library or Internet access

Presentation resources (poster board, PowerPoint or Keynote, LCD projector, etc.)

Geothermal Energy Uses chart (second page of this handout)

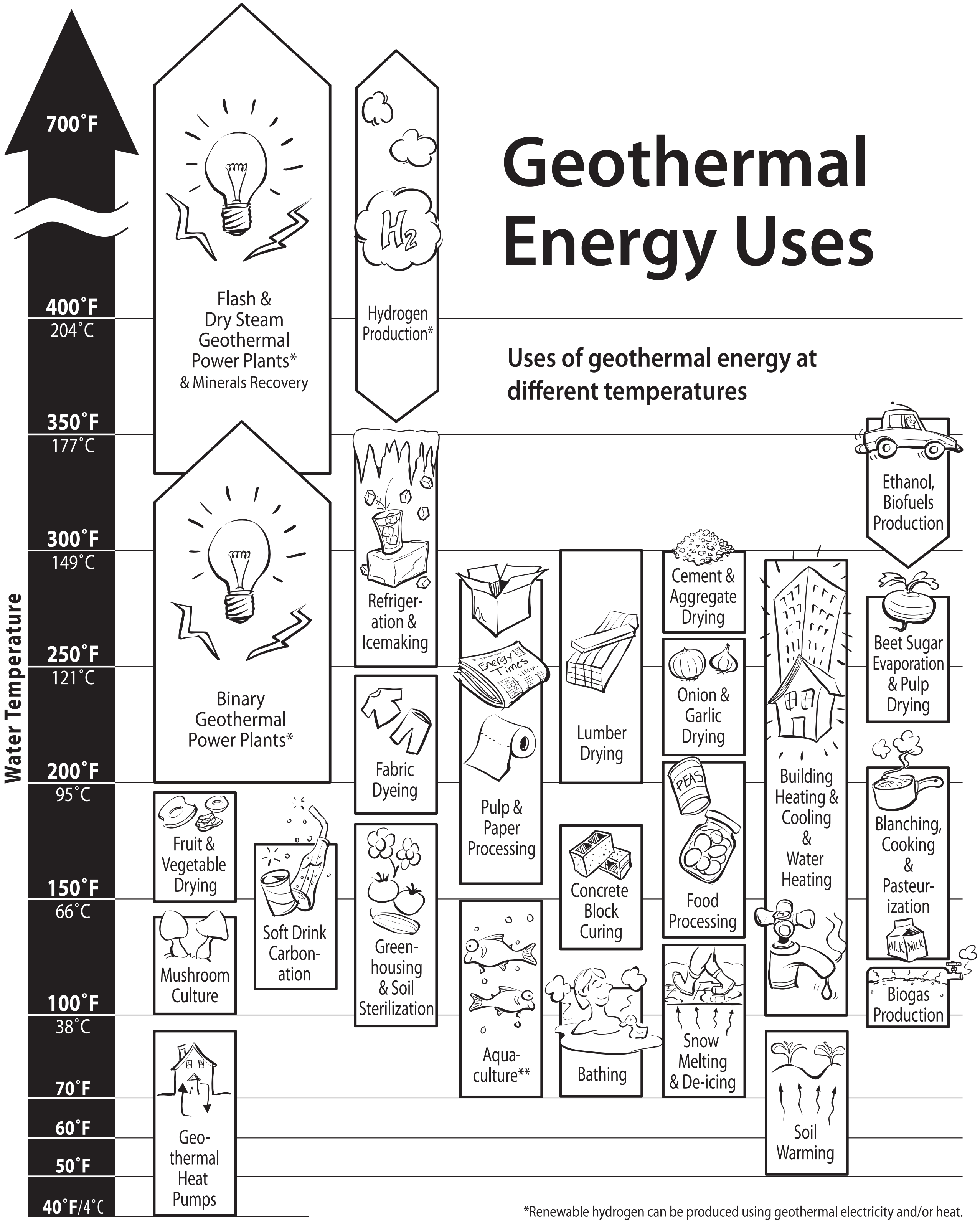
Procedures

1. Choose your temperature target/topic (or it may be selected for you).
2. Do research to collect information about your topic. It should include:
   - Identify the target temperature and use
   - Brief description and history of use
   - Current examples and locations in business/society, and how widespread it is
   - How geothermal energy got to the surface. Refer to an aspect of geology learned from Lesson 1.
   - How the heat is used (either directly or to generate electricity)

   Record your information, including citing your sources, on this sheet.
3. Create a brief (2-minute) presentation, with visuals, to share important and interesting aspects of your topic.
4. Present!
5. Take notes on others' presentations.

Geothermal Energy Uses

Uses of geothermal energy at different temperatures



*Renewable hydrogen can be produced using geothermal electricity and/or heat.
**Cool water is added as needed to make the temperature just right for the fish.

References used in your research (minimum of 3)

1.

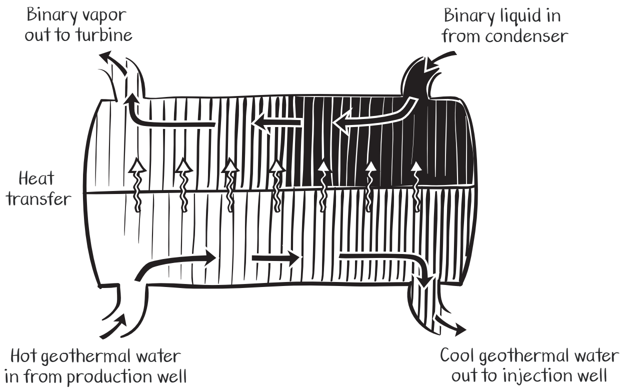
2.

3.

4.

5.

Unit II - Lesson 3: GETTING THE HEAT OUT



Binary Power Plant Heat Exchanger

Objectives

Students will be able to:

- Describe the role heat exchangers play in a binary power plant, in direct use, and in heat pumps
- Explain role Enhanced (or Engineered) Geothermal Systems (EGS) can play in accessing geothermal energy, and evaluate potential implications for development of EGS technology (electricity availability, environmental implications, etc.)

Time

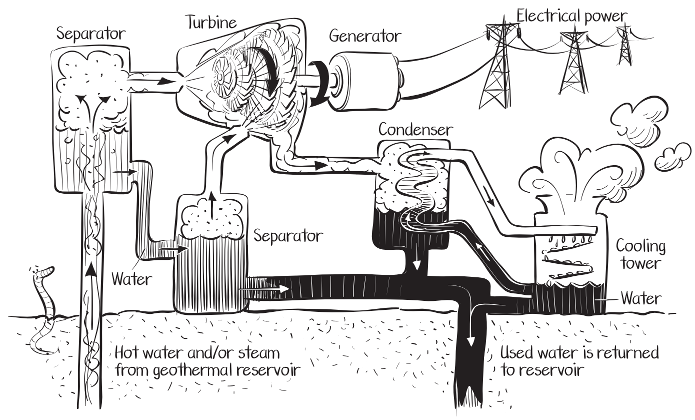
Four class periods

Background

To generate electricity from geothermal energy, the heat energy must first be brought to the surface to be used in a power plant. There are three aspects of the resource that must all be present: first is heat, second is fluid (water) to collect that heat, and third is a pathway for the heated fluid to travel from the geothermal reservoir to the surface.

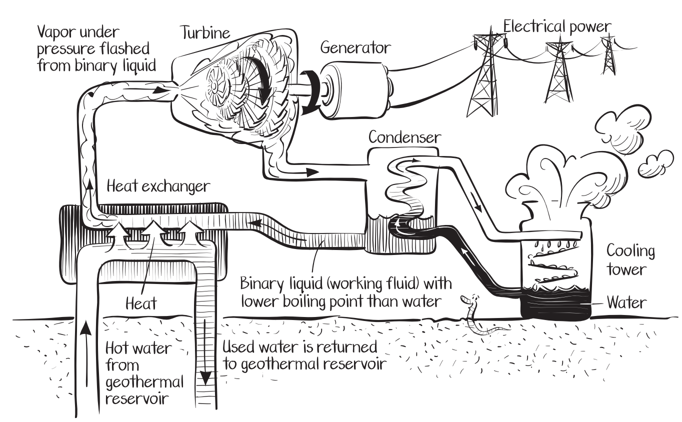
There are also three types of geothermal power plants used to generate electricity:

- The earliest (Lardarello, Italy, 1904) as well as the world's largest source (Geysers in Northern California) is called *dry steam*. High temperature results in hot fluid that is primarily steam, which is used to turn a turbine and generate electricity.
- The second is *flash steam*, which is more common. Hot water at temperatures of at least 392°F (200°C) reaches the surface, then is "flashed" to steam with the pressure drop. The steam turns a turbine to generate electricity. The water is then passed through cooling towers, before being injected back into the reservoir.



Flash Power Plant

- The third type is called a *binary* system, used most often with fluids below 392°F (200°C). The water from the geothermal reservoir is not hot enough to vaporize, but nonetheless carries geothermal energy. The heat from the geothermal fluid is transferred — through a heat exchange mechanism — to heat a second fluid with a lower boiling point, like isopentane (referred to as a binary fluid, or working fluid).



Binary Power Plant

The working fluid boils and expands, producing pressure to spin a turbine and generate electricity. Afterwards the working fluid is condensed back to liquid and reused, while the cooled water is reinjected into the geothermal reservoir — where it is reheated, to be used again. The binary system operates in a closed loop; no emissions escape into the atmosphere.

All geothermal systems are carbon neutral and have few, if any, emissions. Compare that with non-renewable technologies, which create steam by burning fuel.

Many communities around the world currently use Earth's heat. Some generate electricity in one of the three types of geothermal power plant. Others use the geothermal water and heat directly, typically for space heating. There is increased interest in expanding both types of use — an expansion that requires education of citizens and policy-makers.

Materials

Card stock (5 x 7 card or 8.5 x 11), one sheet per student

Binder paper

Scotch tape

Colored pencils

Library or Internet access

LESSON PROCEDURES

Engage :

Useful material, to introduce the lesson and for research, can be found in the references on page 55 and in the folder of Additional Resources-Geo Units I, II, III at www.eere.energy.gov/education/lesson plans.

To generate electricity, a geothermal resource needs (a) heat, (b) fluid to carry the heat, and (c) a pathway for the fluid to carry that heat to the surface. In some areas of Earth's surface, where a, b, and c are all present, we access the hot water and steam resources by drilling a well (similar to an oil well). That hot water and steam shoot up through the well to the surface. In most places, however, one or more of three components is inadequate. In some of those places the resource can be developed by enhancing or engineering the geothermal reservoir systems. The result is an enhanced (or engineered) geothermal system, known as EGS.

To understand EGS, one starts with the premise that a subsurface hot rock formation has cracks, which serve as a "plumbing" system. The plumbing allows fluid to move through the hot rocks to be heated and retrieved. When the cracks are inadequate in their natural state, they can be increased in size and number through drilling techniques, primarily high-pressure injection of water through a wellbore. The process is known as fracturing. When successful, it turns an unusable area of hot rock into a productive EGS development.

Explore:

Distribute **Student Handout**, *Understanding Geothermal Heat Exchangers and Binary Power Plants*, and review with students.

Students devise ways to demonstrate a heat exchanger, an important component of engineering that allows binary power plants to better utilize geothermal heat, greatly expanding the potential opportunities for electricity generation from geothermal energy.

Explain:

Students summarize to each other in small groups how the heat exchanger works, including basic construction and purpose.

Extend:

Students then articulate why this is important in binary plants but not flash or dry steam plants. Finally, why binary plants are an important component of future development of the resource, including EGS technology.

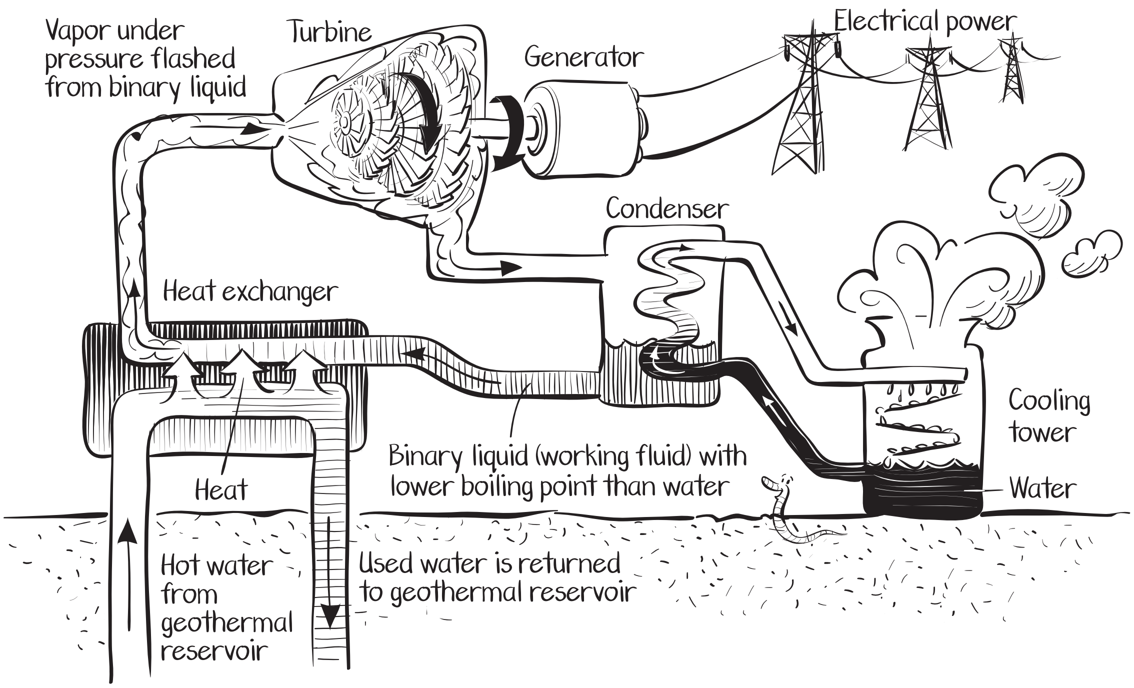
Where in the world is geothermal being developed, and what does it look like? Where *could* it be developed, with EGS? (See maps in Supplemental Information, beginning on page 93.)

Evaluate:

After appropriate research, students (a) chart a comparison of the three types of geothermal power plants, or (b) create a map based on locations of different types of plant, or (c) make a timeline of important events in the development of geothermal technology, including predicted future events based on research. In each case, the standard is to create a tool useful for educating the public.

BENEFITS OF EARTH'S HEAT

Understanding Heat Exchangers and Binary Power Plants



Binary Power Plant

You know that touching a surface warmer than your body temperature can feel uncomfortably hot. As the warmth moves from the surface to you, your hand absorbs heat as the surface cools off. Touching a cold surface feels cold, as the process is reversed.

A heat exchanger in a binary power plant is set up to 'flow' heat. Geothermal fluid releases its heat to a "working fluid," a liquid (such as isopentane) that starts cooler but has a lower boiling point. The working fluid collects enough heat to boil and expand into vapor. The pressure of that vapor turns the turbine in a binary power plant's generator.

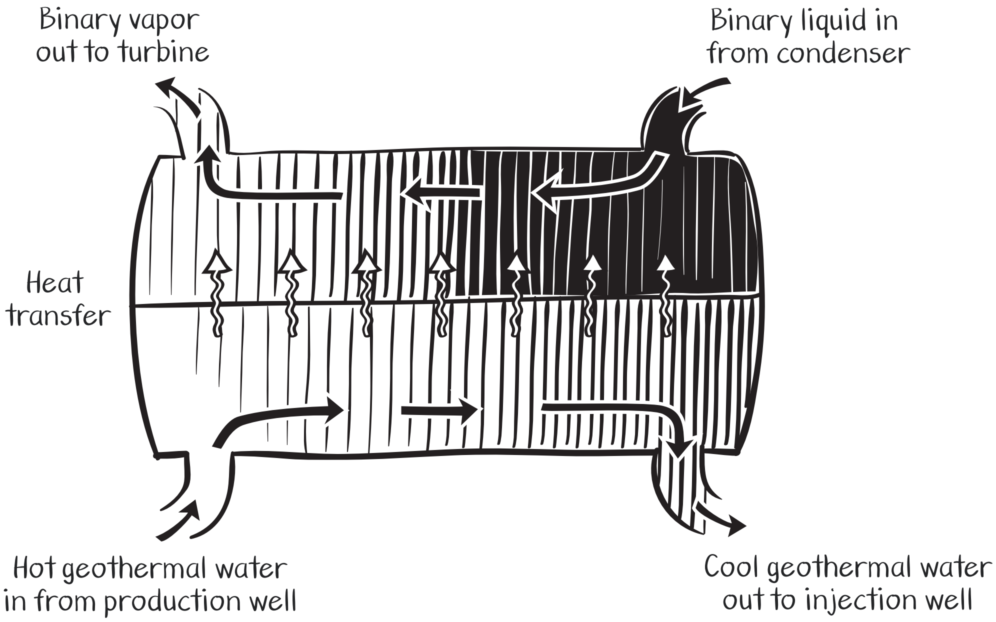
So in the binary process, the geothermal water is used only for its heat, not to produce steam. That is why a heat exchanger is always a part of a binary geothermal power plant.

Isopentane is often used as the working fluid.

Isopentane has a boiling ("flash") point of: 82°F (27.7°C.

Water has a boiling point of 212°F (100°C).

A heat exchanger transfers heat (thermal energy) from a hotter liquid to a cooler one by conduction. That is, heat moves from a material with more heat to a material with less heat. The heat is conducted from the first (hotter) liquid into the second liquid through metal pipes or plates that keep the two liquids separated.

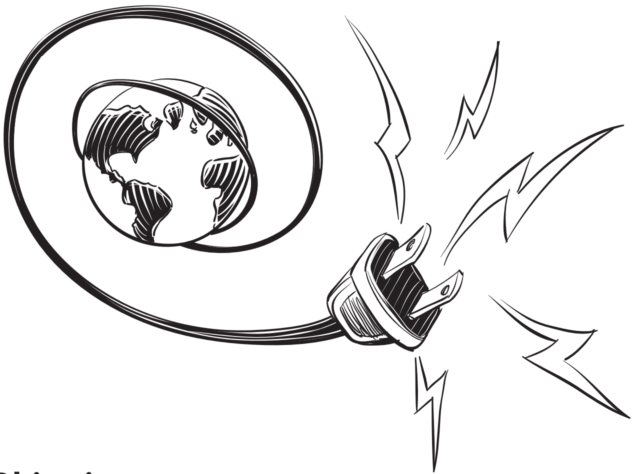


Binary Power Plant Heat Exchanger

In a binary power plant, the heat exchanger transfers the heat from the geothermal fluid — the hotter liquid — to the second liquid. This second liquid flashes to vapor and spins the turbine blades that drive a generator. After doing its job, the vapor is condensed back to a liquid and used over and over again. Voilà, geothermal heat has been used to generate electricity, even though it wasn't hot enough to flash on its own! Once used for its heat, the geothermal water is pumped back into the reservoir.

1. The use of binary power plants is expanding and is expected to continue this trend. Can you give at least one reason for this? (There are at least three reasons.)
2. Give at least two common examples of heat exchange.
3. Devise a simple demonstration, using materials readily available, that will allow other students to visualize heat exchange.
4. **Extend/Extra Credit:** Construct a working heat exchanger using fluids to demonstrate how this important piece of equipment works.

Unit II - Lesson 4: CONVERTING EARTH'S HEAT



Objectives

Students will be able to:

- Identify and describe energy conversions in generation of electricity
- Apply energy conversions to electricity generation
- Trace energy forms and conversions from source to student electricity use
- Compare advantages and disadvantages of different forms of energy production, based on conversion efficiency, as well as connections to environmental and human health

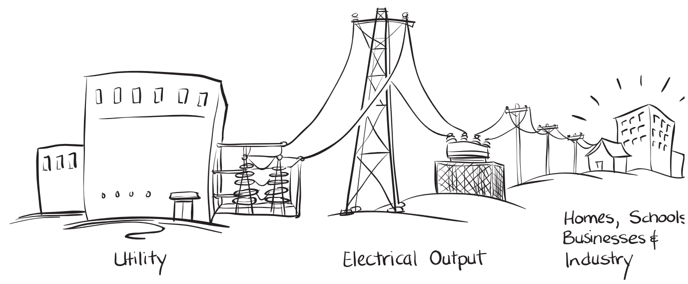
Time

Four class periods

Background

Energy is fundamentally the ability to do work. In various forms, it is responsible for powering our vehicles, heating and cooling our houses, providing electricity for light and other uses, and so much more. The law of conservation of energy, also known as the first law of thermodynamics, states that "energy can neither be created nor destroyed. It can only be transformed from one form to another." We use energy in many ways, which usually involves converting one form of energy into another. Each time this happens, some energy is lost as heat and is no longer available for use. Efficiency is the term used to measure how much remains to be used from the original amount compared with how much is "wasted" as heat.

There are many ways to generate the electricity we usually use as the energy source in our homes. Electricity can be produced without steam, as in water, wind, and sun. Electricity can be produced by manufactured steam, by burning fossil fuels, biomass, or nuclear power. Electricity can also be generated using naturally produced steam, as in geothermal.



Materials

Access to library or Internet

LESSON PROCEDURES

Engage:

Where do you get your energy?
What forms do you use?

Have students work with their parents to evaluate a utility bill: How much energy (measured in kWh) does their household use? Where does their electrical energy come from that they use in their home and pay for? Identify the local utility company, and answer this question, either as a class or individually. Many utilities, for example, have pie charts on their website showing the sources of energy used for electricity generation. Discuss as a class the various sources of energy. Notice, also, that energy can be converted from one form (chemical, solar radiation) to another (electrical). Electricity, in other words, is energy used by us every day, created by converting energy from other forms.

Remember:

W=watt

kW=kilowatt = 1,000 watts= serves average U.S. home

MW=megawatt =1,000 kilowatts=1,000,000 watts

1 megawatt serves about 750 - 1,000 homes in the Unites States

Explore:

Identify and define energy as a natural resource. Brainstorm the forms of energy we use now, and have used in the past. Make sure to include categories for electricity, transportation, and other forms of energy use, as well as direct use such as geothermal heat pumps, hot springs and spas, aquaculture, agriculture, residential and district heating. As students brainstorm, place their answers into categories on the board, and then ask students to come up with titles for the categories. Ideas for categories could include renewable/nonrenewable, electricity/transportation/heat, carbon producing/carbon neutral, or other ideas. The objective is to get students to realize energy can be categorized, based on similarities and differences.

Explore:

Students create a data table of six forms of energy, identifying the energy form, its definition, one or more examples, and units used to measure.

The six fundamental forms of energy are:

1. Mechanical (energy of position or movement, either in kinetic or potential form)
2. Heat (thermal)
3. Radiant (energy of electromagnetic waves, including light)
4. Electrical (energy of electric charges, often used as an intermediary to create the above three forms)
5. Chemical (energy stored in chemical bonds of molecules, such as food and fossil fuels. Breaking the bonds changes the molecules and releases the energy)
6. Nuclear (energy locked in the nucleus of atoms, released by either fusion or fission reactions)

Second, in groups, students create another data table (6 by 6 grid, with each energy form listed down the side as well as along the top) of energy conversions, providing an example of how each form of energy can be converted into another. Students should brainstorm examples both from their lives and from what they know about how electricity is generated.

Explain:

Using the Jigsaw Classroom technique (see http://www.jigsaw.org), students share their conversion examples, correcting or justifying as necessary. As a result of these discussions, the group may choose the best example of each conversion of energy and modify or update their individual data tables. The discussion should be rich. Energy is converted on a regular basis from heat to motion to electricity, back to heat again, often by burning to create steam, but not always.

Extend:

Research the relative advantages and challenges of geothermal power development, including consideration of EGS technology.

Advantages of geothermal power plants for electricity production

- Clean: no fossil fuels are burned, so no carbon dioxide (a greenhouse gas) or other pollutants result from burning fuels to generate heat.
- Reliable: average system availability of 95%, compared with 60-70% for coal and nuclear plants (DOE website)
- Constant: a geothermal plant can be run 24/7, which makes it excellent baseload power.
- Land use: less than coal or nuclear footprint, especially considering mining needed for fuel
- Domestic: reduces our need to import oil, reduces trade deficit, and adds jobs to U.S. economy

Challenges of geothermal power plants for electricity production

- Using current technologies, geothermal power is primarily available only in some locations — where hot magma finds its way close to the surface and heats underground reservoirs to usable temperatures
- High initial costs to drill and build new facilities
- Need adequate volume of hot water/steam and, usually, a surface water source to cool generating equipment. (Some binary power plants are air cooled.)
- Heat and water depletion need to be managed
- Reservoir enhancement can trigger small earthquakes.
- Ongoing research is necessary to improve technology

Research the advantages and disadvantages of another energy source used for electricity generation.

Extend:

Challenge students to describe a sequence of energy transformations, using the maximum number of transformations from source to end use (flow of energy from source to heat). Focus each student on geothermal. Idea: we can create heat to boil water to make steam…why not use earth's heat directly!

Have a class "Town Meeting" to discuss the pros and cons of a new proposed geothermal power plant option for your town. (See Unit III of this guide.)

Evaluate:

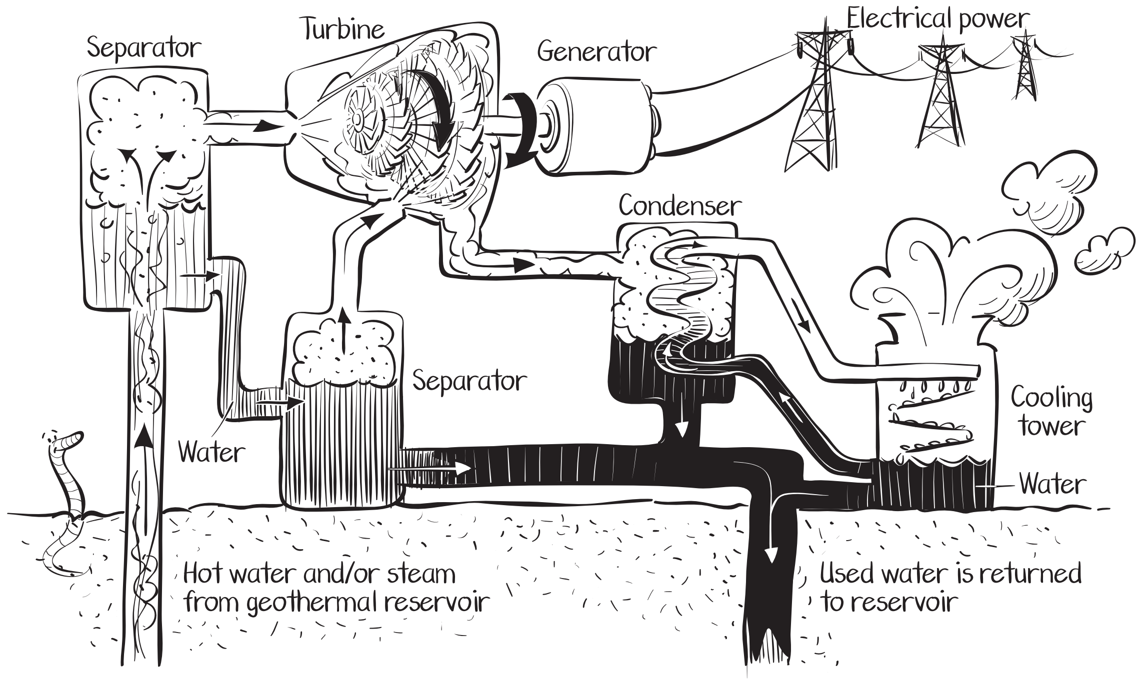
In small teams, or as individuals, students research geothermal and one other type of power plant and the energy conversions involved in the generation of electricity from those sources of energy.

Options include:

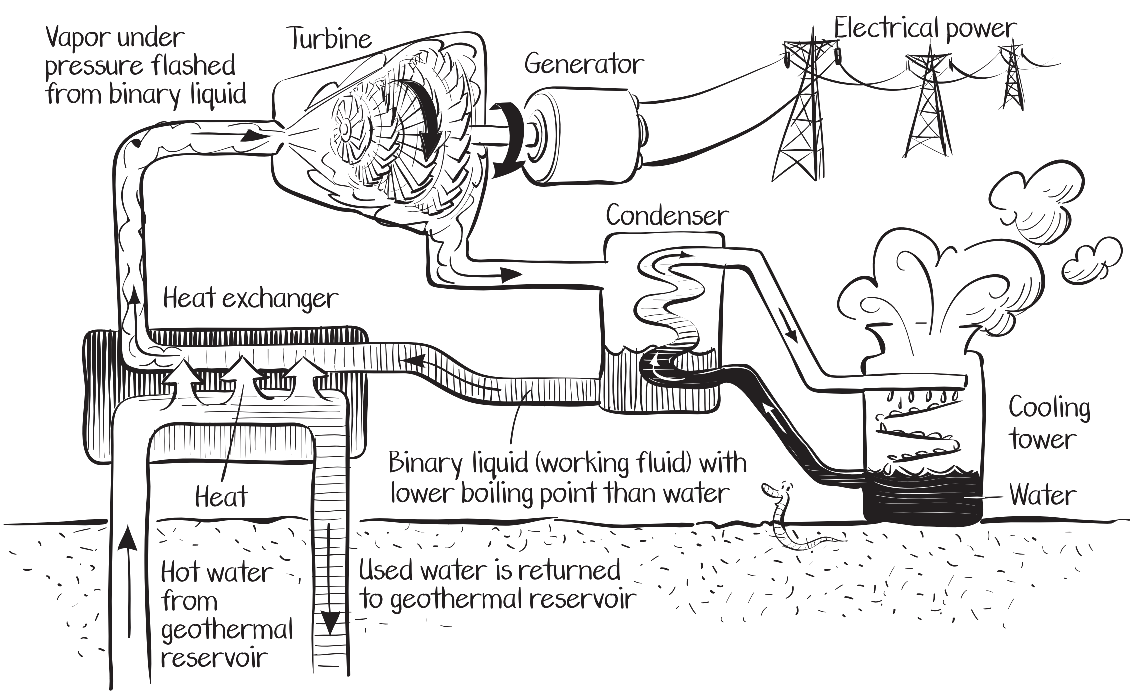
- coal
- oil
- natural gas
- biomass
- nuclear
- hydroelectric
- wind
- photovoltaic
- others depending on teacher or student interest or class size

Research should result in:

- A diagram of how the electricity generation works, including all important components clearly labeled and briefly explained
- Examples and pictures of power plants in existence (local is better, when possible)
- All energy conversions identified, resulting in electricity generated and transmitted
- Published estimates of efficiency, and where energy is lost as heat
- Advantages and disadvantages relating to environmental and human health risks

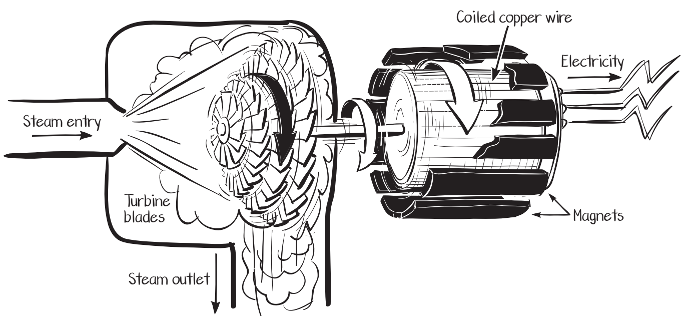


Flash Power Plant



Binary Power Plant

Unit II - Lesson 5: MODELING AND TESTING A TURBINE



Turbine Generator

Objectives

Students will be able to:

- Demonstrate how steam is used to turn a turbine
- Use a visual to explain how energy can be converted from one form to another
- Collect data to establish a relationship between two variables, and graphically analyze that relationship

Time

Four class periods

Background

This investigation demonstrates the use of steam for spinning of a turbine used to generate electricity. It challenges students to design a turbine for maximizing both speed and inertia, two of the variables important for generating electricity. It also highlights the inter-relationship of two variables, speed and distance, and our ability in science to make predictions based on trends that can be illustrated in a graph. Students engage in a process of inquiry as they pursue the relationship between steam energy (rate of motion of pinwheel), distance from steam kettle, or other possible variables.

Materials

Stiff paper plates

Wooden dowels or popsicle sticks

Glue gun or strong tape

Scissors

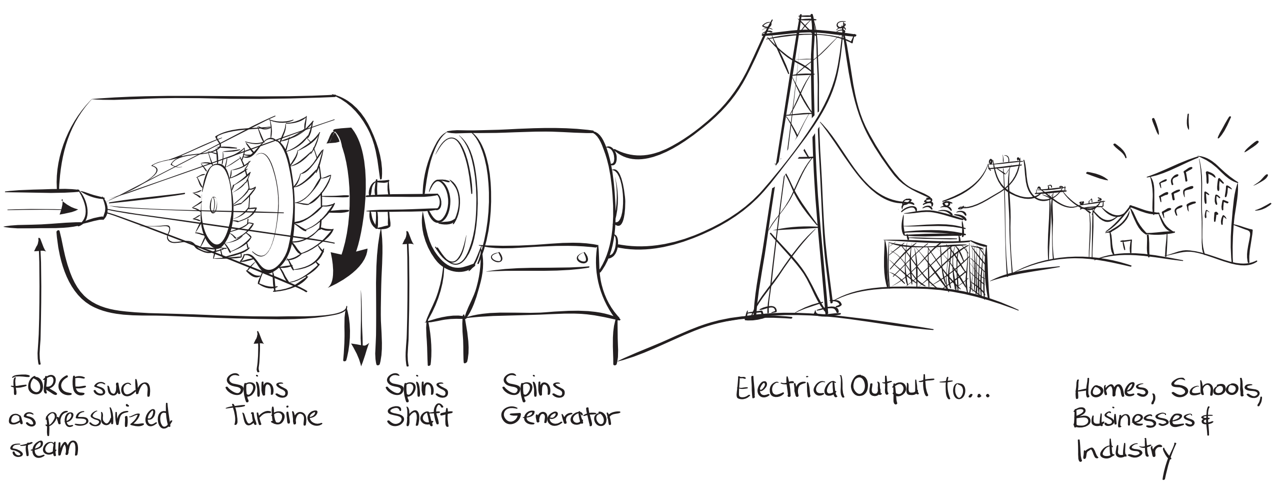
Access to library or research

Note: Kidwind (www.kidwind.org) has been working on kits for wind power, which include some excellent turbine setups

LESSON PROCEDURES

Engage:

As a demonstration, use a pinwheel and a teakettle. With hot steam forced out of the kettle, place a pinwheel in its path and notice that the closer the pinwheel gets to the source, the faster it rotates (too close, and it's difficult to count the rotations). Students are challenged with the goal of designing an efficient turbine, and discovering, through graphing data, the relationships involved in this energy conversion from heat to motion.



Explore:

Distribute student handout, *Modeling and Testing a Turbine*. Students design a turbine, considering and recording size and number of blades, mass of turbine, shape and angle of blades, etc. Their goal is to create the most efficient turbine, maximizing both mass/inertia and rotation rate.

Explain:

From three to five different distances, measure and graph the rotation rate. Graphically, extrapolate the speed of rotation at a distance of zero. This will involve plotting points on a graph of distance and rotation rate (rpm). Use the graph to extrapolate and predict where the rotation would stop, as well as interpolate speed at a particular distance. Then check those two interpolated points experimentally, and analyze the results for experimental error. Students can present their invention, data, and graph to the class.

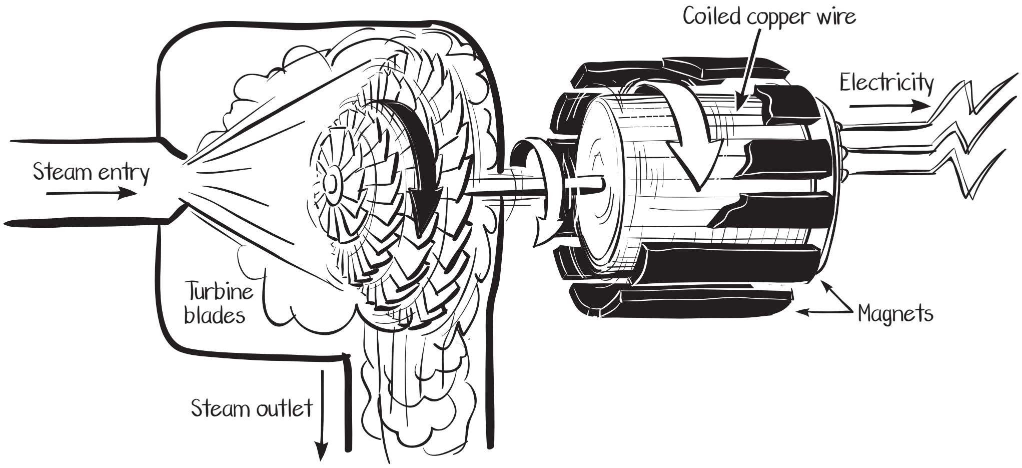
Extend:

1. Students research how turbines are used to generate electricity, with the push of steam and other media, and compare real turbines with those created by students, both in terms of design and possible variable relationships. Depending on student ability, research questions of efficiency and design in different media (wind, water, steam) and with different power sources.
2. Create a website (or have students create it) that students can use to share their "Modeling and Testing a Turbine" designs, data, materials, video clips, and pictures with other students around the country. (You would be amazed how students will try to improve the model.)
3. Build the model and then try to connect the turbine (turning blades) to a generator (like the hand crank model used in physical science classes to generate electricity) and use a multimeter to show the actual production of electricity with the steam.

Evaluate:

Students will be assessed for creation of and use of a line graph, for a successful turbine in terms of both mass and inertia, development of and testing of an hypothesis, and connection and analysis of experimental data to generation of electricity.

Modeling and Testing a Turbine

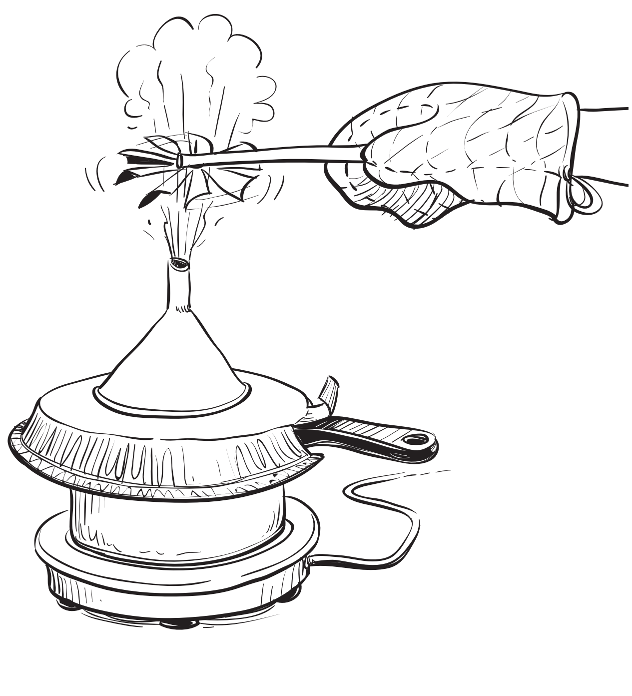


Turbine Generator

Background

A teakettle can act as a model for geothermal energy. This investigation demonstrates the use of steam for spinning of a turbine used to generate electricity, which is a common theme in power generation. Your challenge, as a student engineer, is to design a turbine for maximizing both speed and inertia, two of the variables important for generating electricity. This investigation also highlights the relationship between the two variables of speed and distance, and our ability in science to make predictions based on trends that can be illustrated in a graph.

Students design a turbine, considering and recording size and number of blades, mass of turbine, shape and angle of blades, etc. Their goal is to create the most efficient turbine, maximizing both mass/inertia and rotation rate.



Safety

Steam is hot; scissors and craft knives are sharp. Attention to skin and eyes. Safety goggles are recommended.

Predictions

- What will happen to the rate of spinning of the turbine with a change in the water's temperature?
- How will the size of the opening for the steam affect the result?

Materials

Kidwind (www.kidwind.org) has been working on kits for wind power, which include some interesting and useful turbine setups. If these are not available, be creative on your own and create a spinning turbine from whatever materials you think will work well.

Stiff paper plates

Wooden dowels or popsicle sticks

Glue gun or strong tape

Scissors

Tea kettle

Water

Ruler

Access to library or research

Directions

1. Construct a turbine using the materials listed, or get creative and use other materials to construct your turbine. This may be done in class, but home may also be a good source of creativity and materials.
2. Boil water in the kettle.
3. Hold the device (with tongs and oven mitt, as necessary) near the steam coming out from the kettle. Observe what happens.
4. Devise a safe way to vary the size of the opening from which the steam exits.
5. Record your observations.

Observations

- What do you observe about the rate of spinning as the temperature of water changes?
- What do you observe about the rate of spinning as the size of the opening changes?

Discussion

- Where does the wheel get its power to turn? Explain how this is related to geothermal power plants.

You are now challenged with the goal of designing an efficient turbine, and discovering, through graphing data, something about the relationships involved in this energy conversion from heat to motion.

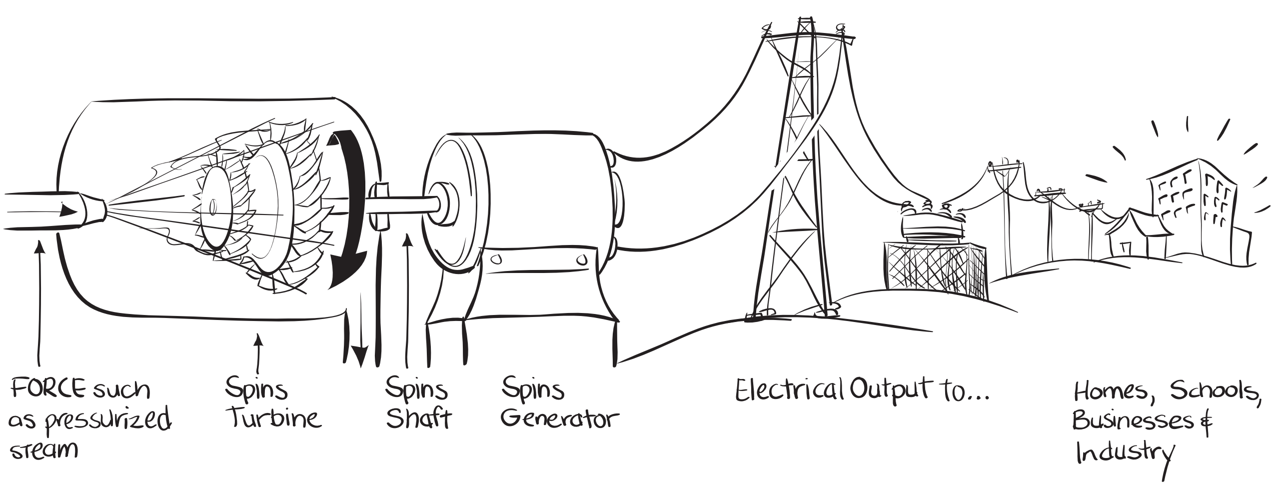
From three to five different distances, measure and graph the rotation rate. This will involve plotting points on a graph of distance on the x-axis and rotation rate (rpm) on the y-axis. Using the graph, extrapolate (predict) where the rotation would stop, as well as interpolate speed at a particular distance. Record both of these on the graph. Then check those two interpolated points experimentally, record your results, and analyze the results for percent experimental error: (predicted minus experimental) divided by experimental times 100. Students should present their invention, data, and graph to the class, along with a possible explanation for the findings.

Going Further

Research how turbines are used to generate electricity, with the push of steam and other media, and compare with those created by students, both in terms of design and possible variable relationships. You may also pursue research on questions of efficiency and design in different media (wind, water, steam) and with different power sources.

Evaluation

You will be assessed for creation of and use of a line graph, for a successful turbine in terms of both mass and inertia, development of and testing of an hypothesis, and connection and analysis of experimental data to generation of electricity.



Unit II - Lesson 6:
HEATING AND COOLING BUILDINGS WITH GEOTHERMAL HEAT PUMPS

Geothermal Heat Pump

An inexhaustible supply of geothermal energy exists just a few feet underground or underwater where temperatures remain fairly moderate at 45°-55°F (7°-13°C) year-round. In this lesson students will research and illustrate geothermal heat pump systems, including the different heat exchange piping systems. They will compare traditional fossil fuel systems to geothermal heat pump systems and can see the value of this environmentally clean and renewable source of energy as a major contributor in the energy industry.

Objectives

Students will be able to:

- Collect and graph data comparing earth's interior temperatures to the ambient air temperatures above the surface
- Identify and compare different types of home and business heating/cooling systems
- Research and list businesses locally or statewide that install direct-use geothermal heat pump systems
- Learn "pros and cons" of different types of heating and cooling systems as compared to geothermal heat exchange systems. Base comparisons on efficiency and costs, including costs to environmental and human health

Geothermal Heat Pumps:
A Different Species of Geothermal Energy

This lesson introduces a different species of energy source, but one that shares the name Geothermal. Geothermal Heat Pumps, also known as GHPs or Geo-Exchange Systems, differ from other uses of geothermal (sometimes called deep geothermal) in some basic ways:

1. A geothermal heat pump system is installed right near the surface of the earth, typically making use of Earth's heat at a depth of only 5 to 200 feet (1.5 to 61 meters), whereas the geothermal systems covered in the previous lessons of this unit usually access Earth's heat up to a mile or two (or more) below the surface.
2. A portion of the ground heat used by a geothermal heat pump is absorbed solar radiation, whereas the geothermal heat used to generate electricity generation — and for other uses described in Lessons 1 through 5 of this unit — is all generated from geologic processes inside the earth.
3. A geothermal heat pump system does not require the presence of a geothermal reservoir (or even a hot spring). Geothermal heat pump systems depend only on the constancy of Earth's very near-surface temperature.
4. Because a geothermal heat pump does not depend on a geothermal reservoir, these geothermal systems can be used almost everywhere in the world.

Time

Four/five class periods (depending on time spent independently as homework)

Handout 2, *Collecting Local Geothermal Data* requires up to 30 days and you may want to begin this earlier.

Background

Teacher should become familiar with the technology and structures of the ground-source geothermal heat pump (GHP), and basics of Geothermal Energy Exchange systems. View handouts, diagrams and video clips from the GeoExchange organization (www.geoexchange.org).

Geothermal heating and cooling systems are the most energy efficient, environmentally clean, and cost-effective space conditioning systems available (according to the EPA). Geothermal exchange systems use the earth's energy capabilities (located just eight feet below the surface) to heat and cool and to provide hot water for homes or businesses. Earth is a huge energy storage device that absorbs 47% of the sun's radiant energy. The geothermal exchange system can tap into the fairly moderate year-round temperatures of 45° F to 55° F just these few feet below the surface. In winter, the system brings the natural earth warmth up into a building and moves it throughout with a heat pump. In summer, the system works in an opposite fashion to provide air-conditioning (absorbs heat inside the building, transferring it to the cooler earth below).

The geothermal energy used in these systems is renewable, and geothermal heat pump systems are more efficient than the competing fossil fuel technologies. Today in the USA there are over 1,000,000 geothermal exchange systems in place. The EPA has identified that geothermal heat pump systems significantly reduce greenhouse gases and other air emissions associated with fossil fuel based conventional heating/cooling systems. This renewable and environmentally clean energy source will play an important role in reducing our dependency on foreign oil and our consumption of electricity.

Materials

Small styrofoam cooler

Two thermometers

Graph paper

Ruler

Clock

Color pencils

2″diameter PVC pipe 7′- 8′ long with cap

String 3′- 4′ long

Tape

Shovel or post-hole digger

LESSON PROCEDURES

Engage:

Show students the videos of geothermal exchange from www.geoexchange.org

Lead discussion and list the types of heating systems currently used in their home and school. Compare cost of fuel, fuel type, emissions, size, and maintenance of heating/cooling unit.

Explore:

Demonstrate to students the earth's ability to store heat by filling a small styrofoam cooler with ice and place a lid (making a hole for the thermometer) on it. Use second thermometer to record room temperature (ambient air). Students will record both temperatures every 2 minutes for 30 minutes.

Students construct a data table to record temperatures.

Explore:

Pass out **Student Handout 1**, *Types of Geothermal Exchange Piping Systems.*

Student will use computers to research the different types of geothermal exchange piping systems and illustrate them.

Explore:

Pass out **Student Handout 2,** *Collecting Local Geothermal Data*.

Students construct a data table to record ambient air temperature, ground temperature, time, date, cloud cover (weather) for 30 days (or fewer).

Students will conduct an experiment to test the average interior earth's temperature.

Explain:

Lead a brief discussion of fossil fuel-driven heating and cooling systems as compared to geothermal heat pumps.

Identify only one advantage and disadvantage for students.

Create a scenario for students to become consumer news reporters who must present their message using a medium.

Extend:

Pass out **Student Handout 3,** *Geothermal Heat Exchange Systems – Pros and Cons.*

Students will research the various fossil fuel-driven heating/cooling systems available for homes and businesses.

Students can use any medium (approved by instructor) to present message.

Explain:

Students create a line graph comparing the earth's temperature (cooler) and the ambient room temperature (representing the atmosphere's ground temperature).

Heat exchange piping diagrams include color, labels and heat-flow directions.

Students test local ground temperatures and compare to ambient air temperatures.

Use PowerPoint, a poster, a video from www.geoexchange.org, or other visual to present comparison of traditional fossil fuel heating and cooling systems to geothermal heat pump exchange systems.

Evaluate:

Student illustrations/diagrams should include: color, clarity of labels, detail of information, correctness of scale and all important components.

Line graph (demonstration of Earth's ability to store heat) should include X and Y labels, graph title, ruler-straight and different-colored lines.

Student lab write-up (portfolio) including required criteria.

Student will be assessed for a medium comparison of traditional fossil fuel systems vs. geothermal heat pump systems for heating and cooling.

Types of Geothermal Heat Pumps

Geothermal heat pumps can be used for heating and cooling buildings nearly anywhere. The United States leads and accounts for most of the development and installation of these geothermal heat pumps worldwide.

Materials

Blank paper or poster board

Pencil and eraser

Ruler

Colored pencils

Internet access

Procedure

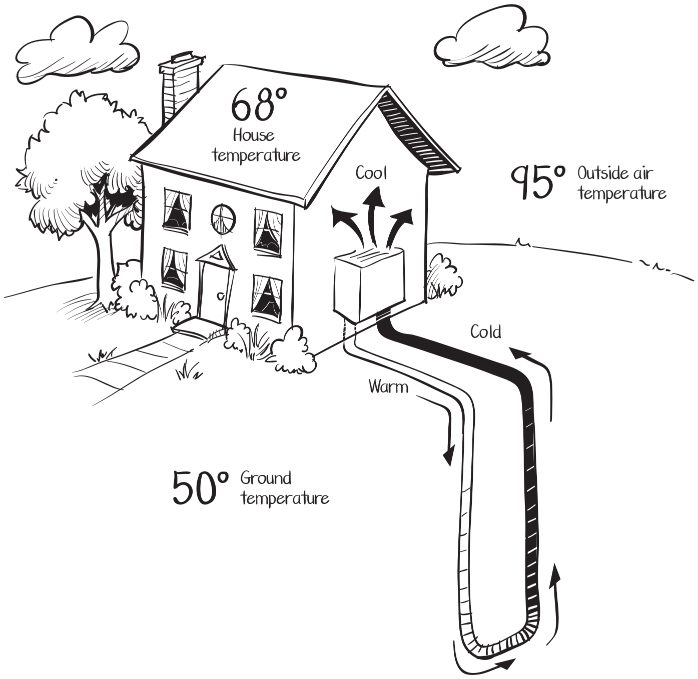
Research and diagram the vertical, horizontal, pond and slinky configurations of heat exchange piping systems. Label the heat-flow directions.

Review Questions

Answer the following questions on a separate paper. Use the Internet to research your responses to the following questions.

1. What is a heat pump and list some of its common uses?
2. Why are rocks and soil good insulators?
3. Discuss the consumer resistance to geothermal heat pumps.
4. What factors determine the type (vertical, horizontal, pond, and slinky) of geothermal piping used?
5. Compare the geothermal heat pump system to the conventional fossil fuel type heating system. Are there any significant energy savings?
6. Would you consider this type of renewable energy source for your home? Why or why not?

Collecting Local Geothermal Data



The average underground temperature of the soil (10′ down) is 45°-55°F (7°-13°C). In winter, a geothermal heat pump brings the earth's natural warmth up to your house and then transfers it into each room. In summer, the system works in reverse to supply air conditioning by absorbing the heat from inside the home and transferring it to the cooler earth below.

Prediction

Will the earth's interior temperature stay constant compared to the outside (ambient) air?

Materials

2″diameter PVC pipe 6′- 8′ long

Two end caps

Duct tape

Two thermometers

Measuring tape

Shovel or post-hole digger

String (6′- 8′)

Pencil

Paper – plain and graph

Directions

1. Create a data table in your journal/notes/binder. It should include the following:
   - Columns for date, time, outside (ambient) air temperature, inside air (bottom of PVC pipe) temperature
   - Rows for 30 days of data (teacher will decide)
2. Once location has been approved, dig a 4′ to 5′ deep hole (5″-6″ diameter) and place the capped end of the 2″ diameter PVC pipe into hole. About 2′-3′ should be exposed above the ground. Fill in soil around PVC pipe. Place thermometer (attached to string and string taped to outside of pipe) into PVC pipe and cap end.

3. Let PVC pipe and interior thermometer sit for 24 hours.
4. Using the second thermometer record the outside air temperature and remove cap and quickly read interior air temperature. Record both readings in your data table for assigned number of days. Note date and time also.
5. Diagram your experiment and label parts.

Observation

Take notes on the weather daily, as you collect both interior and exterior temperatures (e.g., cloud cover, rain, wind, etc.)

Going Further

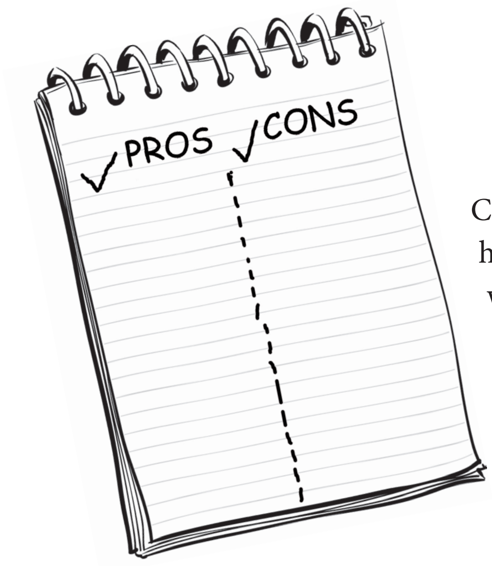
Research various states for data on recorded earth temperatures at different depths, and compare to your data. What were the correlations, if any? Record ideas on how you can you improve your experiment to get better results.

Evaluation

You will be assessed for the creation of a graph that successfully displays your data (include this in the write-up) Students will create a write-up of the experiment that includes:

- Title page
- Problem statement
- Hypothesis
- Experiment steps
- Recorded data in table
- Graphed data
- Conclusion
- **Extra**: If you have a digital camera, create a pictorial essay page of the experiment.

Geothermal Heat Exchange System – Pros and Cons



Central heating systems have been considered a necessity in our homes and businesses for many years. As a consumer you will want to compare available conventional fossil fuel systems with the newer, cleaner "Down to Earth" comfort system. What do you compare? Some suggestions would be safety, installation cost, operating cost, maintenance cost, comfort and the effect on the environment.

You will need:

Computer with Internet access

Medium software (PowerPoint, Publisher, Video)

Procedure

1. Play the role of a consumer reporter to report the pros and cons of geothermal heat pump system compared with conventional fossil fuel systems.
2. Choose a medium to report your findings.
3. Students present their media projects.

Evaluation

1. Students will share their creations with the class in the form best fitted for their chosen medium.
2. Student can be evaluated on detail of information, clear and consistent focus, organization, supporting information, style, grammar, spelling, etc.

RESOURCES FOR THIS UNIT

1. *An Evaluation of Enhanced Geothermal Systems Technology* (2008), U.S. DOE, EERE, http://www1.eere.energy.gov/geothermal
2. Brown, Lester R., Plan B 4.0; *Mobilizing to Save Civilization* (New York: W.W. Norton & Company, 2009). www.EarthPolicyInstitute.org
3. DOE (Department of Energy), Office of Energy Efficiency and Renewable Energy (EERE) http://www.eere.energy.gov
4. Dunn, Craig. Making Room… Fractures are coming through! Nov/Dec 2010, http://www.nacleanenergy.com
5. *Energy for Keeps*, 3rd edition. Energy Education Group. 2010 http://www.energyforkeeps.org
6. *Future of Geothermal Energy*, http:// geothermal.inl.gov/publications/future _of_geothermal_energy.pdf
7. GeoHeat Center, Oregon Institute of Technology http://www.geoheat.oit.edu
8. GEO (Geothermal Education Office) website, with resources, slide show and video: http://www.geothermal.marin.org
9. Geothermal Energy Association (Industry Trade Group) (preliminary report on Geothermal Energy, the Potential for Clean Power from the Earth) http://geo-energy.org (good 'Geothermal 101 Energy Basics')
10. *Geothermal Energy,* Pacific Northwest Edition (Curriculum Unit). Geothermal Education Office. 1994
11. Geothermal Heat Pump Industry Association. http://www.geoexchange.org
12. Geothermal Resources Council www.geothermal.org
13. International Ground Source Heat Pump Association: http://www.igshpa.okstate.edu/
14. NREL (National Renewable Energy Lab) http://www.nrel.gov
15. Rand, Tom, P.Eng, PhD. *Enhanced Geothermal: Clean Energy's Holy Grail*. Nov/Dec 2010. http://www.nacleanenergy.com
16. *Stories From a Heated Earth, Our Geothermal Heritage*. Cataldi, R., Hodgson, S.F., Lund, Geothermal Resources Council
17. *The smart guide to Geothermal: How to Harvest Earth's Free Energy for Heating & Cooling*; Pixyjack Press, http://www.pixyjackpress.com
18. U.S. Department of Energy, Geothermal Technologies: http://www.eere.energy.gov/topics/geothermal.html
19. USGS Circular 726, *Assessment of Geothermal Resources of the United States* – 1975 (White and Williams, 1975)
20. USGS Circular 790, *Assessment of Geothermal Resources of the United States* – 1978 (Muffler, 1979)
21. USGS Circular 892, *Assessment of Low-temperature Geothermal Resources of the United States* – 1982 (Reed, 1983).
22. USGS Circular 1249 *Geothermal Energy: Clean Power From the Earth's Heat* (2003)
23. USGS, *This Dynamic Earth: The Story of Plate Tectonics* (1996)

Unit II
National Science Education Standards Correlations for Grades 9-12
(Only the standards relevant to Unit II are listed here.)

Science as Inquiry (Content Standard A)
***Geothermal Energy,* Lessons 1-6**

- Abilities necessary to do scientific inquiry: Identify questions and concepts that guide scientific investigations, design and conduct scientific investigations, use technology and mathematics to improve investigations and communications, formulate and revise scientific explanations and models using logic and evidence, recognize and analyze alternative explanations and models, and communicate and defend a scientific argument.
- Understandings about scientific inquiry.

Physical Science (Content Standard B)
***Geothermal Energy,* Lessons 2-6**

- Motions and forces: Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces. These effects help students to understand electric motors and generators.
- Conservation of energy and increase in disorder.
  1. The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.
  2. All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.
  3. Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.
  4. Everything tends to become less organized and less orderly over time. Thus, in all energy transfers, the overall effect is that the energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection and the warming of our surroundings when we burn fuel.
- Interactions of energy and matter: In some materials, such as metals, electrons flow easily, whereas in insulating materials such as glass they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures some materials become superconductors and offer no resistance to the flow of electrons.

Earth and Space Science (Content Standard D)
***Geothermal Energy,* Lessons 1, 3, 4, 6**

- Energy in the Earth system
  1. Earth systems have internal and external sources of energy, both of which create heat. The sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from the earth's original formation.

continued

2. The outward transfer of earth's internal heat drives convection circulation in the mantle that propels the plates comprising earth's surface across the face of the globe.
3. Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents

- Origin and evolution of the Earth system

1. The sun, the earth, and the rest of the solar system formed from a nebular cloud of dust and gas 4.6 billion years ago. The early earth was very different from the planet we live on today.
2. Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years.

Science and Technology (Content Standard E)
***Geothermal Energy,* Lessons 3-6**

- Abilities of technological design: Identify a problem or design an opportunity, Propose designs and choose between alternative solutions, implement a proposed solution, evaluate the solution and its consequences, communicate the problem, process, and solution.
- Understanding about science and technology

1. Many scientific investigations require the contributions of individuals from different disciplines, including engineering. New disciplines of science, such as geophysics and biochemistry often emerge at the interface of two older disciplines.
2. Science often advances with the introduction of new technologies. New technologies often extend the current levels of scientific understanding and introduce new areas of research.
3. Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
4. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems.

Science in Personal and Social Perspectives (Content Standard F)
***Geothermal Energy,* Lessons 1-6**

- Natural resources

1. Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.
2. The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.
3. Humans use many natural systems as resources. Natural systems have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

continued

- Environmental quality
  1. Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.
  2. Materials from human societies affect both physical and chemical cycles of the earth.
  3. Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, overconsumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth.
- Natural and human-induced hazards
  1. Normal adjustments of earth may be hazardous for humans. Humans live at the interface between the atmosphere driven by solar energy and the upper mantle where convection creates changes in the earth's solid crust. As societies have grown, become stable, and come to value aspects of the environment, vulnerability to natural processes of change has increased.
  2. Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.
  3. Some hazards, such as earthquakes, volcanic eruptions, and severe weather, are rapid and spectacular. But there are slow and progressive changes that also result in problems for individuals and societies. For example, change in stream channel position, erosion of bridge foundations, sedimentation in lakes and harbors, coastal erosions, and continuing erosion and wasting of soil and landscapes can all negatively affect society.
  4. Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards—ranging from those with minor risk to a few people to major catastrophes with major risk to many people. The scale of events and the accuracy with which scientists and engineers can (and cannot) predict events are important considerations.
- Science and technology in local, national, and global challenges
  1. Science and technology are essential social enterprises, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge.
  2. Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.
  3. Progress in science and technology can be affected by social issues and challenges. Funding priorities for specific health problems serve as examples of ways that social issues influence science and technology.

continued

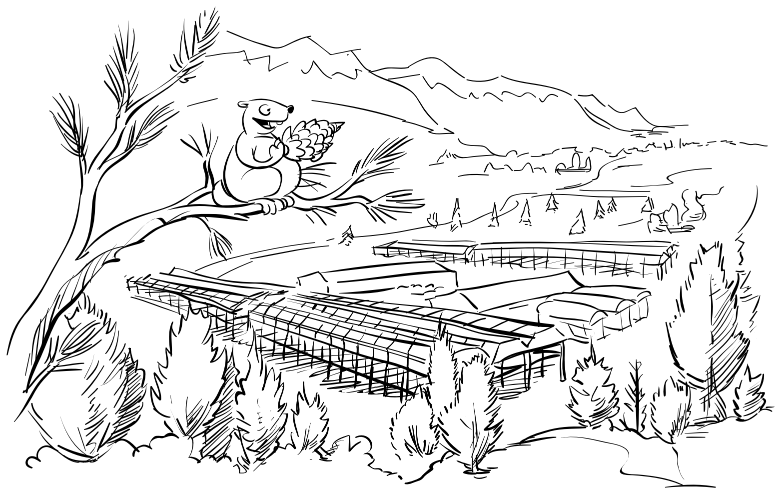
4. Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions—"What can happen?"—"What are the odds?"—and "How do scientists and engineers know what will happen?"
5. Humans have a major effect on other species. For example, the influence of humans on other organisms occurs through land use—which decreases space available to other species—and pollution—which changes the chemical composition of air, soil, and water.

History and Nature of Science (Content Standard G)
***Geothermal Energy,* Lessons 3, 6**

- Science as a human endeavor
  1. Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.
  2. Scientists have ethical traditions. Scientists value peer review, truthful reporting about the methods and outcomes of investigations, and making public the results of work. Violations of such norms do occur, but scientists responsible for such violations are censured by their peers.
  3. Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.
- Historical perspectives
  1. In history, diverse cultures have contributed scientific knowledge and technologic inventions. Modern science began to evolve rapidly in Europe several hundred years ago. During the past two centuries, it has contributed significantly to the industrialization of Western and non-Western cultures.

Unit III
GEOTHERMAL ENERGY: ENERGY AND PUBLIC POLICY

Subjects:
U.S. History, U.S. Government, Environmental Science



UNIT OVERVIEW

THE FOLLOWING LESSONS introduce the potential of geothermal energy production to students of American Government and how policy debate surrounds this issue as it moves through the democratic process.

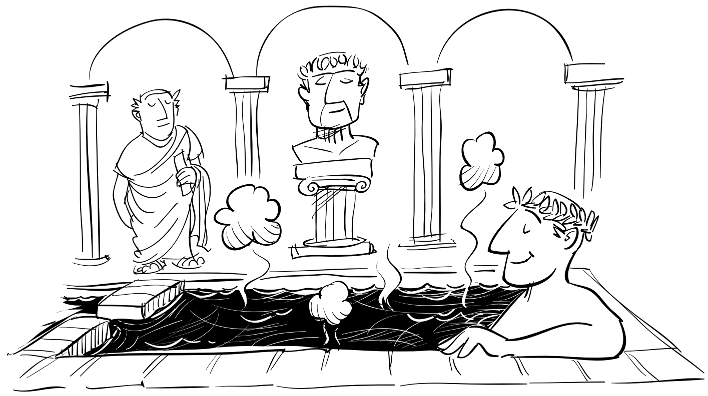
Each lesson is designed to progressively teach students the history, development, benefits and challenges of geothermal energy as an alternative energy source in the United States. Content knowledge includes specific science and engineering aspects of the several geothermal power plant technologies, including those related to development of Enhanced (or Engineered) Geothermal Systems (EGS).

Lesson 1, ***The History of Geothermal Energy,*** introduces geothermal energy to students by helping them create a timeline that explores the history and use of hot springs and geothermal reservoirs for energy.

Lesson 2, ***Geothermal Energy Development in the United States***, and **Lesson 3,** ***Mock Town Council and Geothermal Energy,*** introduce energy-related local, state, and federal government policy development to students through the creation of a mock town council meeting where council members must decide the fate of a geothermal energy power plant proposal. Student groups will conduct online research to learn the science behind geothermal energy, pros and cons of the issue, and the democratic processes of public policy development.

Finally, **Lesson 4,** ***The Future of Geothermal Energy Systems in the United States,*** will conclude the curriculum for this unit by having students debate geothermal energy development and its relevance as one of many options for alternative energy development in the United States.

Unit III - Lesson 1: THE HISTORY OF GEOTHERMAL ENERGY



Learning Objectives

Students will be able to:

- Understand the historical applications of geothermal energy and apply that knowledge by creating timelines.
- Investigate the contemporary methods of geothermal energy use as a renewable resource and the science behind them.
- Research the current methods of generating electricity from geothermal energy including dry steam, flash steam and binary-cycle (including enhanced geothermal systems.
- Examine the various groups that have an interest or concern about the future of geothermal energy development.
- Demonstrate the complex requirements and political issues that revolve around proposed geothermal power plants.

Time

One full block period, or one and a half traditional class periods

Background

Introducing this lesson will require teacher research in order to gain a general understanding of renewable energy sources such as solar, biomass, hydrogen fuels, and geothermal reservoirs. It is also recommended that teachers examine the history of geothermal use before this lesson is introduced to students. The following websites provide a comprehensive overview:

http://www.eere.energy.gov/

http://www.geothermal.marin.org

Materials

Poster paper (butcher paper or 11″ x 14″ copy paper also works)
Colored pencils/markers
Rulers
Computer with Internet access
Projector/Screen or Smart Board
Keynote/PowerPoint presentation software
Pen/pencil
Notebook paper

LESSON PROCEDURES

Engage:

1. Ask students what types of renewable energy sources are currently available to us. Lead discussion of solar, wind, biomass, hydroelectric, ocean (tides, currents), and geothermal.
2. Tell students that for the next four lessons they will focus on the renewable energy source of geothermal energy production in the United States and the challenges of power plant development in a democracy.

Explore:

3. Distribute handout, "Geothermal History Timeline."
4. Tell students they will now create a visual geothermal history timeline using the handout.
5. Distribute poster paper (11″ x 14″) and write the following timeline requirements on the white board:
   a. Title of timeline: "Geothermal History Timeline"
   b. Ten events required
   c. A short paragraph describing each event in your own words
   d. One hand-drawn picture illustrating each event
   e. Timelines must be carefully and thoughtfully drawn. Attention to detail is required
6. Tell students they will now use the handout and colored pencils/markers to complete their timelines.
7. Allow 40 minutes for students to complete timeline.
8. Circulate around the classroom asking questions of students about the various elements of geothermal use in history. Allow them to discover and explain what they know about geothermal use today.

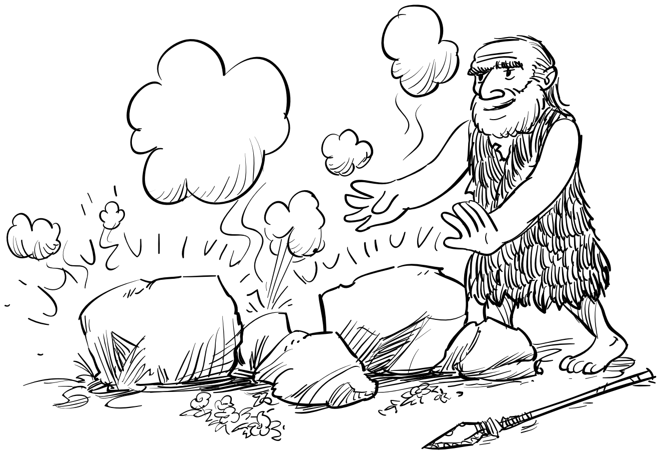
Explain:

9. Next, tell students that they will now need to take notes in preparation for a class project that begins next class.
10. Use portions of the slide show available at www.geothermal.marin.org to lecture and introduce students to the following **vocabulary**:

    geothermal reservoir
    enhanced geothermal systems (EGS)
    plate tectonics
    Ring of Fire
    production well
    injection well
    steam turbine
    dry steam
    flash steam
    binary cycle

11. Tell students that they will need to understand the definitions of these terms for the project that will be introduced in the next class.
12. LESSON REVIEW. Close with the students by reviewing the major points of the lesson.

GEOTHERMAL ENERGY AND PUBLIC POLICY
Geothermal History Timeline



Instructions: Use 10 of the following historical events to create a timeline on the history of geothermal history. Your timeline must include the title, "A Human History of Geothermal Energy Use." Under the title you must have your name, the date, and your class period. Your best work is required. Neatness, imagination, and creativity are essential. Use of colored pencils and/or markers is required.

1. According to archeological digs, it has been discovered that approximately 10,000 years ago, American Paleo-Indians settled near hot springs. It's believed that the Indians used the hot springs for activities including bathing and heating.
2. 300 BCE - Ancient Romans used hot springs to heat their baths and homes. This "magic water" was also used for medicinal and cooking purposes.
3. It's believed that the Larderello Fields near Pisa, Italy, was the site of the first geothermal energy use in industry during the late 18th century. Geothermal energy was used to extract boric acid from the Larderello Fields through the use of steam.
4. In Iceland, Eggert Olafsson and Bjarni Palsson, at Thvottalaugar in Reykjavik and in Krisuvik on the southwest peninsula, in 1755-1756 drilled the first trial wells for hot water. They are considered two pioneers of the natural sciences in Iceland.
5. The first known commercial use of geothermal energy in the United States occurred in Hot Springs, Arkansas, where, in 1830, Asa Thompson charged one dollar each for the use of three spring-fed baths. i
6. In Oregon in 1864 a hotel owner used geothermal energy from underground hot springs to heat rooms.
7. In 1892 the world's first regional geothermal heating began in Boise, Idaho, eventually serving 200 homes and 40 downtown businesses.

8. In Italy, in 1904, Prince Piero Ginori Conti invented the first geothermal power plant at the Larderello dry steam field. It is still operational today.
9. The Geysers Resort Hotel, California, was the site of the first geothermal power plant in the United States. It was built in 1922 by John D. Grant, and generated enough electricity for the entire resort. The resort produced 11 megawatts (MW) of power and operated successfully for more than 30 years. It ceased operation when new and cheaper power sources became available.
10. In 1960, Pacific Gas and Electric began operating the first successful geothermal power plant in the U. S. at The Geysers.
11. In 1970, the Geothermal Steam Act was enacted, providing the Secretary of the Interior with the authority to lease public lands and other federal lands for geothermal exploration and development in an environmentally sound manner. Reinjection of spent geothermal fluids back into the production zone began as a means to dispose of wastewater and maintain reservoir life.
12. In 1977, the U.S. Department of Energy (DOE) was formed. Hot dry rock geothermal power is demonstrated with financial assistance from DOE. Scientists developed the first hot dry rock reservoir (now known as EGS) at Fenton Hill, New Mexico.
13. Today, there are more than 60 important geothermal power plants in working order in the U.S., and many more across the globe.

National Social Studies Standards Correlations for Lesson 1

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme VIII: Science, Technology, and Society

Social studies programs should include experiences that provide for the study of relationships among science, technology, and society.

- Enable learners to identify, describe, and examine both current and historical examples of the interaction and interdependence of science, technology, and society in a variety of cultural settings;
- Provide opportunities for learners to make judgments about how science and technology have transformed the physical world and human society and our understanding of time, space, place, and human-environment interactions.

Unit III - Lesson 2: GEOTHERMAL ENERGY DEVELOPMENT IN THE U.S.

Objectives

Students will be able to:

- Research geothermal energy systems development as a renewable energy source in the United States
- Develop strategies as members of a group who have a "stake" in the proposed development of a geothermal plant
- Prepare position papers and/or PowerPoint/ Keynote presentations for a Mock Town Council meeting reflecting their reasons for or against the development of a geothermal plant in their community

Time Allotted

One full block period, or one and a half traditional class periods

Background

Review geothermal energysystems with students using the following websites;

www.geothermal.marin.org

www.geo-energy.org

http://www1.eere.energy.gov/geothermal/ geothermal_basics.html

Review handouts available under "Materials."

Teacher should be well acquainted with teaching how to create position papers and assisting students with PowerPoint or Keynote presentation software.

Materials

Handouts:
  "Geothermal Power Plant Project" instructions
  Stakeholder information sheet handouts
Computer lab

LESSON PROCEDURES

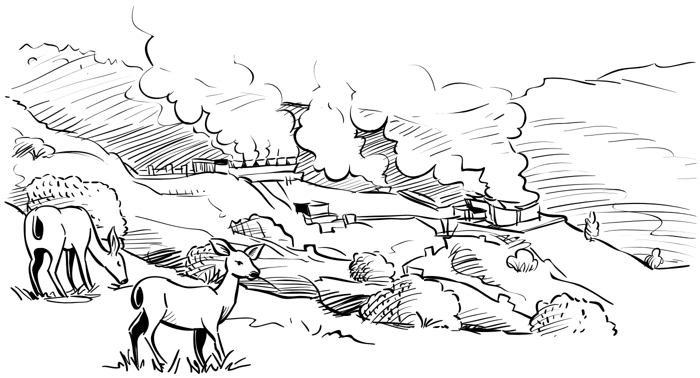
Extend:

1. Distribute "Geothermal Power Plant Project" handout to each student.
2. Arrange students into heterogeneous groups of five.
3. Tell groups that they will now take on the role of one of the following "stakeholders" in the development of a geothermal plant in Rock Station, Colorado:
   a. Resort owners
   b. Bureau of Land Management (Department of the Interior)
   c. Property rights/homeowners group
   d. Geothermal Futures, Inc.
   e. Colorado State Governor's office
   f. Town Council
   g. Department of Energy
4. Carefully go over instructions of project with the class.
5. Next, randomly select the stakeholder groups by distributing a stakeholder information sheet for each. (See stakeholder information sheets.)
6. Tell students they will now go to the computer lab where they will research geothermal energy production and how each of their stakeholder groups responds to the development of this power plant.

7. Computer Lab: Each group's goal is to create position papers/PowerPoint presentations and present them to a mock Rock Station Town Council next class.
8. Tell students that presentations will be no longer than five minutes for each group
9. PowerPoint or Keynote are required with each presentation. All members must share in the group's presentation.
10. Five minutes before the end of class, check with student groups to make sure all members of the group have met the criteria for project research and that each person has a role to play in his or her group's presentation.
11. Tell student stakeholder groups they will prepare for a Mock Town Council Meeting where they will give their five-minute PowerPoint presentation before the council and prepare to answer questions from council members.
12. Discuss with each stakeholder group the specific requirements outlined in their handouts.

GEOTHERMAL ENERGY AND PUBLIC POLICY

State and Local Government: Geothermal Power Plant Project



Preliminary Instructions: You have been placed into a "Stakeholder" group with an interest either for or against the proposed development of a 10 megawatt geothermal plant in Rock Station, Colorado.

Your group has been assigned the "Stakeholder" group ___________________________________.

Group Requirements

1. Your job is to research the following: geothermal energy, how it is produced, the environmental advantages and impacts it presents as an energy source, geothermal activity in the area of Rock Station, Colorado,, and what positions your group strongly holds on the development of a geothermal power plant at Rock Station, Colorado.
2. Your group's challenge is to convince the Rock Station Town Council that they should adopt your position.
3. Your group will put together five-minute PowerPoint presentation and a Position paper.
4. One placard to be displayed during the presentation must be made by each group demonstrating their position.
5. Each student must take notes during town council meeting.

Instructions for Group Position Paper

Your Position Paper is your group's formal written statement of your opinion of the geothermal power plant proposal at Rock Station, Colorado.

It must include a thesis statement within an introduction paragraph, three additional paragraphs citing evidence to support three different reasons of your group's position, and a concluding paragraph. A graphic organizer to help you with the position paper and grading rubric are attached.

Instructions for your group's PowerPoint

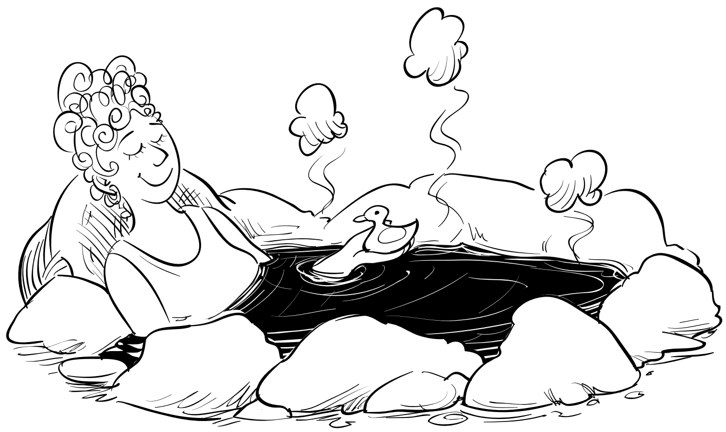
This PowerPoint must include elements of your Position Paper including but not limited to your opinion of the geothermal power plant proposal and evidence/reasons in support of your opinion. Length and number of slides in your PowerPoint depends on how many you need for all members of your group to participate and the five-minute time limit. Pictures, graphs, statistics, or charts that support your group's position are required.

Plan your Position Paper

Complete the following graphic organizer in order to plan your five paragraphs.

Introduction (Thesis statement and position)
Body Paragraph One (First reason)
Body Paragraph Two (Second reason)
Body Paragraph Three (Third reason)
Conclusion (Thesis restatement and body summation)

GEOTHERMAL ENERGY AND PUBLIC POLICY
Rock Station Spa Resort Owners Information Sheet



Your group represents a small but vocal group of business owners who are fiercely protective of the scenic beauty of the Rock Station region and their use of geothermal reservoirs for the hot springs resorts they control. There are four resort owners in the area but many more statewide.

Their greatest fear is that, despite assurances from the federal government, tapping into the geothermal reservoirs that exist underneath them will adversely affect the use of hot springs for their resort. Although they have no evidence that the amount of geothermal water would decrease or the temperature of that water would go down, they fear it could occur.

According to the Department of Interior's own Environmental Impact Report for the entire Western Region, the following is quoted:

> If geothermal leases were developed, the following general adverse impacts would be expected:
>
> - Long-term loss of vegetation, habitat, and soil.
> - Short-term and intermittent noise impacts from construction and maintenance activities. Operations would have minimal noise impacts in most areas on federal lands. However, areas with minimal noise sources, *i.e.*, remote areas, would experience a greater change in the noise characteristics.
> - Long-term visual impact from power plants and infrastructure.
> - Short-term impact to ground water during drilling.

Because your business is located in a remote region of Colorado, any short-term effects of construction and drilling would be devastating because tourism, they believe, would drop off significantly.

Research Assistance

These websites are useful for research:

http://www.mtprinceton.com/cabins.html

http://www.blm.gov/co/st/en/BLM_Programs/energy.html

http://nathrop-colorado.com/

http://www.geo-energy.org/

www.geothermal.marin.org

http://www1.eere.energy.gov/geothermal/geothermal_basics.html

http://rechargecolorado.com/images/uploads/pdfs/mtprinceton_henderson.pdf

http://rechargecolorado.com/images/uploads/pdfs/315HeldHendersonMtPrinceton.pdf

GEOTHERMAL ENERGY AND PUBLIC POLICY

Bureau of Land Management (Dept. of the Interior) Information Sheet

Your group represents the Bureau of Land Management (BLM), a division of the United States Department of the Interior. The BLM's primary responsibility is to manage federal land (public land owned by the federal government, which means it's owned by you and me).

The following was taken directly from the BLM's website:

> The BLM manages more Federal land than any other agency — about 245 million surface acres as well as 700 million sub-surface acres of mineral estate. As these lands are increasingly tapped to develop clean, renewable energy, the U.S. lessens its dependence on foreign oil and provides opportunities for creating new jobs to support local communities. Public lands also provide sites for new modern transmission facilities needed to deliver clean power to consumers.

The following has been excerpted from the BLM's Environmental Impact Statement of the current uses of geothermal energy in the Western United States:

> The The BLM currently (at the end of fiscal year 2007) administers approximately 480 geothermal leases that covered over 700,000 acres. Of those, 57 are producing geothermal energy, 54 are for electrical generation and three are for direct use.

Your position on the Rock Station Geothermal Plant in Colorado is to support the use of public lands for the benefit of all Americans. You have a specific responsibility to "lease" subsurface land (land below the surface) to private industry for the development of renewable energy. The plant at Mt. Princeton would be the first one in the state.

Use research from the websites listed on the following page to develop your presentation.

Research Assistance

http://www.blm.gov/wo/st/en/prog/energy.html

http://www.geo-energy.org/

www.geothermal.marin.org

http://www1.eere.energy.gov/geothermal/geothermal_basics.html

http://rechargecolorado.com/images/uploads/pdfs/mtprinceton_henderson.pdf

http://rechargecolorado.com/images/uploads/pdfs/315HeldHendersonMtPrinceton.pdf

The website below includes a PowerPoint presentation from the BLM on geothermal energy. It is not specific to Mt. Princeton, however. Some of it may be used and modified to meet your needs for presenting to the Town Council.

http://www.blm.gov/wo/st/en/prog/energy/geothermal/geothermal_nationwide.html

GEOTHERMAL ENERGY AND PUBLIC POLICY
Property Rights/Homeowners Group Information Sheet

As native Coloradans, you are extremely concerned about the natural beauty of Colorado, the long-term disruption of a geothermal energy plant, and the potential increase in residential development that a project of this scope may bring.

According to the Department of Interior's own Environmental Impact Report for the entire Western Region of the U.S., the following is quoted:

> If geothermal leases were developed, the following general adverse impacts would be expected:
>
> - Long-term loss of vegetation, habitat, and soil.
> - Short-term and intermittent noise impacts from construction and maintenance activities. Operations would have minimal noise impacts in most areas on federal lands; however, areas with minimal noise sources, i.e., remote areas, would experience a greater change in the noise characteristics.
> - Long-term visual impact from power plants and infrastructure.

All representatives from your group own their homes around Rock Station and include ranchers, business owners, fishermen, hunters, and environmentalists. All of them agree on one thing: A new geothermal energy plant would ruin the pastoral, rural life they all enjoy by increasing energy output for the area which would provide opportunity for residential developers to build new homes and increase the region's population.

Research Assistance

These websites can be used to develop your presentation.

http://www.state.co.us/visit_dir/OutdoorRec.html
(Contains links to outdoor recreation sites — a major draw for people who want to enjoy Colorado's outdoors.)

http://nathrop-colorado.com
(The website of a small community near the proposed location of the Mt. Princeton geothermal plant.)

http://www.geo-energy.org/

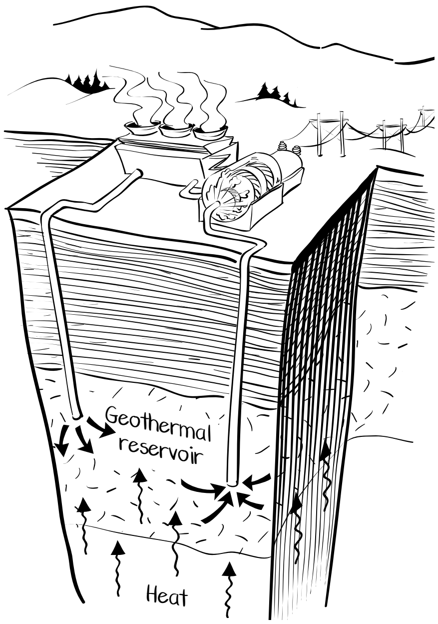
www.geothermal.marin.org

http://www1.eere.energy.gov/geothermal/geothermal_basics.html

http://rechargecolorado.com/images/uploads/pdfs/mtprinceton_henderson.pdf

http://rechargecolorado.com/images/uploads/pdfs/315HeldHendersonMtPrinceton.pdf

GEOTHERMAL ENERGY AND PUBLIC POLICY
Pro-Geothermal Energy Group Information Sheet



The name of the company you represent is Rock Station Geothermal Futures, Inc. The company has been drilling test wells 2,000-3,000 feet deep in several locations throughout the region for the last year and has determined that there is a geothermal reservoir that can produce 15,000 gallons per minute (GPM).

Geologists and engineers who work for the company have determined that with current technology, the rate of flow from the reservoir can be sustained indefinitely allowing the production of a 10-megawatt power plant.

As the lead company interested in leasing the subsurface land in this region, you must convince the Rock Station Town Council that a geothermal power plant is environmentally safe, does not disrupt the natural beauty of the region, provides long-term jobs, and mitigates (lessens the severity of) any economic disruption to hot springs resorts in the area.

The long-term economic benefit to this company would be significant and, if successful with this proposal, could lead to other geothermal power plant development in the Western United States.

Research Assistance

You can use the following websites for research:

http://www.geo-energy.org/

www.geothermal.marin.org

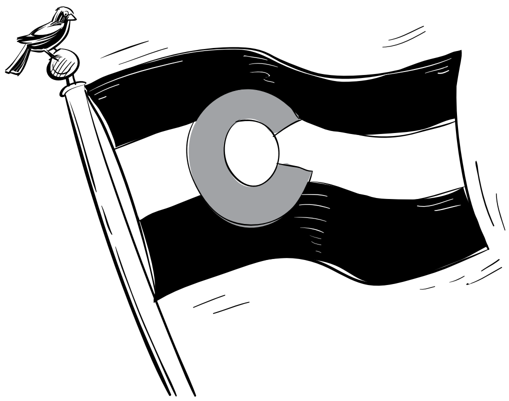
http://www1.eere.energy.gov/geothermal/geothermal_basics.html

http://rechargecolorado.com/images/uploads/pdfs/mtprinceton_henderson.pdf

http://rechargecolorado.com/images/uploads/pdfs/315HeldHendersonMtPrinceton.pdf

GEOTHERMAL ENERGY AND PUBLIC POLICY

Colorado State Governor's Energy Office Information Sheet



The Governor of Colorado is determined to have Colorado lead the nation in the development of renewable energy. Geothermal, along with wind and solar power generation, are major themes of the Governor's energy office. This political direction is an effort to bring more jobs to the state.

To this end, the Governor's office, through the State Energy Office, has pushed through state legislation that has provided funds to the University of Colorado to investigate the future of geothermal resources.

The Governor and his Energy Office strongly support the development of a geothermal power plant in Rock Station and strongly encourage the Rock Station Town Council to issue a Memorandum of Agreement with the State Public Utilities Commission. This memorandum is the last hurdle for Rock Station Geothermal Futures, Inc. to begin development of the plant.

Research Assistance

Use research from the following websites to develop your presentation.

http://www.energyincolorado.org/resources/geothermal

http://rechargecolorado.com/index.php/programs_overview/

http://www.geo-energy.org/

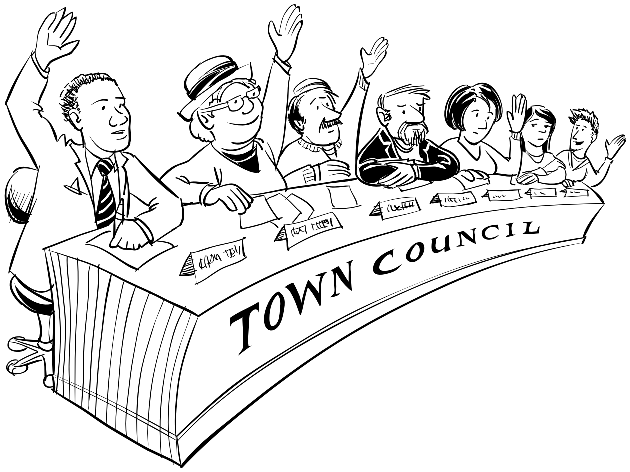
www.geothermal.marin.org

http://www1.eere.energy.gov/geothermal/geothermal_basics.html

http://rechargecolorado.com/images/uploads/pdfs/mtprinceton_henderson.pdf

http://rechargecolorado.com/images/uploads/pdfs/315HeldHendersonMtPrinceton.pdf

GEOTHERMAL ENERGY AND PUBLIC POLICY
Town Council Information Sheet



The Rock Station Town Council has been considering geothermal energy use for the last two decades but because of strong local opposition, approval of a geothermal power plant has repeatedly been put on hold. Opposition includes local hot springs resort owners and a vocal homeowner's group.

Now, however, new technologies as well as strong support from the Colorado State Governor's office and the U.S. Department of Energy make the construction and location of this power plant more appealing.

Your responsibility will be to listen to all sides of this proposal and to either approve or disapprove of a Memorandum of Agreement with the Colorado State Governor's office. This memorandum is the last hurdle that developers need before building the geothermal power plant in Rock Station.

If you reject the plant proposal, you must use the Position Paper handout to provide the voting public with a position thesis and specific supporting evidence.

If you approve the plant proposal, you must figure out how to mitigate (lessen the impact of) the concerns of homeowners and resort owners.

Requirements

1. Instead of researching and producing a PowerPoint, each of your group's members must complete the accompanying "Pro and Con" handout with research.
2. Additionally, each member of the council must come up with five questions to ask the presenters during the Town Council meeting.
3. Make a decision; not all council members need to agree. A simple majority is necessary for approval or rejection.

Research Assistance

Begin your research at:

http://www.eere.energy.gov

Other resources:

http://www.geocollaborative.org/about/default.htm

http://www.geothermal-biz.com/utilities.htm

http://salidacitizen.com/2009/11/blm-defers-mt-princeton-geothermal-lease-sale/

http://rechargecolorado.com/index.php/programs_overview/

http://www.geo-energy.org/

www.geothermal.marin.org

http://www1.eere.energy.gov/geothermal/geothermal_basics.html

http://rechargecolorado.com/images/uploads/pdfs/mtprinceton_henderson.pdf

http://rechargecolorado.com/images/uploads/pdfs/315HeldHendersonMtPrinceton.pdf

http://www.mtprinceton.com/cabins.html

http://www.blm.gov/co/st/en/BLM_Programs/energy.html

http://nathrop-colorado.com/

Pro's and Con's of Geothermal Energy Development

Arguments For:	Arguments Against:

GEOTHERMAL ENERGY AND PUBLIC POLICY
US Department of Energy Information Sheet

Your group represents the U.S. Department of Energy (DOE).

The following was taken directly from the DOE's website:

> The mission of the Energy Department is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

The following was taken directly from the DOE's Loan Program Office (LPO) website:

> The mission of LPO is to accelerate the domestic commercial deployment of innovative and advanced clean energy technologies at a scale sufficient to contribute meaningfully to the achievement of our national clean energy objectives—including job creation; reducing dependency on foreign oil; improving our environmental legacy; and enhancing American competitiveness in the global economy of the 21st century.

Your position on the Rock Station Geothermal Plant in Colorado is to support its development as directed by the mission statements above.

Research Assistance

Use research from the following websites to develop your presentation.

http://energy.gov/science-innovation/energy-sources/renewable-energy/geothermal

http://energy.gov/articles/calpine-americas-largest-geothermal-energy-producer

http://energy.gov/articles/energy-department-finalizes-loan-guarantee-ormat-geothermal-project-nevada

http://lpo.energy.gov/

http://www.geo-energy.org/

www.geothermal.marin.org

http://www1.eere.energy.gov/geothermal/geothermal_basics.html

National Social Studies Standards Correlations for Lesson 2

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme VI: Power, Authority, and Governance

Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of Power, Authority, and Governance.

- Enable learners to examine the rights and responsibilities of the individual in relation to their families, their social groups, their community, and their nation;
- Help students to understand the purpose of government and how its powers are acquired, used, and justified;
- Help learners to analyze and explain governmental mechanisms to meet the needs and wants of citizens, regulate territory, manage conflict, and establish order and security;
- Challenge learners to apply concepts such as power, role, status, justice, democratic values, and influence to the examination of persistent issues and social problems;

Theme VII: Production, Distribution, and Consumption

Social studies programs should include experiences that provide for the study of how people organize for the production, distribution, and consumption of goods and services.

- Challenge learners to apply economic concepts and reasoning when evaluating historical and contemporary social developments and issues;
- Guide learners in the application of economic concepts and principles in the analysis of public issues such as the allocation of health care or the consumption of energy, and in devising economic plans for accomplishing socially desirable outcomes related to such issues.

Theme VIII: Science, Technology, and Society

Social studies programs should include experiences that provide for the study of relationships among science, technology, and society.

- Enable learners to identify, describe, and examine both current and historical examples of the interaction and interdependence of science, technology, and society in a variety of cultural settings;
- Provide opportunities for learners to make judgments about how science and technology have transformed the physical world and human society and our understanding of time, space, place, and human-environment interactions;
- Have learners analyze the way in which science and technology influence core societal values, beliefs, and attitudes and how societal attitudes influence scientific and technological endeavors;
- Prompt learners to evaluate various policies proposed to deal with social changes resulting from new technologies;
- Help learners to identify and interpret various perspectives about human societies and the physical world using scientific knowledge, technologies, and an understanding of ethical standards of this and other cultures;
- Encourage learners to formulate strategies and develop policy proposals pertaining to science, technology, and society issues.

Unit III - Lesson 3: ROCK STATION MOCK TOWN COUNCIL AND GEOTHERMAL ENERGY

Objectives

Students will be able to:

- Role-play a mock town council meeting on the topic of the proposed construction and development of a geothermal plant in Colorado.
- Learn the procedures of local government and how it responds to the public interest which may surround alternative energy issues.

Time

One full block period or one and a half traditional class periods

Background

Teachers should have an understanding of municipal government, the workings of city and town councils, and the policy/budget issues they decide. Although each state and often each city has published procedural documents which can be found online, the following website can be quickly accessed and reviewed.

http://www.cacities.org/index.jsp

This lesson and accompanying handouts reference a fictitious location in the United States that is considering the development of a geothermal plant.

Materials

Computer and computer projection (or equivalent) necessary for PowerPoint or Keynote presentations.

Debate handout for next class

PROCEDURES

Extend:

1. Arrange class with five desks facing the rest of the class. This is where council members will sit.
2. Tell members of each group to sit together throughout presentations.
3. Note-taking is required for each student in preparation for a debate next class.
4. Teacher will give groups five minutes to prepare for mock Town Council meeting.
5. Teacher will introduce the mock council meeting by providing a list to council members, which identifies the presentation order. The meeting begins when the first group is asked to come forward and make their presentation.
6. If groups go beyond the five-minute time allotment, council members will ask them to stop but give them an opportunity to add comments after all presentations.
7. Council members will ask clarifying questions throughout presentations.
8. At the conclusion of the presentations, council members will retreat to the hallway where they will discuss the presentations.
9. After a few minutes, council members will return and announce their decision.
10. Following the town council meeting, the teacher will conduct a review of local government process by asking students how they felt about the process and whether or not they felt their voices were heard.

11. Also, discuss whether or not council members were given enough information to make a responsive decision in considering their community and its future.
12. Tell student stakeholder groups to turn in their position papers and PowerPoint/Keynote presentations for assessment.
13. To close, divide class into two opposing sides and tell them they will begin to prepare for a debate next class. Distribute the rules for debate and write the following prompt on a white board:

    Can geothermal power production reach levels equal to wind and solar power production in 20 years?

    One side will argue that geothermal power production will not attain levels of production with other renewable energies while the other side will argue that they will. Teachers can require students to take notes during the debate as an assessment.
14. Tell students to use the research they've gathered throughout the previous lessons and to access the websites presented to prepare for their side of the debate.

National Social Studies Standards Correlations for Lesson 3

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme VI: Power, Authority, and Governance

Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of Power, Authority, and Governance.

- Enable learners to examine the rights and responsibilities of the individual in relation to their families, their social groups, their community, and their nation
- Help students to understand the purpose of government and how its powers are acquired, used, and justified
- Help learners to analyze and explain governmental mechanisms to meet the needs and wants of citizens, regulate territory, manage conflict, and establish order and security
- Challenge learners to apply concepts such as power, role, status, justice, democratic values, and influence to the examination of persistent issues and social problems

Theme VII: Production, Distribution, and Consumption

Social studies programs should include experiences that provide for the study of how people organize for the production, distribution, and consumption of goods and services.

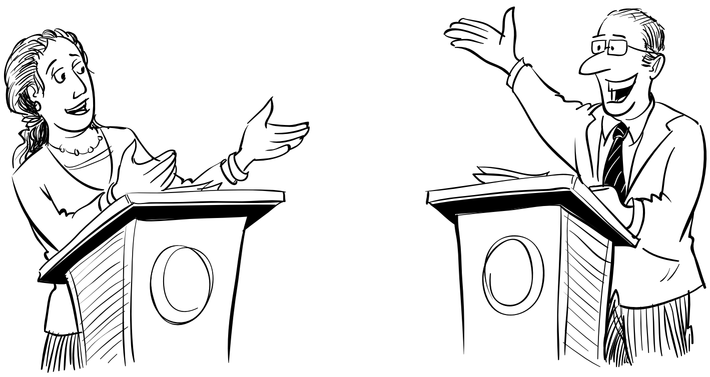
- Enable learners to explain how the scarcity of productive resources (human, capital, technological, and natural) requires the development of economic systems to make decisions about how goods and services are to be produced and distributed
- Challenge learners to apply economic concepts and reasoning when evaluating historical and contemporary social developments and issues
- Guide learners in the application of economic concepts and principles in the analysis of public issues such as the allocation of health care or the consumption of energy, and in devising economic plans for accomplishing socially desirable outcomes related to such issues

Theme VIII: Science, Technology, and Society

Social studies programs should include experiences that provide for the study of relationships among science, technology, and society.

- Provide opportunities for learners to make judgments about how science and technology have transformed the physical world and human society and our understanding of time, space, place, and human-environment interactions
- Have learners analyze the way in which science and technology influence core societal values, beliefs, and attitudes and how societal attitudes influence scientific and technological endeavors
- Prompt learners to evaluate various policies proposed to deal with social changes resulting from new technologies
- Encourage learners to formulate strategies and develop policy proposals pertaining to science-technology-society issues.

Unit III - Lesson 4: THE FUTURE OF GEOTHERMAL ENERGY SYSTEMS IN THE UNITED STATES



Objectives

Students will be able to:

- Engage in a debate on the future of geothermal energy as a renewable energy source in the United States
- Analyze the various types of geothermal energy development including EGS
- Learn about potential geothermal energy jobs and plant development from private and government sources

Time Allotted

One full block period or one and a half traditional class periods

Background

Although debate rules for this lesson are provided, teachers should feel free to use their own rules if preferred. How long each student is allowed to speak during his or her side of the debate depends on class size and class time. For this lesson, allow only 30-40 minutes for the debate so there will be time for evaluation of the debate and/or time for an expert in the geothermal energy field who can present real world information to students.

Materials

Pencil and paper for note taking
Computer and projector

PROCEDURES

Extend/Evaluate

1. Arrange class with an even number of desks facing each other before class begins.
2. Tell students they have five minutes to meet with their respective teams for last minute preparation before debate begins.
3. At end of five minutes, go over rules of debate so that students are clear about them and their responsibilities during the debate which will focus on the prompt, "Can geothermal power production reach equal levels of nuclear, wind, and solar power production in 20 years?"
4. Begin debate by selecting one side to give their opening statement followed by the other side.
5. Continue debate until 30-40 minutes is up.
6. At end of debate, tell teams they have two minutes to prepare a closing statement.
7. Select one side for the closing statement followed by the other side.
8. End debate by conducting a discussion with entire class on how they felt the debate progressed. Ask them questions such as; What is the potential of geothermal energy? (prompt with what they've learned about present-day uses, binary systems, and EGS); What challenges are there in developing heat from parts of the Earth's crust where geothermal reservoirs do not exist? What potential environmental questions should be considered? What engineering challenges might there be?

9. Have students turn in any research they used in preparation, opening and closing statements, and notes taken during the debate, for assessment.
10. End the lesson by introducing Enhanced Geothermal Systems to students by visiting the following website.

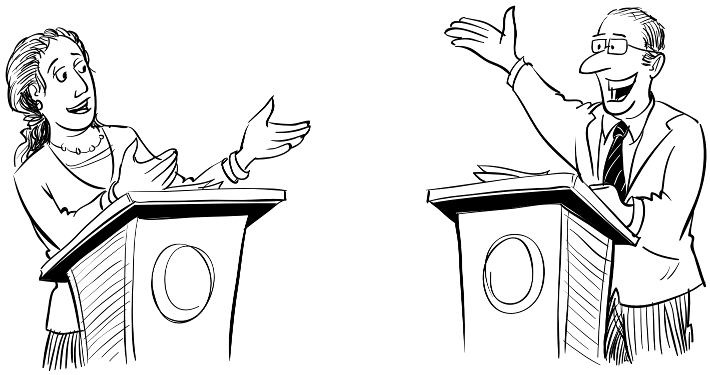
    http://www1.eere.energy.gov/geothermal/

VOCABULARY

geothermal reservoir
enhanced geothermal systems (EGS)
plate tectonics
Ring of Fire
production well
injection well
steam turbine
dry steam
flash steam
binary cycle

RENEWABLE ENERGY (NON-GEOTHERMAL) VS. GEOTHERMAL POWER

Philosophical Chairs: A Debate Activity



Description

Philosophical Chairs debate involves the entire class in a discussion/debate activity that employs a controversial prompt with a pro-con response. Desks are arranged facing each other and the class is divided into two groups.

Debate Rules

- Each side must prepare an opening and closing statement.
- All speakers have one minute to speak.
- With the exception of the opening and closing statements, a student must briefly summarize the previous speaker's points to that speaker's satisfaction before he begins his own comments.
- After a student speaks, she must wait until two students on her side have spoken before speaking again.
- The teacher can call "time-out" periodically, to clarify, reflect on the process or content, or refocus.
- Everyone needs to speak at least once during the discussion.
- Attack the ideas, not the person.
- Think before you speak. Organize your thoughts and sign post (*e.g.*, have three points.)
- One speaker at a time; others are listeners. Participant note-taking can reinforce this rule.
- Debate continues until five minutes before the end of the period.

Philosophical Prompt

Can geothermal power production reach levels equal to wind and solar power production in 20 years?

National Social Studies Standards Correlations for Lesson 4

National Standards – NCSS Curriculum Standards – Thematic Strands II

Theme VI: Power, Authority, and Governance

Social studies teachers should possess the knowledge, capabilities, and dispositions to organize and provide instruction at the appropriate school level for the study of Power, Authority, and Governance.

- Help students to understand the purpose of government and how its powers are acquired, used, and justified
- Provide opportunities for learners to examine issues involving the rights, roles, and status of individuals in relation to the general welfare
- Help learners to analyze and explain governmental mechanisms to meet the needs and wants of citizens, regulate territory, manage conflict, and establish order and security
- Challenge learners to apply concepts such as power, role, status, justice, democratic values, and influence to the examination of persistent issues and social problems

Theme VII: Production, Distribution, and Consumption

Social studies programs should include experiences that provide for the study of how people organize for the production, distribution, and consumption of goods and services.

- Enable learners to explain how the scarcity of productive resources (human, capital, technological, and natural) requires the development of economic systems to make decisions about how goods and services are to be produced and distributed
- Challenge learners to apply economic concepts and reasoning when evaluating historical and contemporary social developments and issues;
- Guide learners in the application of economic concepts and principles in the analysis of public issues such as the allocation of health care or the consumption of energy, and in devising economic plans for accomplishing socially desirable outcomes related to such issues

Theme VIII: Science, Technology, and Society

Social studies programs should include experiences that provide for the study of relationships among science, technology, and society.

- Enable learners to identify, describe, and examine both current and historical examples of the interaction and interdependence of science, technology, and society in a variety of cultural settings
- Provide opportunities for learners to make judgments about how science and technology have transformed the physical world and human society and our understanding of time, space, place, and human-environment interactions

Have learners analyze the way in which science and technology influence core societal values, beliefs, and attitudes and how societal attitudes influence scientific and technological endeavors; prompt learners to evaluate various policies proposed to deal with social changes resulting from new technologies

- Encourage learners to formulate strategies and develop policy proposals pertaining to science-technology-society issues

GEOTHERMAL ENERGY GLOSSARY

A

acid rain: common name for any precipitation (rain, snow, sleet, hail, fog) having a high amount of sulfuric acid and/or nitric acid or having a pH lower than 5.6. Normal rain has a pH of 5.6 - 5.7. Fossil fuel power plants are a major source of acid rain.

agriculture: the growing (farming) of plants, flowers, trees, grains, and other crops. Greenhouses can be heated with hot water from geothermal reservoirs. In some places pipes of hot water are buried under the soil. Geothermal heat is also used to dry crops.

aquaculture: the farming of fish and other water-dwelling organisms in freshwater or seawater. Geothermal water is used to help speed the growth of fish, prawns and alligators. China probably has more aquaculture operations than any other country.

aquifer: a large permeable body of underground rock capable of yielding quantities of water to springs or wells. Aquifers provide about 60% of American drinking water. Underground aquifers of hot water and steam are called geothermal reservoirs.

B

balneology: using hot spring mineral water for therapy. This is perhaps the oldest use of natural geothermal waters.

baseload power: the amount of power needed to supply the minimum anticipated demand for electricity at any given time.

binary power plant: geothermal power plant that uses a heat exchanger to transfer heat to a second (binary means two) liquid that flashes to vapor and drives a turbine-generator.

boiling point: temperature at which a single substance, such as water, changes from a liquid to a gas (steam) under normal atmospheric pressure. The boiling point at which water transitions to steam is 212°F (100°C). Some liquids boil at a lower temperature than water — a principle utilized in binary power plants. Boiling point is also affected by pressure. The greater the pressure, the higher the boiling point. This principle is put to work in geothermal (flash) power plants when superheated (hotter than boiling) geothermal water is brought up wells. The hot water flashes to steam when the pressure is released as it reaches the surface. This phenomenon also occurs naturally, resulting in such features as geysers.

brine: a geothermal solution containing significant amounts of sodium chloride or other salts.

BTU: British thermal unit; the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at standard conditions (equal to 252 calories).

C

caldera: a bowl-shaped landform, created either by a huge volcanic explosion (which destroys the top of a volcano) or by the collapse of a volcano's top.

cap rocks: rocks of low permeability that overlie a geothermal reservoir.

carbon dioxide (CO_2): a gas produced by the combustion of fossil fuels and other substances. CO_2 also occurs naturally in large amounts in molten magma, which is involved in the explosive eruption of volcanoes. See *greenhouse effect*.

chemical energy: energy inherent in the chemical bonds which hold molecules together. Examples are coal and oil, which have energy potential that is released upon combustion.

combustion: the burning of gas, liquid, or solid, in which the fuel is oxidized, producing heat and often light.

condense: to change from a gas to drops of liquid. Water-cooled geothermal power plants use cooling towers to cool the used steam and condense it back to water for injection back to the edge of the reservoir. In binary power plants, an organic liquid is first vaporized (with heat from geothermal water) to drive a turbine, then cooled and condensed back to a liquid and recycled again and again in a closed loop.

condenser: equipment that condenses turbine exhaust steam into condensate.

conduction: the transfer of heat as a result of the direct contact of rapidly moving molecules through a medium, or from one medium to another, without movement of the media. The heat from geothermal water, for instance can be conducted through metal plates or pipes to heat other water for district heating systems or a second organic liquid for use in binary power plants.

continental drift: the theory that the continents have drifted apart when a supercontinent, Pangaea, broke apart. See *plate tectonics*.

convection currents: the currents caused by hot air or fluid rising and falling. Hot air or fluid expands and is therefore less dense than its cooler surroundings, thus it rises; as it cools it contracts, becomes more dense and sinks down creating something of a rolling motion. These motions are thought to be party of the dynamic geologic processes that drive the movement of crustal plates. See *plate tectonics*.

cooling tower: a structure in which heat is removed from hot condensate.

core (outer and inner): the extremely hot center of the earth. The outer core is probably molten rock and is located about 3,200 miles (5,100) kilometers down from the earth's surface; the inner core may be solid iron and is found a the very center of the earth — about 4,000 miles (6,400 kilometers) down.

crust: the solid outermost layer of the earth, mostly consisting of rock, and ranging from 3 - 35 miles (4.8 - 56 kilometers) thick, comprises the topmost portion of the lithosphere (see *lithospheric plates*). Earth's crust insulates us from the hot interior.

cultivate: to grow and tend (plants or crops), farm.

D

dehydrate: to free from moisture in order to preserve; to dry fruits, vegetables or lumber, for instance. A factory in Nevada, for example, uses geothermal heat to dehydrate onions and garlic for restaurants.

density: the amount of mass in a given volume of something. Two objects can be the same size but have different densities because one of the objects has more mass "packed" into the same amount of space. Objects are smaller when they are cold, larger when hot.

direct use: use of geothermal water and it's heat to grow fish, dry vegetable, fruit and wood products, heat greenhouses and city buildings, or provide hot water for spas.

district heating system: a heating system that provides heat to a large number of buildings all from a central facility. In geothermal district heating systems, one or more wells can serve entire districts.

drilling: boring into the earth to access geothermal resources, usually with oil and gas drilling equipment that has been modified to meet geothermal requirements.

dry steam power plant: geothermal power plant that uses steam directly from a steam-filled geothermal reservoir.

E

earthquake: the vibration or movement of the ground caused by a sudden shift along faults (cracks) in the earth's crust; most earthquakes occur at the places where tectonic plate edges meet.

efficiency: the ratio of the useful energy output of a machine or other energy-converting plant to the energy input.

electric current: the continuous flow of electrons; often referred to as electricity.

electrical energy: energy of electric charges or electric currents.

electron: the smallest part of an atom (atoms are the tiny particles of which all substances are made). Electrons may be freed from atoms to produce an electric current.

energy: the ability to do work, such as making things move and heating them up. Energy can take many forms, including electrical, chemical, radiant, mechanical and heat.

energy conversion: the changing of energy from one form to another. One of the many examples are heat energy being converted into mechanical energy, and then mechanical energy into electrical energy, as is done in steam-driven electric power plants.

energy efficiency: the measure of the amount of energy which any technology can convert to useful work; technology with a higher energy efficiency will require less energy to do the same amount of work.

energy resource: a source of useable power which can be drawn on when needed. Energy resources are often classified as renewable or non-renewable.

enhanced, or engineered, geothermal systems (EGS): Rock fracturing, water injection, and water circulation technologies to sweep heat from the unproductive areas of existing geothermal fields or new fields lacking sufficient production capacity. Permeability can be created in hot rocks by hydraulic fracturing — injecting large volumes of water into a well at a pressure high enough to break the rocks. The artificial fracture system is mapped by seismic methods as it forms, and a second well is drilled to intersect the fracture system. Cold water can then be pumped down one well and hot water taken from the second well for use in a geothermal plant.

Environmental Protection Agency (EPA): Federal government agency that makes and enforces standards for pollution control; designed to protect the environment.

eruption: the explosive discharge of material such as molten rock and gases, or hot water (as from volcanoes or geysers).

F

fault: a crack or break in the earth's crust along which movement has occurred, often resulting in earthquakes.

fissure: in geology, an extensive crack, break, or fracture in rock.

flash power plant: a geothermal power plant that uses a process in which geothermal water is converted to steam to drive a turbine.

fracture: a crack in the earth's crust along which no movement has occurred.

fumarole: a small hole or vent in the earth's surface, found near volcanic areas, from which steam or gases shoot out.

G

generator: a machine that converts mechanical power into electricity by spinning copper wires (conductors) within a magnetic field.

geology: study of the planet Earth, its composition, structure, natural processes, and history.

geothermal energy: the earth's natural interior heat. The word geothermal comes from the Greek words geo(earth) and therme (heat), and means the heat of the earth. Earth's interior heat originated from its fiery consolidation from dust and gas over 4 billion years ago and is continually regenerated from the decay of radioactive elements that occur in all rocks.

geothermal (ground source) heat pump: a space heating/cooling system which moves heat from and to the earth, as opposed to making heat using a fuel source. Geothermal heat pumps take advantage of the almost constant temperature just a few feet underground — usually warmer than the air in winter and cooler than the air in summer.

geothermal gradient: the rate of temperature increase in the earth as a function of depth. Temperature increases an average of 1° Fahrenheit for every 75 feet in descent.

geothermal phenomena: an observable event at the surface, whose occurrence is the result of the earth's internal heat; includes volcanoes, geysers, hot springs, mud pots and fumaroles.

geothermal power plant: a facility which uses geothermal steam or heat to drive turbine-generators to produce electricity. Three different types make use of the various temperature ranges of geothermal resources: dry steam, flash and binary.

geothermal reservoir: a large volume of underground hot water and steam in porous and fractured hot rock. The hot water in geothermal reservoirs occupies only 2 - 5% of the volume of rock, but if the reservoir is large enough and hot enough, it can be a powerful source of energy. Geothermal reservoirs are sometimes overlaid by a layer of impermeable rock. While geothermal reservoirs usually have surface manifestations such as hot springs or fumaroles, some do not.

geothermal resource: the natural heat, hot water, and steam within the earth.

geothermal water (geothermal resources): water heated by the natural heat inside the earth.

geyser: a natural hot spring that sends up a fountain of water and steam into the air; some geysers "spout" at regular intervals and some are unpredictable.

Geysers, The: a large geothermal steam field located north of San Francisco. The Geysers is home to 22 power plants.

global warming/greenhouse effect: the trapping of heat in the atmosphere. Incoming solar radiation goes through the atmosphere to the earth's surface, but outgoing radiation (heat) is absorbed by water vapor, carbon dioxide, and ozone in the atmosphere. At certain levels this is beneficial because it keeps the planet warm enough for life as we know it. However, an increase in the normal amount of carbon dioxide and other gases may contribute to a human-caused warming trend that could have serious effects on global climate, the global ecosystem, and food supplies.

groundwater: water that collects underground, mostly from surface water that has seeped down through cracks and pores in rock.

H

health spa: an establishment (often commercial) which is visited by guests seeking therapy and relaxation; many center around hot mineral springs or use hot water from geothermal wells.

heat exchanger: a device in which heat is transferred by conduction through a metal barrier from a hotter liquid or gas, to warm a cooler liquid or gas on the other side of the metal barrier. Types of heat exchangers include "shell and tube," and "plate."

heat flow: movement of heat from within the earth to the surface, where it is dissipated by radiation into the atmosphere, surface water, and space.

heat transfer: the transmission of heat. There are three forms of heat transfer: "conduction," "convection," and "radiation." See these terms.

hot dry rock: a potential source of accessible heat energy within the earth's crust; a geothermal resource created when hot but impermeable (does not allow water to pass through) underground rock structures are fractured to allow infiltration of water, thus creating an artificial geothermal reservoir. Geothermal engineers now use the term "enhanced, or engineered, geothermal systems" (EGS) to refer to systems using hot dry rock.

hot spot: areas of volcanic activity found in the middle of lithospheric plates, caused from an upwelling of concentrated heat in the mantle. Hot spots remain stationary while the plates move over them, often leaving a chain of extinct volcanoes as the plate moves away from the hot spot; examples include the Hawaiian Islands and Yellowstone National Park.

hot springs: a natural spring that puts out water warmer than body temperature and therefore feels hot; may collect in pools or flow into streams and lakes; a geothermal phenomenon.

hydrogen sulfide: a gas with a disagreeable odor, frequently dissolved in geothermal waters in small amounts; toxic at high concentrations.

hydrothermal: hydro means water and thermal means heat. Literally, hydrothermal means hot water. Steam and hot water reservoirs are hydrothermal reservoirs. Hot dry rock resources and magma resources are not considered to be hydrothermal resources.

hydrothermal resource: underground systems of hot water and/or steam.

I

impermeable: does not allow liquids to pass through easily — certain rock types and clay soil are impermeable.

injection well: a well through which geothermal water is returned to an underground reservoir after use. Geothermal production and injection wells are constructed of pipes layered inside one another and cemented into the earth and to each other. This protects any shallow drinking water aquifers from mixing with deeper geothermal water.

K

KGRA: known Geothermal Resource Area; region identified by the U.S. Geological Survey as containing geothermal resources.

Kilowatt: 1,000 watts—a unit of electric power; abbreviated kW. One kilowatt of electricity serves about 750 homes in the U.S.

Kilowatt Hour: the energy represented by 1 kilowatt of power consumed for a period of 1 hour — equal to 3,413 BTUs; abbreviated kWh.

L

lava: molten magma that has reached the earth's surface.

M

magma: hot, thick, molten (liquid) rock found beneath the earth's surface; formed mainly in the mantle.

mantle: the semi-molten interior of the earth that lies between the core and the crust making up nearly 80% of the earth's total volume; extends down to a depth of about 1800 miles (2,900 kilometers) from the surface.

mechanical energy: the energy an object has because of its motion or position and the forces acting on it.

megawatt (MW): a unit of power, equal to a thousand kilowatts (kW) or one million watts(W). The watt is a unit of power (energy/time), the rate energy is consumed or converted to electricity.

mineralized: containing minerals; for example, mineralized geothermal water contains dissolved minerals from inside the earth.

molecules: extremely tiny particles of which all materials are made .

mud pot (paint pot): thermal surface feature which occurs where there is not enough water to support a geyser or hot spring even though there may be some hot water below. Steam and gas vapors bubble up through mud formed by the interaction of gases with rock.

N

natural gas: a gas mixture (mostly methane) trapped underground in many places near the surface of the earth; a fossil fuel.

nitrogen oxides (Nox): formed in combustion; appear as yellowish-brown clouds; can irritate lungs, cause lung diseases, lead to formation of ozone (harmful in the lower atmosphere, but necessary as protection from UV rays in the upper atmosphere).

nonrenewable resource: resources not replaced or regenerated naturally within a period of time that is useful; includes fossil fuels, uranium and other minerals.

P

Pangaea: the huge supercontinent which scientists think may have existed 250 million years ago. All of the continents may have at one time been joined together to make this huge land mass.

particulates (particulate matter): dust, soot, smoke and other suspended matter; can be respiratory irritants. Particulate matter smaller than 10 microns (pm10) has been found to be particularly harmful to health.

pasteurize: to use high temperatures to destroy disease-causing bacteria.

permeable: able to transmit water or other liquids; for example, rock with tiny passageways between holes, fractured rock, and gravel are permeable.

plate tectonics: the study of the movement of large crustal plates (lithospheric plates) of the earth's shell. The earth's shell is broken into several pieces (12 large ones and several smaller ones). These plates move toward and away from one another at about the rate our fingernails grow. The process that creates the dynamic movement of the plates includes the convection of magma in the mantle and lithosphere. Plate tectonics helps to explain continental drift, seafloor spreading, volcanic eruptions and other geothermal phenomena, earthquakes, mountain formation and the distribution of some plant and animal species.

porous: full of small holes (pores); able to be filled (permeated) by water, air, or other materials.

power plant: a central station where electricity is produced using turbines and generators.

pressure: the force exerted over a certain area. Our atmosphere exerts pressure on the surface of the earth, and layers of rock exert pressure on those below them.

R

radiant energy: energy (heat) that is transferred by rays or waves, especially electromagnetic waves, through space or another medium. Radiation.

renewable resource: a resource that can be used continuously without being used up (because it regenerates itself within a useful amount of time). Examples include water (small hydro) and wind power, solar energy, and geothermal energy.

reservoir: see *geothermal reservoir.*

rift zone: long narrow fractures in the crust found along ocean floor or on land, from which lava flows out; often associated with spreading centers from which tectonic plates are diverging, such as the mid-Atlantic Ridge.

Ring of Fire: a belt of intense volcanic, geothermal and earthquake activity found all around the Pacific Rim caused by plate tectonic activity.

S

steam: the vapor form of water that develops when water boils. Steam is made of very tiny heated water particles (molecules) which are bouncing around and bumping into each other at very high speeds. These heated water molecules are also spreading out and expanding in every direction they can. If we confine or trap water in a container, with a pipe as an opening, and heat the water to steam, it will create great pressure in the container and will rush out of the pipe with a great deal of force. This force (the "power" of steam) can be put to work turning a turbine connected to an electricity generator.

subduction boundary: one of two types of converging plate boundaries which occurs when one plate plunges under another overriding plate.

sulfur oxides (Sox): pungent, colorless gases (including sulfur dioxide (SO_2); formed primarily by the combustion of fossil fuels; may damage the respiratory tract, as well as plants and trees.

sustainable: material or energy sources which, if managed carefully, will provide the needs of a community or society indefinitely, without depriving future generations of their needs.

T

therapeutic: the treatment of disease or other disorder; something that may benefit health. (Geothermal) hot springs are often thought of as therapeutic.

transmission lines: wires that transport electricity over long distances.

turbine: a machine with blades that are rotated by the forceful movement of liquid or gas, such as air, steam or water or a combination.

V

vaporize: to change into the gas form anything which is normally a liquid or a solid; the term is most commonly used in reference to water (which vaporizes to steam).

volcano: an opening in the earth's crust from which lava, steam, and/or ashes erupt (or flow), either continuously or at intervals.

voltage: the measure of the amount of force that "pushes" an electric current.

W

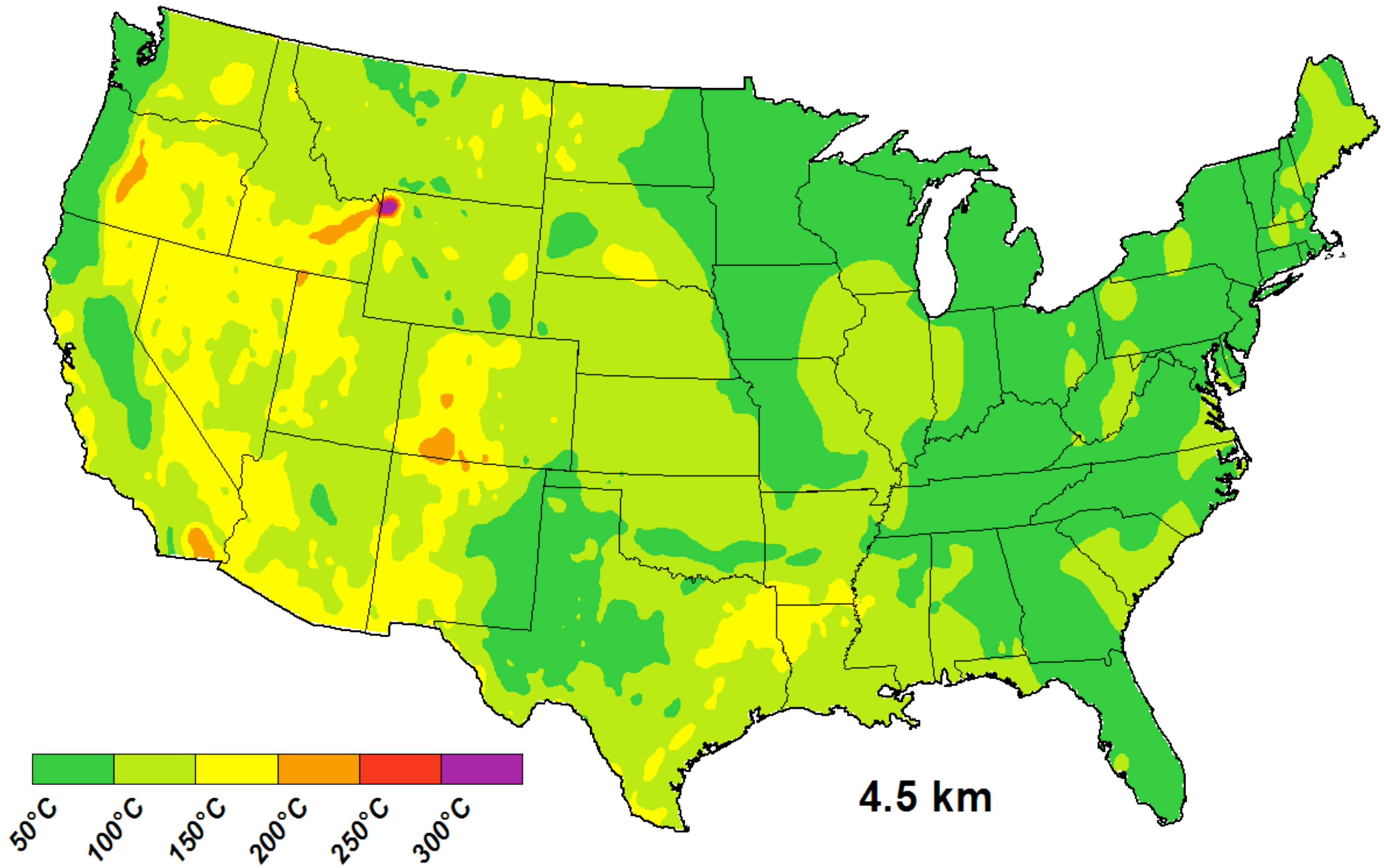
water phases: the change of water from one state to another. The change from ice to liquid is melting; the reverse process is freezing. The change from liquid to gas is evaporation and the product is water vapor; the change from water vapor to liquid is called condensation. Evaporation and condensation are both important functions in geothermal phenomena and in geothermal technology.

Watt (W): the measure of the amount of current flowing through a wire at a given time.

SUPPLEMENTAL INFORMATION

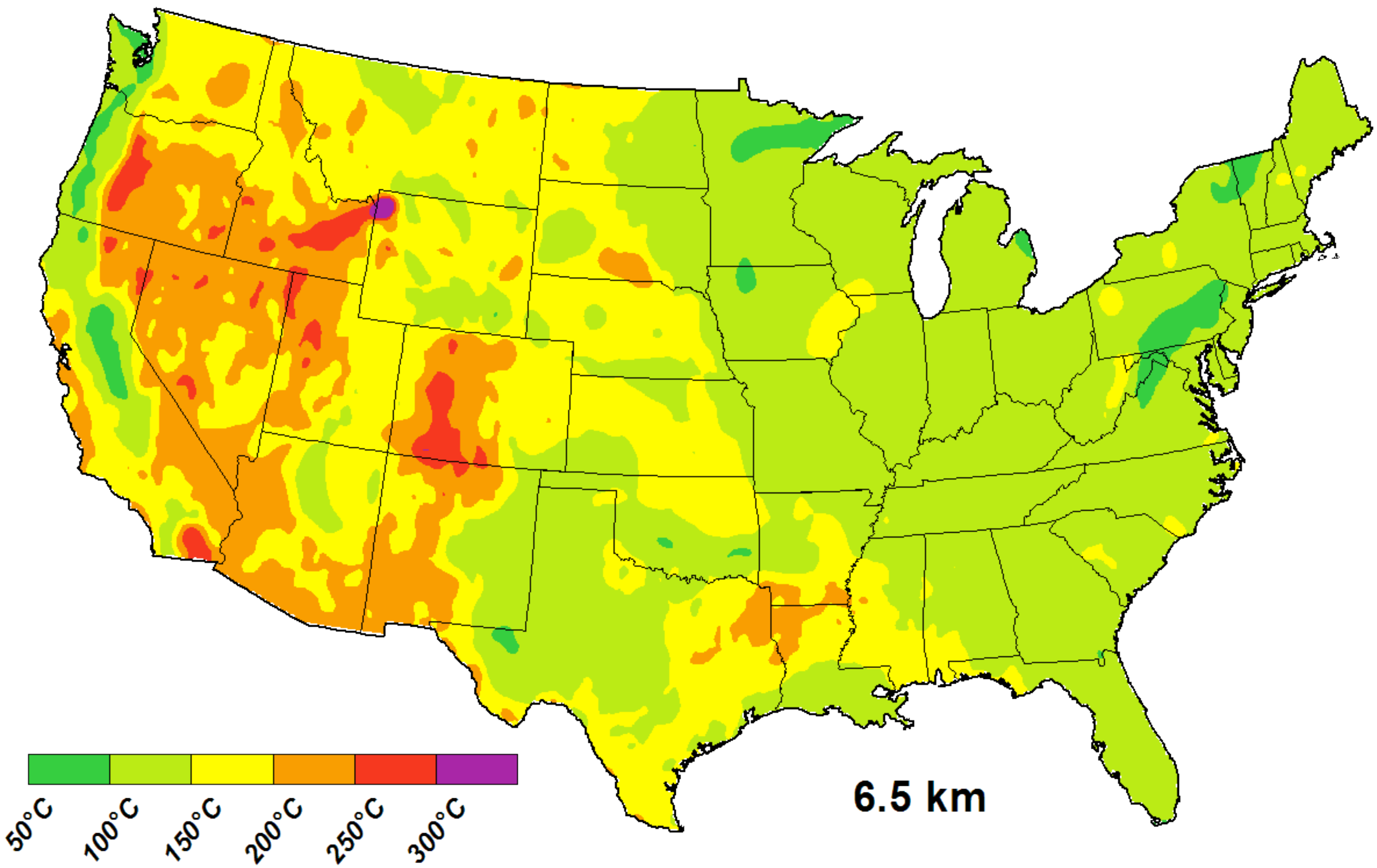
Earth's Temperatures at Depth

Temperatures at 4.5 km Depths



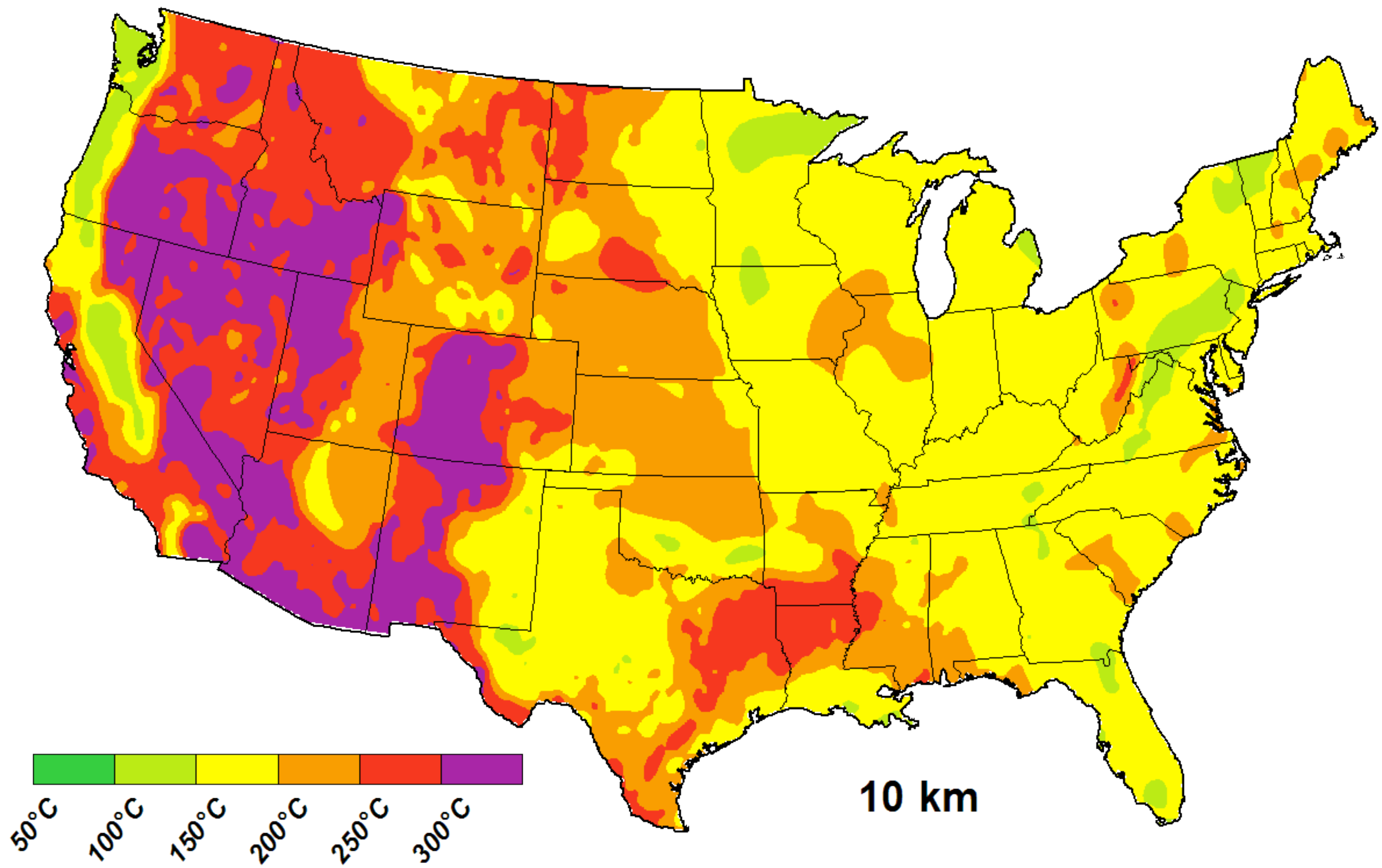
The Future of Geothermal Energy — Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, MIT Department of Chemical Engineering, January 2007

Temperatures at 6.5 km Depths

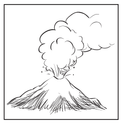


The Future of Geothermal Energy — Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, MIT Department of Chemical Engineering, January 2007

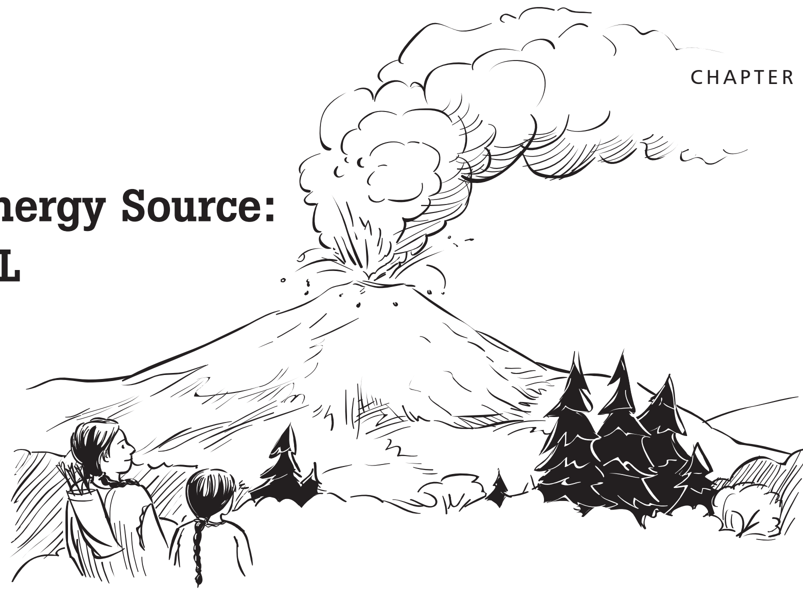
Temperatures at 10 km Depths



The Future of Geothermal Energy — Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century, MIT Department of Chemical Engineering, January 2007



Renewable Energy Source: GEOTHERMAL



TERMS IN GLOSSARY

- binary power plant
- conduction
- crust
- dry steam power plant
- enhanced geothermal systems (EGS)
- fissure
- flash power plant
- fumarole
- geothermal reservoir
- groundwater
- heat exchanger
- hot dry rock
- hydrogen sulfide
- magma
- mantle
- modular
- mud pot
- porous
- subducting
- tectonic plates
- wastewater
- working fluid

PEOPLE HAVE ALWAYS BEEN FASCINATED with volcanoes and their fiery displays of nature's power. Many ancient societies believed volcanoes were homes to temperamental gods or goddesses. Today science tells us that volcanoes result from the immense heat energy — geothermal energy — found in Earth's interior. This heat also causes hot springs, fumaroles (steam vents) and geysers.

Over the ages, humans have benefited from Earth's geothermal energy by using the hot water that naturally rises up to the earth's surface. We have soaked in hot springs for healing and relaxation and have even used them as instant cooking pots. Hot springs have also been an important part of cultural life and healthy lifestyles, especially in Japan and Europe.

Today we drill wells deep underground to bring hot water to the surface. We use the heat energy from this geothermal water to warm buildings, to speed the growth of plants and fish, and to dry lumber, fruits and vegetables. (See "Direct Use Geothermal," page 149.) We use the energy from the hottest water to generate electricity.

POWER SKETCH: Fine Neighbor

Set amidst the open vistas and forests of the eastern Sierra Nevada of California, a power plant churns out enough electricity for about 40,000 homes. The natural setting is not marred by smoky emissions, because there are none. This geothermal power plant uses hot water resources from an underground geothermal reservoir to power its turbine generators. Many tourists and residents of nearby Mammoth Lakes don't even notice that the power plant is right there beside the main highway.

Mammoth Lakes geothermal power plant

THE GEOTHERMAL RESOURCE

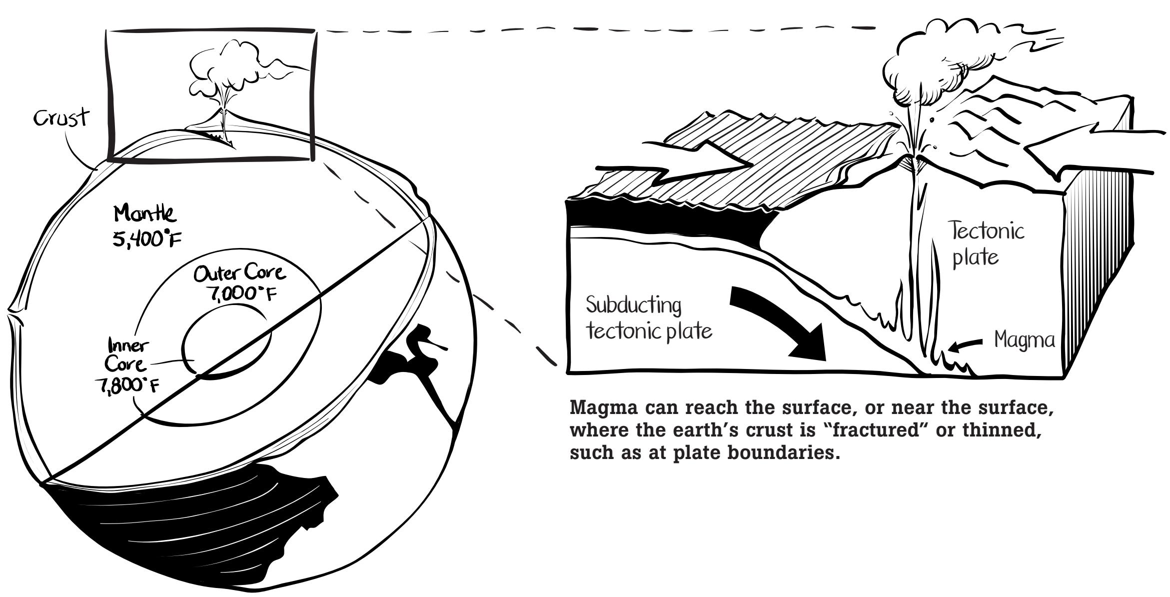
Geo means earth and *thermal* means heat. Geothermal energy is the earth's heat energy.

The Inner Earth: Hot, Hot, Hot!

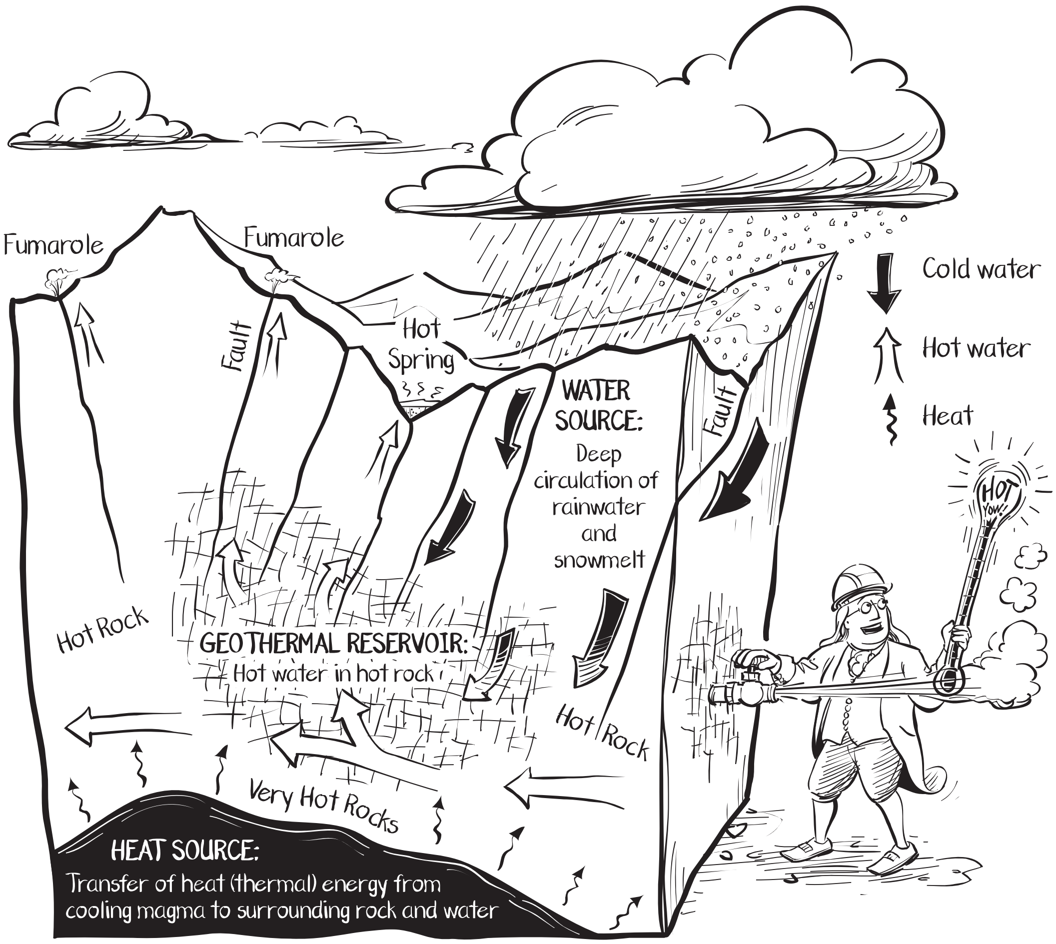
Billions of years ago our planet was a fiery ball of liquid and gas. As the earth cooled, an outer rocky crust formed over the hot interior, which remains hot to this day. This relatively thin crust "floats" on a massive underlying layer of very hot rock called the mantle. Some of the mantle rock is actually melted, or molten, forming magma.

The heat from the mantle continuously transfers up into the crust. Heat is also being generated in the crust by the natural decay, or breakdown, of radioactive elements found in most rocks.

The crust is broken into enormous slabs — tectonic plates — that are actually moving very slowly (about the rate your fingernails grow) over the mantle, separating from, crushing into, or sliding (subducting) under one another. The edges of these huge plates are often restless with volcanic and earthquake activity. (See "Hot Locations," page 56.) At these plate boundaries, and in other places where the crust is thinned or fractured, magma is closer to the surface. Sometimes magma emerges above ground — where we know it as lava. But most of it stays below ground where, over time, it creates large regions of very hot rock.



Magma can reach the surface, or near the surface, where the earth's crust is "fractured" or thinned, such as at plate boundaries.



A geothermal reservoir is a large underground area of hot permeable rock saturated with extremely hot water.

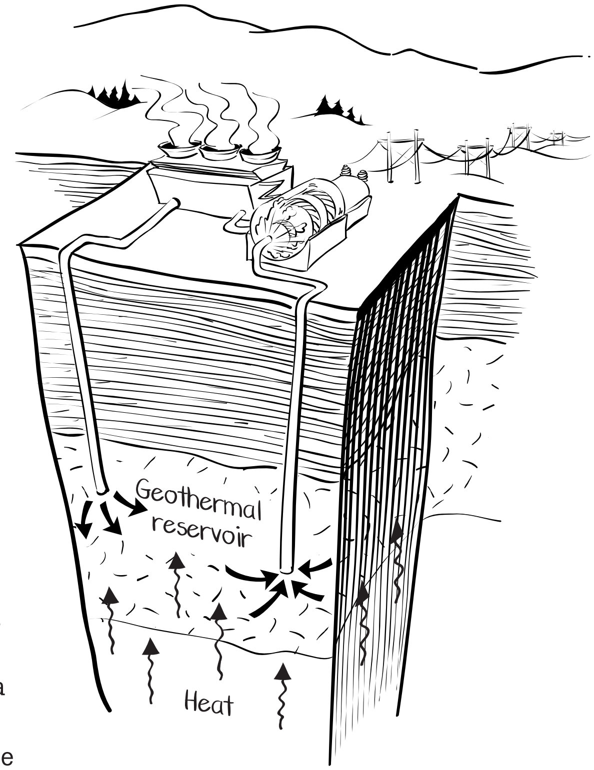
Geothermal Reservoirs: Earth's Natural Boilers

Rainwater and melted snow can seep miles below the surface, filling the pores and cracks of hot underground rock. This water can get really hot. It can reach temperatures of 500°F (260°C) or higher — well above the normal boiling point of 212°F (100°C).

Sometimes this hot water will work its way back up (hot water is less dense than cold and so tends to rise). If it reaches the surface it forms hot springs, fumaroles, mud pots, or geysers. If it gets trapped deep below the surface, it forms a "geothermal reservoir" of hot water and steam. A geothermal reservoir is an underground area of cracked and porous (permeable) hot rock saturated with hot water. The water and steam from these super hot reservoirs are the geothermal resources we use to generate electricity.

GENERATING ELECTRICITY FROM GEOTHERMAL RESOURCES

Geothermal reservoirs can be found from a few hundred feet deep to two miles or more below Earth's surface. To reach them, we drill wells and then insert steel pipe (casing). Now with an open passageway to the surface, the hot geothermal water or steam shoots up the well naturally or is pumped to the surface. From here it's piped into a geothermal power plant.

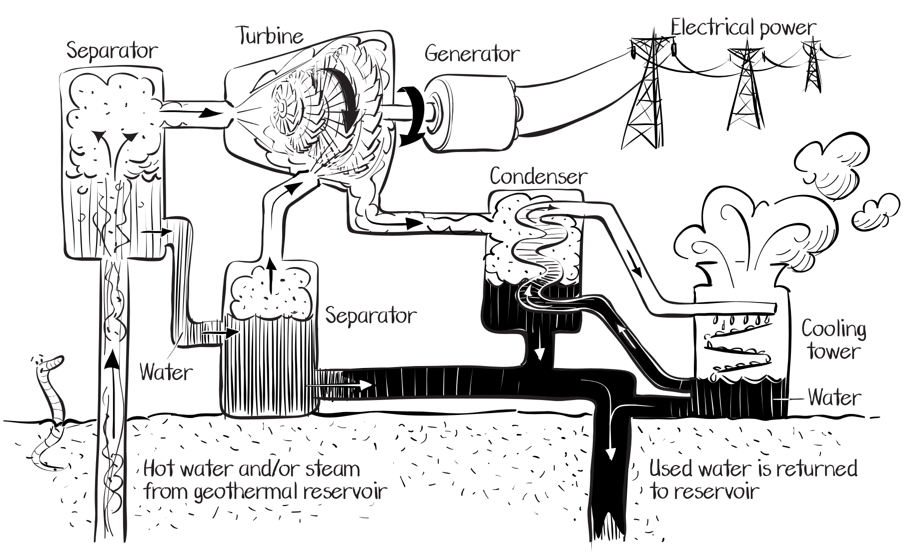


Hot water or steam from a geothermal reservoir shoots up a geothermal well, spins the turbine-generator, and is returned to the reservoir.

Geothermal Power Plants

There are different kinds of geothermal power plants, because there are different kinds of geothermal reservoirs.

Flash Steam Power Plants. Flash steam plants use really hot geothermal reservoirs of about 350°F (177°C) or higher. From the well, high-pressure hot water rushes through pipes into a "separator," where the pressure is reduced. This causes some of the water to vaporize vigorously ("flash") to steam, the force that drives the turbine-generators. After the steam does its work, it is condensed back into water and piped back down into the geothermal reservoir so it can be reheated and reused. Most geothermal power plants in the world today are flash plants.

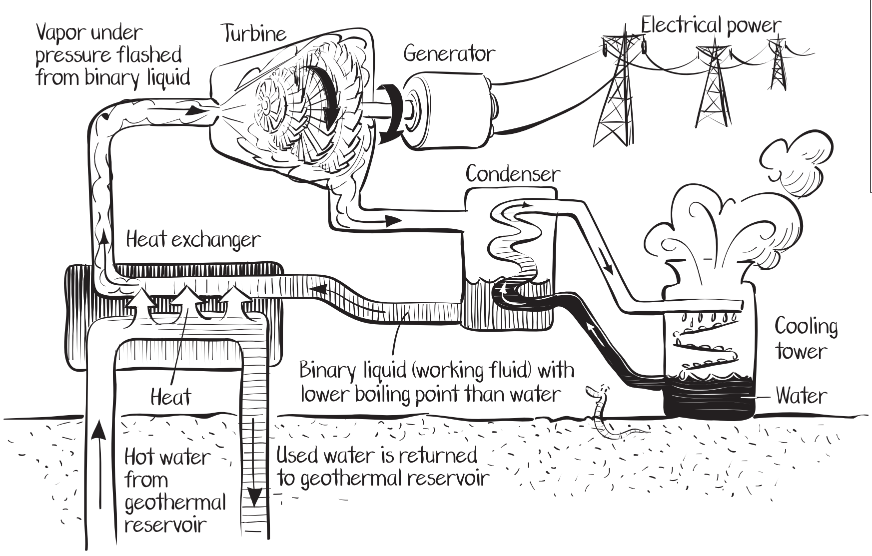


Flash steam plants can include one steam/water separator or, more commonly, two separators (shown here).

Dry Steam Power Plants. Very few geothermal reservoirs are filled naturally with steam, not water. This means that the wells will produce only steam. The power plants that run on this steam are called "dry steam" power plants. Here, the steam blasts right into the turbine blades (they do not need separators), then is condensed to water and piped back into the reservoir. Though dry steam reservoirs are rare, they have been important to the development of geothermal power, especially in California, Italy, and Japan.

Binary Power Plants. In some geothermal reservoirs, the water is hot (usually over 200° F, or 93°C), but not hot enough to produce steam with the force needed to turn a turbine-generator efficiently. Fortunately, we can generate electricity from these "moderate temperature" reservoirs using binary power plants. Moderate-temperature reservoirs are more common than high-temperature reservoirs, so the use of binary power plants is expanding worldwide.

In the binary process, the geothermal water is used only to heat a second liquid. After passing through a heat exchanger, the geothermal water is pumped right back into the reservoir. It is that second "working fluid" that flashes to vapor and drives the turbine. (See sidebar.)



Binary power plant

HEAT EXCHANGERS

Heat exchangers are used in electricity generation when the heat source is hot, but not quite hot enough to bring water to a boil to create forceful steam.

A heat exchanger transfers heat (thermal energy) from a hotter liquid to a cooler one by conduction. The heat is conducted from the first (hotter) liquid into the second liquid (the "working fluid") through metal pipes or plates that keep the two liquids separated.

The second liquid is usually one with a lower boiling point than water, so it vaporizes, or "flashes" to vapor, at a lower temperature than does water. Sometimes, such as in certain solar thermal power plants, where the first liquid is oil or another material, the second liquid can be water.

The force of the rapidly expanding vapor or steam spins the turbine blades that drive a generator. The vapor or steam can then be condensed back to a liquid and used over and over again.

All Shapes and Sizes

Geothermal power plants come small (200 kW to 10 MW), medium (10 MW to 50 MW), and large (50 MW to 100 MW and larger). A geothermal power plant usually consists of two or more turbine-generator "modules" in one plant. Extra modules can be added as more power is needed.

Binary plants are especially versatile because they can use relatively low reservoir temperatures. Small binary modules can be built quickly and transported easily. These little power plants are great for use in remote parts of the world, far from transmission lines. One interesting plant is installed in the rugged mountains of Tibet (People's Republic of China). At a soaring 14,850 feet (4,526 meters), it is the highest geothermal power plant in the world.

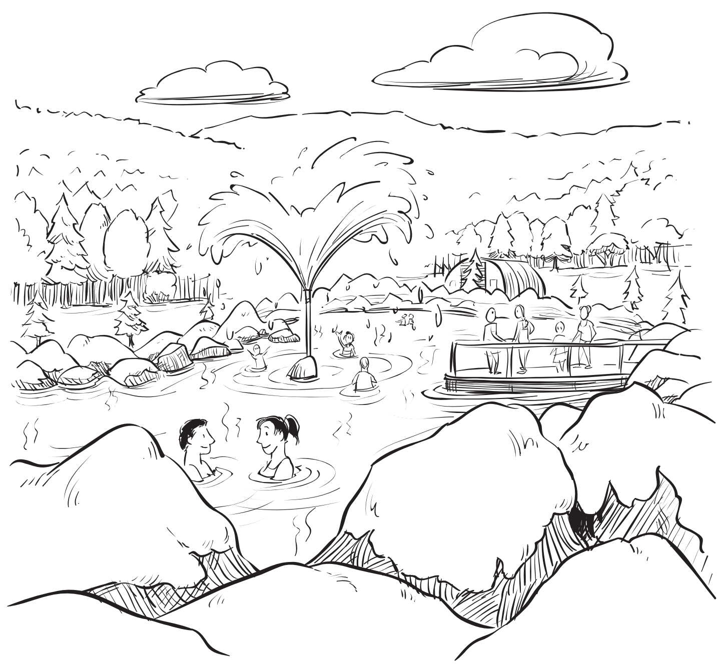
Small binary plants are also popular in sometimes remote hot spring spas and health resorts. They add the convenience of electricity while maintaining an environmental and healthful appeal.

REMINDER

W = watt
kW = kilowatt = 1,000 watts
MW = megawatt = 1,000 kilowatts
1 megawatt can serve about 1,000 homes in the United States.

HOT TIMES IN ALASKA!

Chena Hot Springs Resort has found an answer to high energy demands by tapping into the local geothermal resource. Chena is just east of Fairbanks — only 150 miles south of the Arctic Circle. Winters are extremely cold, with temperatures dropping to -50ºF and colder. This means a LOT of energy is required for heating as well as for electricity. Chena is using a small binary power plant to generate 400 kW of geothermal power with a resource that's only 165ºF — the lowest geothermal temperature ever used for making electricity. The resort is also using geothermal water to make ice, heat buildings and greenhouses, and — of course — for the natural hot springs pools that make Chena famous.



Geothermal at Work Around the Globe

So far, the U.S. produces more electricity from geothermal energy than does any other country. Six states now have geothermal power plants. California has the most, followed by Nevada, Utah, Hawaii, Idaho, Alaska, Oregon, Wyoming, and New Mexico. More are planned in these states and are also being considered in Arizona, Colorado, Florida, Louisiana, Mississippi, and Washington.

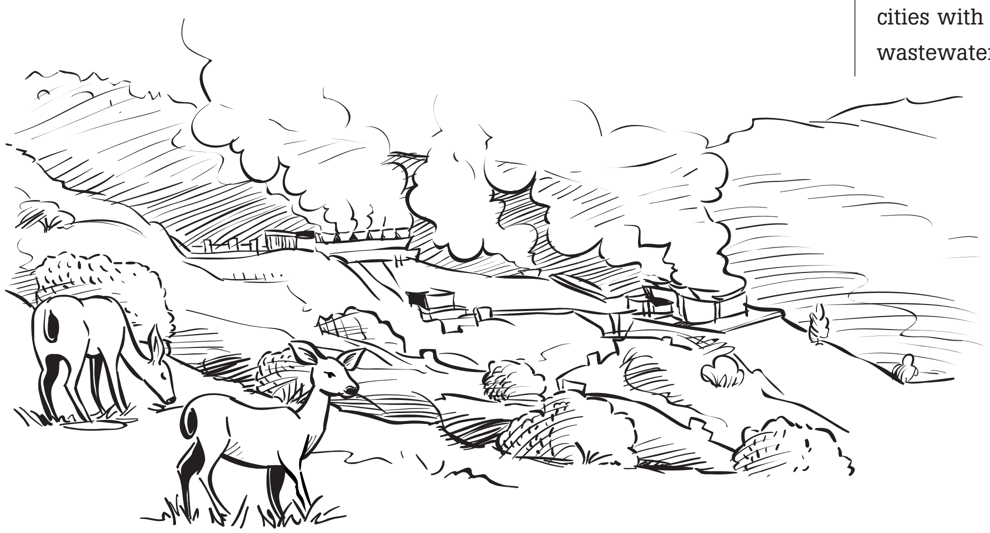
U.S. geothermal power plant types vary widely. One little 300 kW geothermal powerhouse in northern California runs all by itself and automatically radios an operator when it needs maintenance. At one of Nevada's geothermal plants, the heat from geothermal water is used to dry onions and garlic before it is injected back into the reservoir. Hawaii's geothermal plants provide about 20 percent of the electricity used on the Big Island. And the world's largest single geothermal power plant, 185 MW, is nearing construction near southern California's Salton Sea.

The Philippines and Indonesia have abundant geothermal resources. Geothermal generates about one-fourth of the electricity in the Philippines, making this country the second largest user of geothermal electricity in the world (after the United States). Italy was the site of the first geothermal power development. Its beautiful dry steam field of Larderello, developed in 1904, is still generating electricity today. Other places with large geothermal power developments include Mexico, Iceland, New Zealand, Japan, and several Central American countries.

"THE GEYSERS"

A geothermal field in northern California is named "The Geysers" (though it has no geysers — only fumaroles). It once was the site of a famous resort — attracting hardy travelers the likes of Jack London and Teddy Roosevelt. Today it is the world's largest single source of geothermal electrical power. Even its reservoir is rare, being one of the few in the world that produce steam (rather than mostly water). After over 50 years, The Geysers' 21 power plants still reliably generate enough electricity to power a city the size of San Francisco — about 900 MW.

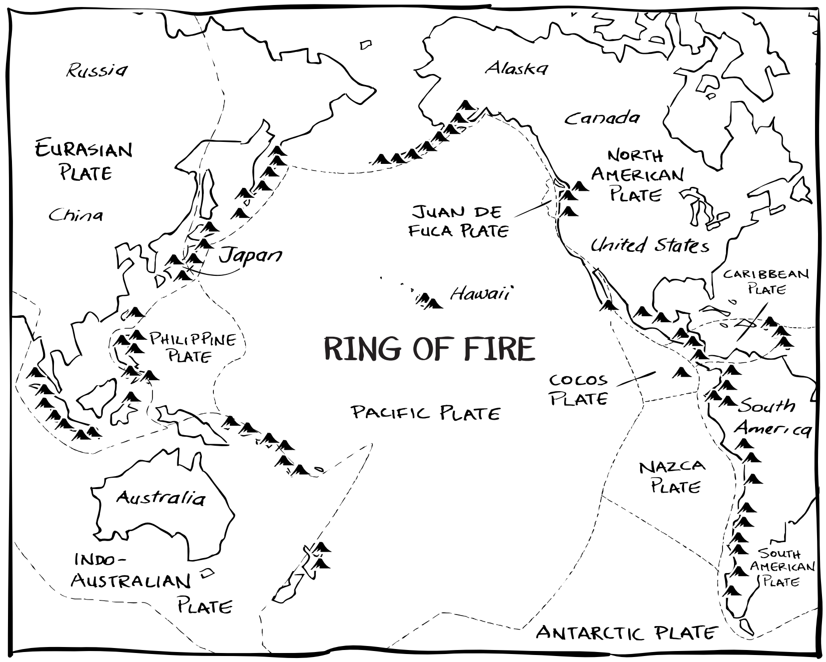
To top it off, cities in Lake and Sonoma Counties are piping their cleaned wastewater many miles to The Geysers and injecting it deep into the geothermal reservoir. This practice helps sustain the productive life of the reservoir for electicity production while providing nearby cities with environmentally safe wastewater disposal.



Geothermal power plants at The Geysers in California

HOT LOCATIONS

The edges of the continents that surround the Pacific Ocean (the Pacific "Ring of Fire") are prone to earthquakes and volcanoes and have some of the best geothermal resources in the world. This includes the western part of North, Central, and South America; New Zealand; Indonesia; the Philippines; Japan; and Kamchatka (eastern Russia). These countries all have coastlines that sit on or near the boundaries of tectonic plates. Some of the other prime geothermal locations include Iceland, Italy, the Rift Valley of Africa, and Hawaii.



This map shows the edges of the tectonic plates (they all have names) that form the "Ring of Fire." Most countries in this area have lots of geothermal energy.

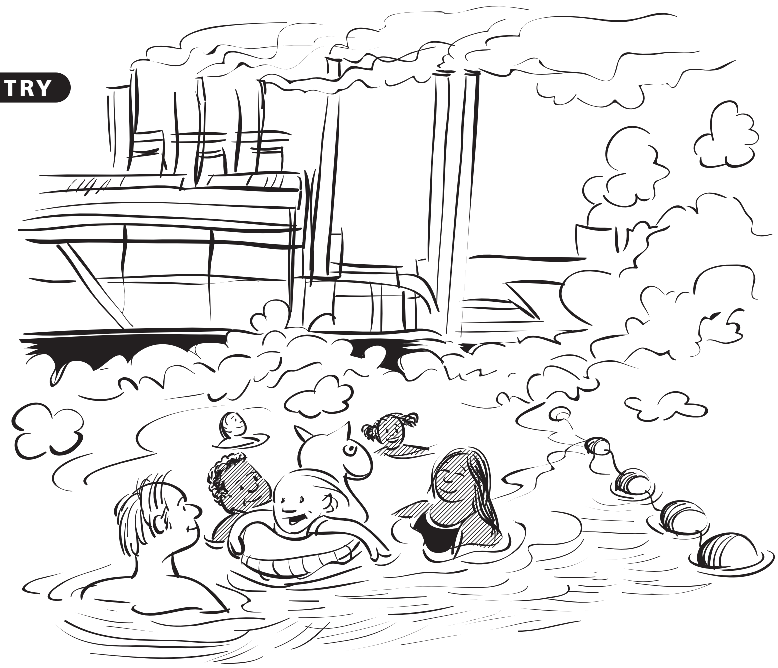
Enhanced Geothermal Systems: New Energy from "Engineered" Reservoirs

There are many places underground where the rock is really hot but doesn't naturally contain much water. Researchers are working on ways to pump water down into this hot rock, creating "engineered" geothermal reservoirs. Called "enhanced geothermal systems" (EGS) or (less often) "hot dry rock," this method involves drilling a well into the hot rock and injecting high-pressure cold water to expand natural cracks (fractures) or to make new ones. Then more water is pumped down into the fractured rock. The heat from the rock transfers to the water, and the now-hot water is pumped up a separate well to generate electricity in a binary power plant.

A U.S. project at Los Alamos, New Mexico, first demonstrated that EGS can work. Japan, France, Germany, Switzerland, Australia, and other countries are also working on this method. In the United States and elsewhere, similar processes are being adapted to boost the production of already-developed natural geothermal reservoirs.

HOT ENERGY FOR A COLD COUNTRY

Iceland is such an active geothermal area that hot springs occasionally bubble up right into people's living rooms! People in this cool-weather country make really good use of their abundant geothermal energy resource. They use it for everything from heating homes, offices, and greenhouses to warming swimming pools and generating electricity. In the middle of winter, it is not uncommon to see people soaking in the steamy hot pool found right outside a geothermal power plant.



Some spas in Iceland are located right next to geothermal power plants.

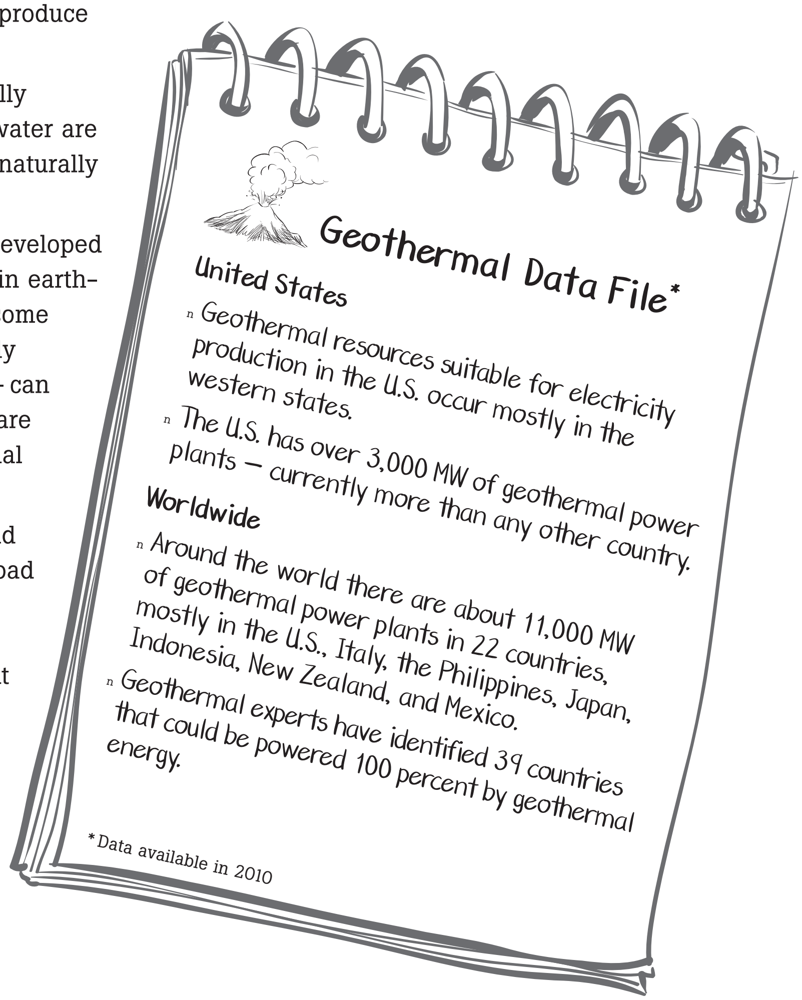
CONSIDERATIONS

- Geothermal power plants produce no smoke. What comes out the top of a geothermal plant cooling tower is steam (water vapor) with only trace amounts of natural minerals and gases from the geothermal reservoir. Flash and dry steam plants produce only a small fraction of air emissions compared to fossil fuel plants. (See page 135.) Binary power plants have virtually no emissions.
- Geothermal power plants use very little land compared to conventional energy resources and can share the land with wildlife or grazing herds of cattle. They operate successfully and safely in sensitive habitats, in the midst of crops, and in forested recreation areas. However, they must be built at the site of the geothermal reservoir, so there is not much flexibility in choosing a plant location. Some locales may also have competing recreational or other uses.
- Geothermal wells are sealed with steel casing, cemented to the sides of the well along their length. The casing protects shallow, cold groundwater aquifers from mixing with the deeper geothermal reservoir waters. This way the cold groundwater doesn't get into the hot geothermal reservoir and the geothermal water doesn't mix with potential sources of drinking water.

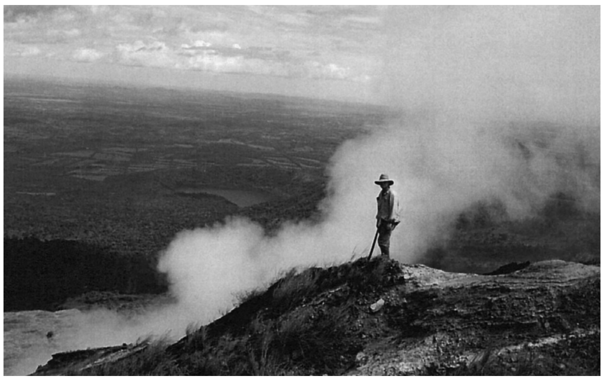
(continued)

CONSIDERATIONS (continued)

- Geothermal water contains varying concentrations of dissolved minerals and salts. Sometimes the minerals are extracted and put to good use. Examples are zinc (for electronics and for making alloys such as bronze and brass) and silica. At reservoirs with higher concentrations, advanced geothermal technology keeps the salty, mineralized water from clogging and corroding power plant equipment.
- Most geothermal reservoirs contain varying amounts of dissolved gases such as hydrogen sulfide. This gas smells bad (like rotten eggs), even at very low concentrations, and is toxic at high concentrations. Modern geothermal technology ensures that geothermal power plants capture these gases before they go into the air. Some gas removal processes can produce sulfur for use in fertilizers.
- Geothermal reservoirs must be carefully managed so that the steam and hot water are produced no faster than they can be naturally replenished or supplemented.
- Geothermal resources are generally developed in areas of high seismic activity, i.e., in earthquake country. Critics point out that some geothermal development — particularly with enhanced geothermal systems — can cause small earthquakes. Regulators are examining this issue where geothermal projects are near residential areas.
- Geothermal power plants run day and night, so they provide reliable baseload electricity. Most can increase their output of electricity to provide more power at times of greater demand. But geothermal power plants can't be used exclusively for peaking power; if geothermal wells were turned off and on repeatedly, expansion and contraction (caused by heating and cooling) would damage the wells.



Creating Electricity from Geothermal Resources



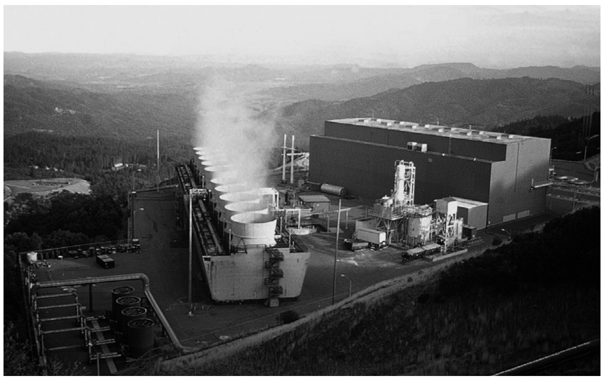
Finding Geothermal Resources
Abundant geothermal resources occur in the countries bordering the Pacific — the "Ring of Fire." Geologists explore volcanic regions like this steaming hillside in El Hoyo, Nicaragua, and other regions of the world where resources can occur even with no volcanoes or other surface evidence. *(Photo courtesy of Trans-Pacific Geothermal Corporation)*

Getting to the Geothermal Reservoir
If geologists find encouraging signs of deep heat, wells will be drilled. Drill rigs can be small water-well truck-mounted rigs, or large drill rigs like these, erected onsite. Geothermal wells can be drilled over two miles deep. *(Photo courtesy of Geothermal Education Office, Tiburon, CA)*

Testing a Geothermal Well
If a geothermal reservoir is discovered, the well is flow-tested to determine the pressure, temperature, and chemistry of the reservoir. Large "separators" can be used to safely control the hot steam, such as for this well test at the Blue Mountain power project in Nevada. *(Photo courtesy of Nevada Geothermal Power, Vancouver, Canada)*

Power Around the Clock
This turbine generator works fine outdoors at a geothermal project in California's Imperial Valley. Geothermal power plants provide baseload power, so these turbine generators operate 24 hours a day. *(Photo courtesy of Geothermal Education Office, Tiburon, CA)*

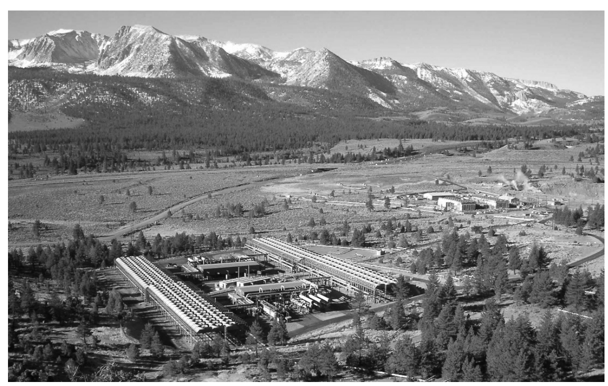
Creating Electricity from Geothermal Resources



World-Record Power
The Geysers steam field in northern California is the largest producing geothermal development in the world, with 21 power plants. Those white plumes you see are steam (water vapor); geothermal plants do not burn fuel or produce smoke. *(Photo courtesy of Calpine Corporation, San Jose, CA)*

Geothermal Plumbing
This flash steam plant is in East Mesa, California. Geothermal flash technology was invented in New Zealand. You can see the huge pipes bringing hot water and steam to the power plant, where it spins turbine generators. The used water is returned to the reservoir. *(Photo courtesy of Geothermal Education Office, Tiburon, CA)*

Compact Model
This small binary power plant is in Fang, Thailand. By using a heat exchanger, binary technology creates electricity from lower temperature reservoirs. Worldwide, developers are working on ways to produce power at ever lower temperatures.
(Photo courtesy of Geo-Heat Center, Oregon Institute of Technology)



Generation without Emissions
This air-cooled binary geothermal power plant nestles in the mountains at Mammoth Lakes, California. It is emission-free and consumes no water or chemicals. *(Photo courtesy of Ormat Technologies, Inc., Reno, NV)*