Geothermal Energy

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For the Teacher

Deep inside the Earth, at depths near 150 kilometers, the temperature and pressure is sufficient to melt rock into magma. As it becomes less dense, the magma begins to flow toward the surface. Once it breaks through the crust it is referred to as lava. Lava is extremely hot; up to 1,250 °C. Average lava temperatures are about 750°C. A normal household oven only reaches temperatures near 260°C (500°F)!

The rock located just above the magma is also very hot but remains solid. What if we could harness this thermal energy and use it to generate electricity or heat homes and businesses? We would have a domestic, clean, and nearly inexhaustible energy supply. Geothermal energy is one of the components of the National Energy Policy: "Reliable, Affordable, and Environmentally Sound Energy for America's Future", (pg. 6-5).

Our ancient ancestors knew about this free and reliable energy. They bathed and prepared food in hot springs and many cultures considered geysers and other surface geothermal features as sacred places. Today, due to the explorations and calculations of many scientists and engineers, we've realized that only 1% of the geothermal energy contained in the uppermost ten kilometers of the Earth's crust is 500 times that contained in all the oil and gas resources of the world! The next step is designing technology that can harness this immense, renewable, and low to no - emission energy reservoir.

Geothermal energy can be usefully extracted from four different types of geologic formations. These include hydrothermal, geopressurized, hot dry rock, and magma.

Hydrothermal reservoirs have been the most common source of geothermal energy production worldwide. They contain hot water and/or steam trapped in fractured or porous rock formations by a layer of impermeable rock on top. Hydrothermal fluids can be used directly to heat buildings, greenhouses, and swimming pools, or they can be used to produce steam for electrical power generation. These power plants typically operate with fluid temperatures greater than 130^{o}C.

Geopressurized resources are from formations where moderately high temperature brines are trapped in a permeable layer of rock under high pressures. These brines are found deeper underground than hydrothermal fluids and have high concentrations of salt, minerals, and dissolved methane gas. In addition to producing steam for electrical power generation, minerals can be extracted from brines and used as supplementary revenue for a power plant. This process is known as co-production.

Hot dry rock reservoirs are generally hot impermeable rocks at depths shallow enough to be accessible

(<3,000 m). Although hot dry rock resources are virtually unlimited in magnitude around the world, only those at shallow depths are currently economical. To extract heat from such formations, the rock must be fractured and a fluid circulation system developed. This is known as an enhanced geothermal system (EGS). The water is then heated by way of conduction as the it passes through the fractures in the rock, thus becoming a hydrothermal fluid.

The final source of geothermal energy is magma, which is partially molten rock. Molten rock is the largest global geothermal resource and is found at depths below 3-10km. Its great depth and high temperature (between 700°C and 1200°C) make the resource difficult to access and harness. Thus, technology to use magma resources is not well developed.

Geothermal power is already an important energy resource for our nation and the world. Hydrothermal plants in the western states now provide about 2,500 megawatts of constant, reliable electricity, which meets the residential power needs for a city of 6 million people. Over 8,000 megawatts are currently being produced worldwide.

A variety of industries, including food processing, aquaculture farming, lumber drying, and greenhouse operations, now benefit from direct geothermal heating. The alligators in the following picture are grown in geothermally heated water in Idaho.

Hydrothermal systems also provide district heating. District systems distribute hydrothermal fluid from one or more geothermal wells through a series of pipes to several individual houses and buildings, or blocks of buildings.

National Science Education Standards by the National Academy of Sciences

Science Content Standards: Grades 6-8

Science As Inquiry

- **Content Standard A:**
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry

Physical Science

- **Content Standard B:**
  - Properties and changes of properties in matter
  - Motions and Forces
  - Transfer of energy

Earth and Space Science

- **Content Standard D:**
  - Structure of the Earth System

Science and Technology

- **Content Standard E:**
  - Abilities of technological design
  - Understandings about science and technology

Science in Personal and Social Perspectives

- **Content Standard F:**
  - Populations, Resources, and Environments
  - Science and technology in society

History and Nature of Science

- **Content Standard G:**
  - Science as a human endeavor
  - Nature of science

Technology Description

Exploration and Drilling

Many scientists, including geologists and hydrologists, chemical and civil engineers, and expert drilling technicians come together to collect and analyze information on the characteristics of a potential geothermal resource site. Sites are evaluated based on three primary criteria: heat content, fluid content, and permeability of the rock.

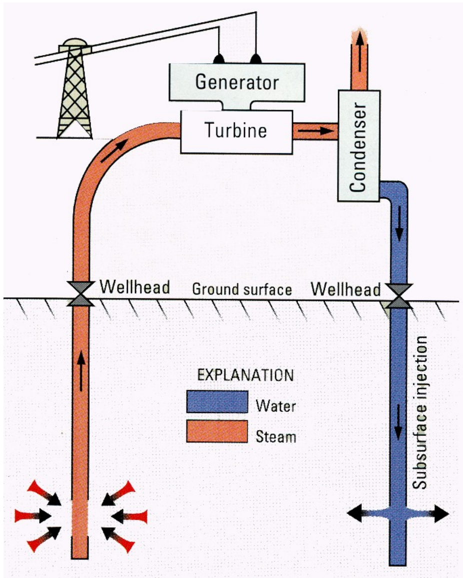
Fortunately for geothermal explorers, hundreds of thousands of test holes have already been drilled all over the world by oil and gas companies. Researchers are able to use data from these deep wells to obtain information about the thermal energy in the area. These holes can also provide a way to use structural methods such as seismicity, gravity, and magnetic surveys to help determine the permeability beneath the surface. Electrical resistivity surveys can show how electricity flows through the rock and fluid beneath the surface and can help determine amount of available hydrothermal fluid.

Once a site is identified as having geothermal potential, more exploratory wells are drilled and more data is collected and analyzed. Only after extensive checking and rechecking is a site recommended for development as one of the following energy conversion systems.

Energy Conversion

The technology used to convert geothermal energy into forms usable for human consumption can be categorized into four groups. The first three: dry steam, flash steam, and binary cycle, typically use the hydrothermal fluid, pressurized brine, or EGS resources to generate electricity. The fourth type, direct use, requires only hydrothermal fluid, typically at lower temperatures, for direct use in heating buildings and other structures. The addition of a small-scale electric heat pump into the system allows the use of low temperature geothermal energy in residences and commercial buildings.

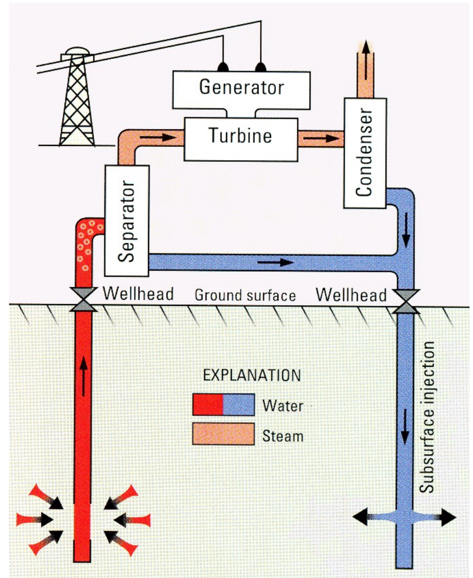
Dry Steam Power Plants



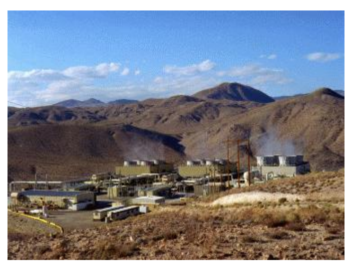
These were the first type of geothermal power plants to be built. The technology was first used at Lardarello, Italy, in 1904, and is still very effective for generating electricity. The plant uses steam that is accessed by drilling directly into the underground source. The steam is piped through a turbine and generator unit, and then condensed back into water and injected back into the subsurface reservoir. This helps to extend the life of the system. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal power. The emissions from this group of

plants consist of excess steam and very small amounts of sulfur dioxide, hydrogen sulfide, and carbon dioxide. Because there is no combustion taking place, the levels of these gasses are much lower than emissions from fossil fuel fired power plants.

Flash Steam Power Plants

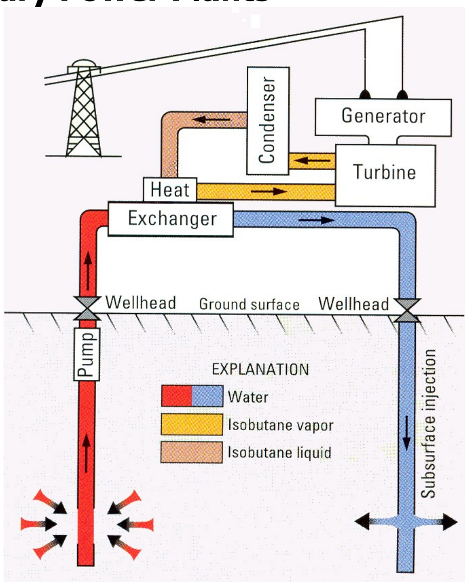


In these power plants, hydrothermal fluid at temperatures greater than 360°C is pushed to the surface by the high pressure in the subsurface reservoir. As this very hot fluid reaches the surface, it enters the separator where the pressure drops instantaneously and most of the liquid flashes into steam. The force generated by the steam is used to drive turbines and produce electricity. The fluid not flashed into steam leaves the separator and rejoins the water from the condenser. The fluid is then

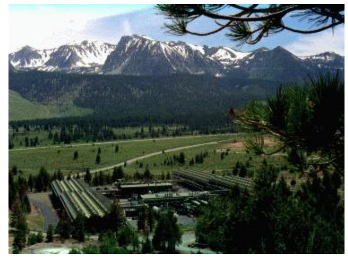


injected back into the Earth so that the process can be renewed over and over again. An example of an area using a flash steam operation is the CalEnergy Navy I flash geothermal power plant at the Coso geothermal field.

Binary Power Plants



These are different from dry steam or flash steam power plants in that the hydrothermal fluid from the subsurface reservoir never comes into contact with the turbine/generator units. In this two-step process, hydrothermal fluid that is not quite hot enough to be used in a flash steam plant is fed into a heat exchanger. Here, heat is transferred from the hydrothermal fluid to a "working liquid" with a lower boiling point than water (usually isobutane or isopentane). The working liquid turns into an energized vapor much like the steam in the flash power plant and turns the turbine/generator unit, producing electricity. The hydrothermal fluid and the working liquid are both contained in "closed loops" and never come in contact with each another. The vapor from the working liquid is condensed and the hydrothermal fluid is returned to the earth. This cycle can be repeated as quickly as the Earth can reheat the fluid. An example of an area using a Binary Cycle power generation system is the Mammoth Pacific binary geothermal power plants at the Casa Diablo

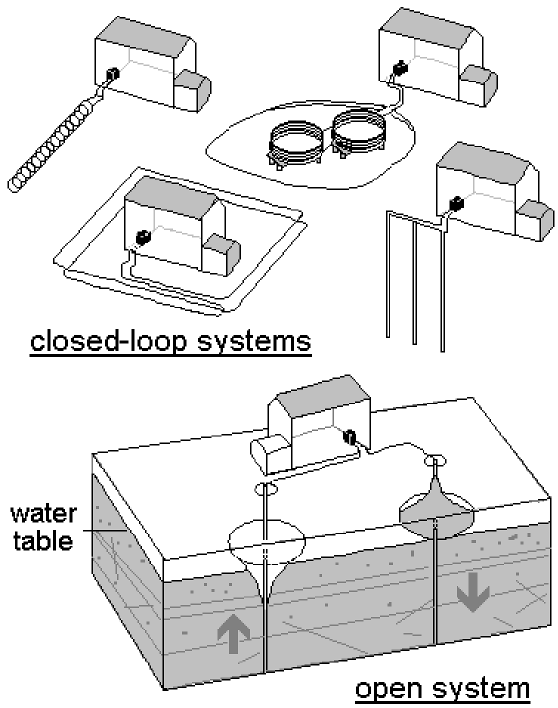


geothermal field. Because warm hydrothermal fluid is a more widespread resource than hot fluid or pressurized brines, binary systems have the potential to make a significant contribution to the overall production of geothermally generated electricity.

Direct use of hot water from geothermal resources can be used to provide heat for industrial processes, crop drying, or heating buildings. In this method, the hot fluid is pumped

directly into a building's hot water-based heating system, under sidewalks, or into pools. The city of Klamath Falls, Oregon, is located in an area of abundant near-surface hydrothermal fluid at the southern part of the Cascade Range. The Oregon Institute of Technology is actually heated by this direct-use system. Sidewalks in the area have tubes buried beneath them so as to prevent the buildup of snow and ice in the winter. Other examples of direct use geothermal resources exist across the entire western United States including the Capitol Mall in Boise, Idaho. Here, the city's geothermal district heating system heats even the Idaho State Capitol Building. Geothermal water is also used by local industries in greenhouses, at fish farms, and by dairies.

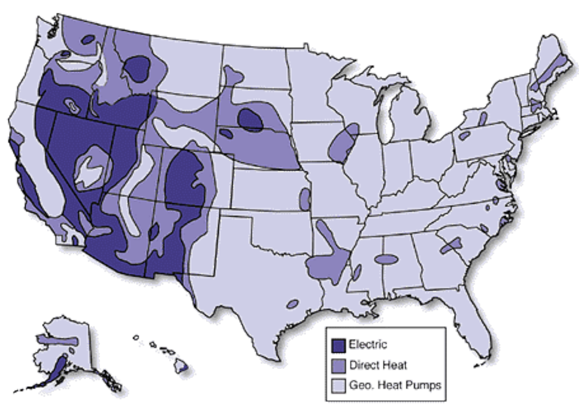
Geothermal Heat Pumps



Also called ground source heat pumps, these systems can be used for heating and cooling buildings virtually anywhere, especially in regions where the geothermal potential is low. The internal heat energy of the Earth and the insulation from surface rocks and soils keep the subsurface at a near constant temperature of about 55 °F (13 °C). Wells are drilled to access the ground water at this temperature, and two types of systems can be employed. An open loop system simply pulls water up, runs it through the heat pump to add heat in the summer, and remove heat in the winter, and then recycles it back into the aquifer. A closed-loop system has the same function, except a loop of tubing is buried underground and filled with fluid, usually antifreeze. These systems work well in areas with moderate climates. Supplemental heating and cooling systems are required in more extreme areas. Some consumer resistance to geothermal heat pumps does exist due to the high initial purchase and installation cost. However, all geothermal heat pumps eventually provide savings on normal utility bills, some in as little as 3 or 4 years.

Overall US Geothermal Potential

The sources and functions of various types of geothermal power vary across the nation. The map below shows that this energy can be tapped and harnessed virtually anywhere in the United States. Current research is focusing on increasing efficiency of current technologies, and expanding the use of this resource into new applications.



Useful sources of information about geothermal energy resources include:

Web Resources:

Geothermal Education Office
http://geothermal.marin.org

Geothermal Technologies Program
http://www.eren.doe.gov/geothermal

Geo-Heat Center
http://geoheat.oit.edu

Idaho National Engineering and Environmental Laboratory
http://geothermal.id.doe.gov

National Renewable Energy Laboratory
http://www.nrel.gov/geothermal

Sandia National Laboratory
http://www.sandia.gov/geothermal

United States Department of Energy, *GeoPowering The West*
http://www.eere.energy.gov/geothermal/deployment_gpw.html

Books:

Cataldi, R. *Stories from a Heated Earth, Our Geothermal Heritage.* Sacramento, CA: Geothermal Resources Council, 1999.

Dickson, M. H. *Geothermal Energy.* West Sussex, England: John Wiley & Sons Ltd., 1995.

Edwards, L. M. *Handbook of Geothermal Energy.* Gulf Publishing Company, 1982.

Elder, J. *Geothermal Systems.* New York, New York: Academic Press, 1981.

Magazines, Handouts, etc:

Duffield, W. A. *Geothermal Energy – Clean Power From the Earth's Heat.* Reston, Virginia: United States Geological Survey, 2003

Geothermal Today. Washington, DC: United States Department of Energy, 2004

Resources for Following Projects:

Calorimeter
Calorimeter, Student Double Walled, Science Kit, #WW6097200, $29.95 (http://www.sciencekit.com)

Thermometers
Plastic-back high range thermometers (-30 to 110 °C), alcohol-filled. Science Kit #WW4600701, $1.95 (http://www.sciencekit.com)

Uncoated Nails
40d or larger nails from a local hardware store. Many stores carry both steel and aluminum nails. These will need to be bent into a U shape before the activity.

Heat Transfer Kit
This kit contains Styrofoam cups, lids, thermometers, and an aluminum heat transfer bar. Sargent Welch #WL6819R, $16.50, pkg. of 5 $82.50

Other possible science supply companies include:

Carolina Biological- www.carolina.com
Frey Scientific – www.freyscientific.com

Project Ideas

1 What factors affect the heat transfer from rock to water?

Learning Objective: The students will know and understand that heat flow is a function of the heat capacities of the substances involved in the transfer as well as the substances' starting temperatures.

Controls and Variables: type of rock, mass of rock and water, starting temperatures of rock and water, time

Materials and Equipment: Styrofoam cups with lids OR calorimeters, thermometers, water at room temperature, small samples of various types of rocks (*i.e.* granite, basalt, sandstone, gneiss), mass balance, boiling water bath OR incubator to heat rocks, tongs, graduated cylinders

Safety and Environmental Requirements: *Caution should be used when handling hot materials.*

Suggestions:
Rock samples should be heated to a constant temperature, then placed into water of known temperature in the calorimeter or cup. From here, the students can measure the total energy change or the rate of energy transfer, compare rock samples or masses of the same rock, or even substitute different metals or household materials.

2 How is energy transferred between fluids in a binary geothermal power plant?

Learning Objective: The students will know and understand that conduction can transfer thermal energy from one liquid to another.

Controls and Variables: container size, volume of liquid, temperature of liquid, type of liquid, time, material of transfer bar or nail

Materials and Equipment: Heat transfer kit OR Styrofoam cups w/ lids, large nails (bent into U shape), and thermometers; water at various temperatures, other liquids (alcohol), graduated cylinders

Safety and Environmental Requirements: *Caution should be* *used when handling hot materials. Alcohol is volatile and should be kept away from any heat source.*

Suggestions: Students can select from the many different variables in this experiment. For example, they can determine the effects of large volumes of liquid on smaller volumes or vary starting temperatures of liquids. They can also experiment with nails or transfer bars made from different metals and/or liquids with different boiling points.

3 How does salinity affect the boiling point of water?

Learning Objective: The students will know and understand that the concentration of solutes in a solution will affect the boiling point of the liquid.

Controls and Variables: type of liquid, volume of liquid, amount of solute, type of salt, boiling point of solution

Materials and Equipment:
hot plate, beakers, high range thermometers, water or other liquids, sodium chloride or other salt, mass balance, graduated cylinders

Safety and Environmental Requirements: *As with all experiments that involve heating and pressure you will need to wear eye protection and heat insulating gloves.*

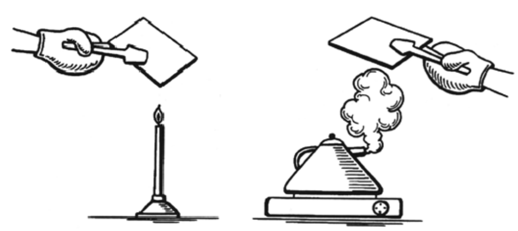
Suggestions: Students can select from many different variables in this experiment. For example, they can determine how the same salt affects the boiling point of different liquids, or how different salts affect the boiling point of water.

4 How do the emissions from a geothermal power plant compare to those from a fossil fuel power plant?

Learning Objective: The students will know and understand that the combustion products from fossil fuel power plants contain particulates (soot) and contribute to air pollution, while the major emission from a geothermal power plant is clean water.

Controls and Variables: fuel source, time, mass of particulates, mass of fuel source

Materials and Equipment:
combustible materials such as candles, Sterno cans, Bunsen burners, charcoal, and wood chips; matches, small pie tins for burning materials, hot plate, teapot, water, small mirror, tongs, oven mitts, 0.01 gram mass balance



Safety and Environmental Requirements: *Caution should be used when handling hot materials, especially the mirror. Fuels are combustible and should be kept contained while burning. When using the Bunsen burner, be sure to keep the mirror high above the flame.*

Suggestions: Students can use multiple fuel sources to determine the amount of particulates produced by each source.

5 How does the size and number of turbine blades and steam jets affect the performance of a model dry steam power plant?

Learning Objective: The students will know and understand that the thermal energy in steam, when coupled with a turbine, can be converted to mechanical energy that can be used to generate electricity.

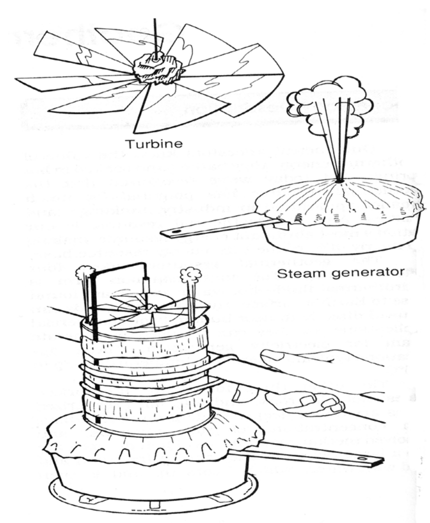
Controls and Variables: size and configuration of turbine, size of holes in bottom of can, number of holes, spacing of holes, speed of turbine

Materials and Equipment: aluminum pie tins (8”), aluminum foil, empty soup or coffee can, 20 cm length of stiff wire or coat hanger, cork, medium cooking pot, hot plate, duct tape, pliers with wire cutter, scissors

Safety and Environmental Requirements: *As with all experiments that involve heating and pressure you will need to wear eye protection and heat insulating gloves. Exercise caution with working with sharp edges of soup or coffee can and pie tin.*

Suggestions: Students can experiment with different sizes and configurations of holes for the steam to pass through. They can also change the configuration of the turbine blades to produce more or less angle or change the diameter of the turbine. The speed of the turbine can be calculated by putting a mark on one edge of the turbine and counting how many revolutions it makes in a specific amount of time.

How to Construct the Model Turbine: Half - fill a medium sauce pan with water and cap it with a secure layer of aluminum foil. Be sure to wrap the edges under the lip of the pan to minimize steam escape. Punch a hole about half the diameter of the coffee or soup can in the middle of the foil.
Cut a hole in the center of a pie plate with the same diameter as the foil. Place this over the foil to provide support for the soup can. This is the steam generator.
Construct a turbine from an aluminum pie pan, making sure that the turbine is smaller in diameter than the can. Bend the stiff wire into a hanger for the turbine and duct tape it to the side of the can, bottom side up. Push the cork onto the end of the hanger. Pierce the exact center of the turbine with a straight pin, then push the straight pin into the bottom of the cork to suspend the turbine over the can. The turbine should hang relatively horizontal and spin freely.



More Project Ideas

What affect does water or steam pressure have on geothermal energy production?

How does the salinity and temperature of hydrothermal fluid affect the metals and/or plastics that are used in construction of a power plant?

What are the social and economic implications of putting a power plant near a hot spring, which are often developed at tourist areas?

What type of geothermal system would be most appropriate for your state, town, school, or house? What savings, in both electricity and dollars, could a geothermal system provide to your community?

Glossary

- binary cycle — a two-part geothermal power plant that enables the use of lower temperature hydrothermal fluid by exchanging heat energy to a liquid with a lower boiling point
- co-production — the extraction of mineral resources from hydrothermal fluids and pressurized brines that generates additional revenue for the power utility
- dry steam — a power plant that uses steam at temperatures above 100 °C
- electrical resistivity surveys — analysis method that can determine the presence of underground water resources
- Enhanced Geothermal System (EGS) — method for using hot, dry rock to produce hydrothermal fluid
- flash steam — a power plant that uses hydrothermal fluids at temperatures above 360 °C which flashes into steam as it enters the plant
- ground source heat pumps — equipment that allows the transfer of energy into or out of a hydrothermal fluid
- heat capacity — the amount of energy it takes to raise the temperature of a substance
- heat exchanger — equipment that allows the transfer of energy from one fluid to another without direct contact between the fluids
- heat flow — the transfer of thermal energy from a higher temperature substance to one of lower temperature
- hydrothermal fluid — water that has been heated by the Earth and usually contains dissolved minerals and gasses
- particulates — tiny particles of carbon and impurities that are released as combustion occurs
- pressurized brines — hydrothermal fluids that are at high temperatures and pressures that contain high levels of dissolved solids

Appendix

SCIENCE FAIR JUDGING GUIDELINES

Science Project Evaluation Criteria

Judging is conducted using a 100-point scale with points assigned to creative ability, scientific thought or engineering goals (II a and b respectively), thoroughness, skill, and clarity. Team projects have a slightly different balance of points that includes points for teamwork. A chart of these point values is located at the end of these criteria. Following is a list of questions for each criterion that can assist you in interviewing the students and aid in your evaluation of the student's project.

I. Creative Ability (Individual – 30, Team – 25)

1. Does the project show creative ability and originality in the questions asked? the approach to solving the problem? the analysis of the data? the interpretation of the data? the use of equipment? the construction or design of new equipment?

2. Creative research should support an investigation and help answer a question in an original way. The assembly of a kit would not be creative unless an unusual approach was taken. Collections should not be considered creative unless they are used to support an investigation and to help answer a question in an original way.

3. A creative contribution promotes an efficient and reliable way to solve a problem. When judging, make sure to distinguish between gadgeteering and genuine creativity.

II.a. Scientific Thought (Individual – 30, Team – 25)

1. Is the problem stated clearly and unambiguously?

2. Was the problem sufficiently limited to allow plausible attack? One characteristic of good scientists is the ability to identify important problems capable of solutions. Neither working on a difficult problem without getting anywhere nor solving an extremely simple problem is a substantial contribution.

3. Was there a procedural plan for obtaining a solution?

4. Are the variables clearly recognized and defined?

5. If controls were necessary, did the student recognize their need and were they correctly used?

6. Are there adequate data to support the conclusions?

7. Does the student recognize the data's limitations?

8. Does the student understand the project's ties to related research?

9. Does the student have an idea of what further research is warranted?

10. Did the student cite scientific literature, or only popular literature (i.e.: local newspapers, Reader's Digest)?

II.b. Engineering Goals (Individual – 30, Team – 25)

1. Does the project have a clear objective?

2. Is the objective relevant to the potential user's needs?

3. Is the solution workable? Unworkable solutions might seem interesting, but are not practical. acceptable to the potential user? Solutions that will be rejected or ignored are not valuable. economically feasible? A solution so expensive it cannot be used is not valuable.

4. Could the solution be utilized successfully in design or construction of some end product?

5. Does the solution represent a significant improvement over previous alternatives?

6. Has the solution been tested for performance under the conditions of use? (Testing might prove difficult, but should be considered.)

III. Thoroughness (Individual – 15, Team – 12)

1. Was the purpose carried out to completion within the scope of the original intent?

2. How completely was the problem covered?

3. Are the conclusions based on a single experiment or replication?

4. How complete are the project notes?

5. Is the student aware of other approaches or theories concerning the project?

6. How much time did the student spend on the project?

7. Is the student familiar with the scientific literature in the studied field?

IV. Skill (Individual – 15, Team – 12)

1. Does the student have the required laboratory, computation, observational and design skills to obtain supporting data?

2. Where was the project done (i.e.: home, school, laboratory, university laboratory)? Did the student receive assistance from parents, teachers, scientists, or engineers?

3. Was the project carried out under adult supervision, or did the student work largely alone?

4. Where did the equipment come from? Did the student build it independently? Was it obtained on loan? Was it part of a laboratory where the student worked?

V. Clarity (Individual – 10, Team – 10)

1. How clearly can the student discuss the project and explain the project's purpose, procedure, and conclusions? Make allowances for nervousness. Watch out for memorized speeches that reflect little understanding of principles.

2. Does the written material reflect the student's understanding of the research? (Take outside help into account.)

3. Are the important phases of the project presented in an orderly manner?

4. How clearly are the data presented?

5. How clearly are the results presented?

6. How well does the project display explain itself?

7. Is the presentation done in a forthright manner, without cute tricks or gadgets?

8. Did the student do all the exhibit work or did someone help?

VI. Teamwork (Team Projects only - 16)

1. Are the tasks and contributions of each team member clearly outlined? How did you delegate responsibilities between each of the team members?

2. Did you designate one person to be the team leader? If so, what were his/her responsibilities? Do you feel that a team leader is a necessary component for a team project? Why or why not?

3. Was each team member fully involved with the project, and is each member familiar with all aspects? How did you approach other team members to make sure the work got done?

4. Did you find it difficult finding the time to work together? What actions did you take to assure that you met as often as necessary to complete the project?

5. Does the final work reflect the coordinated efforts of all team members?

Evaluation Criteria	Individual Projects	Team Projects
Creative Ability	30 points	25 points
Scientific Thought/Engineering Goals	30 points	25 points
Thoroughness	15 points	12 points
Skill	15 points	12 points
Clarity	10 points	10 points
Teamwork	- - - - -	16 points
TOTAL POSSIBLE SCORE	100 points	100 points