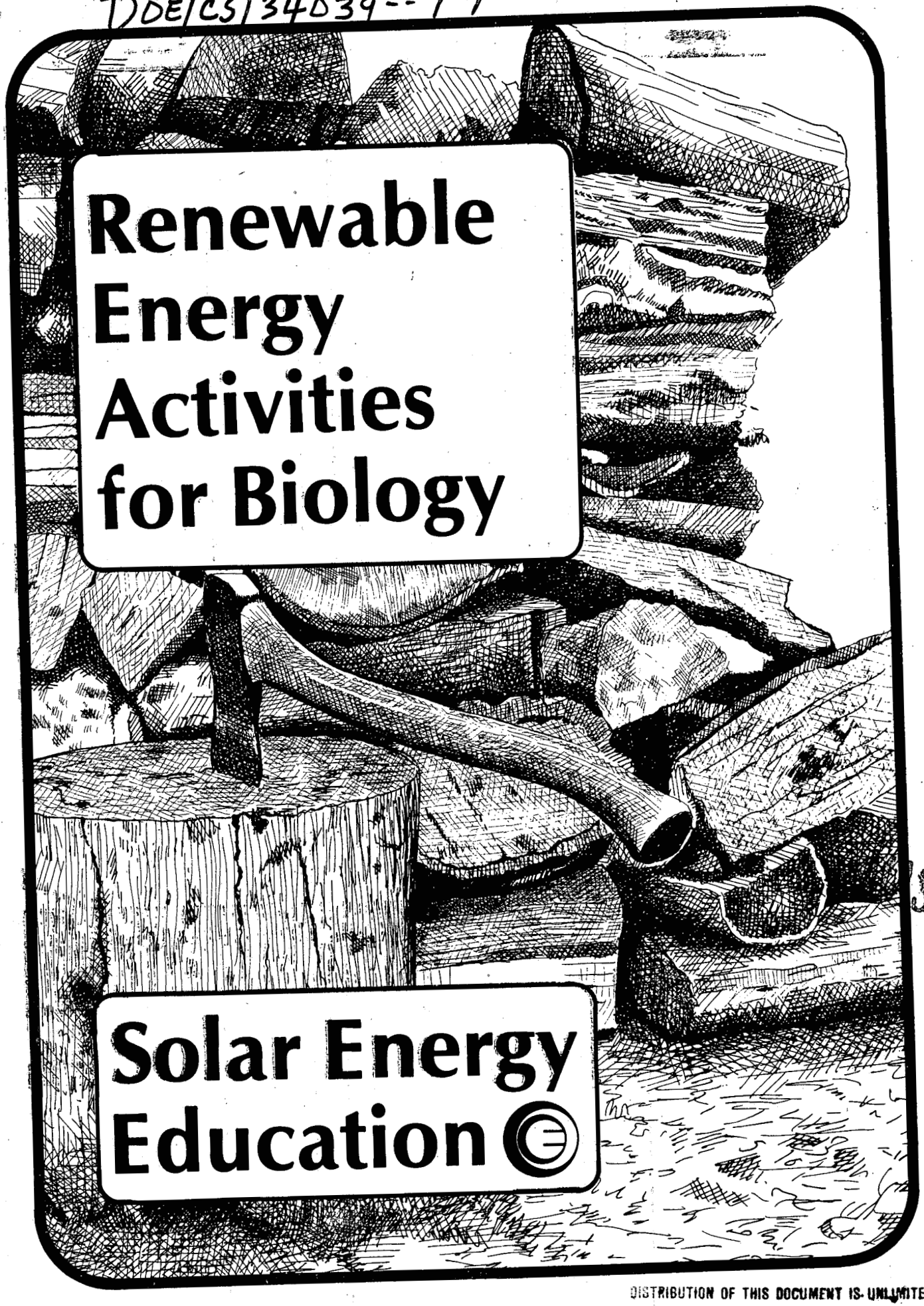
DOE/CS/34039--T7

# Renewable Energy Activities for Biology



## Solar Energy Education

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THE SECONDARY SOLAR ENERGY EDUCATION CURRICULUM

was prepared for
The U.S. Department of Energy

under
Contract Number AC01-77CS 34039

by the
Solar Energy Project

in cooperation with the
New York State Education Department and
SUNY Atmospheric Sciences Research Center

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Date: 11/14/2006

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# Introduction

For the teacher with a full workload and dozens of important topics to cover and skills to teach, the question that may occur in picking up this booklet is

## *Why Teach About Energy?*

If you are asking that question, try to think of an area of human existence that is not affected by energy resources. Energy permeates our lives; it shapes our careers, our leisure, and our aspirations as well as providing food, clothing, and shelter.

Students are aware of this reality. They see that, as available energy resources change, their lives will also change, in ways as yet unknown. They recognize energy as a factor that will have an impact on them personally, for the rest of their lives, and they want to understand their energy options.

## *Subject Skills/Energy Content*

You can capitalize on your students' strong interest in the topic of energy. With renewable energy as the content matter, the following activities are designed to give students practice in the subject skills that are high on your teaching agenda. Whether it's observing, estimating and predicting, measuring, computing, graphing, or constructing apparatus, you'll find here a renewable energy activity, ready to use.

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# The Activities

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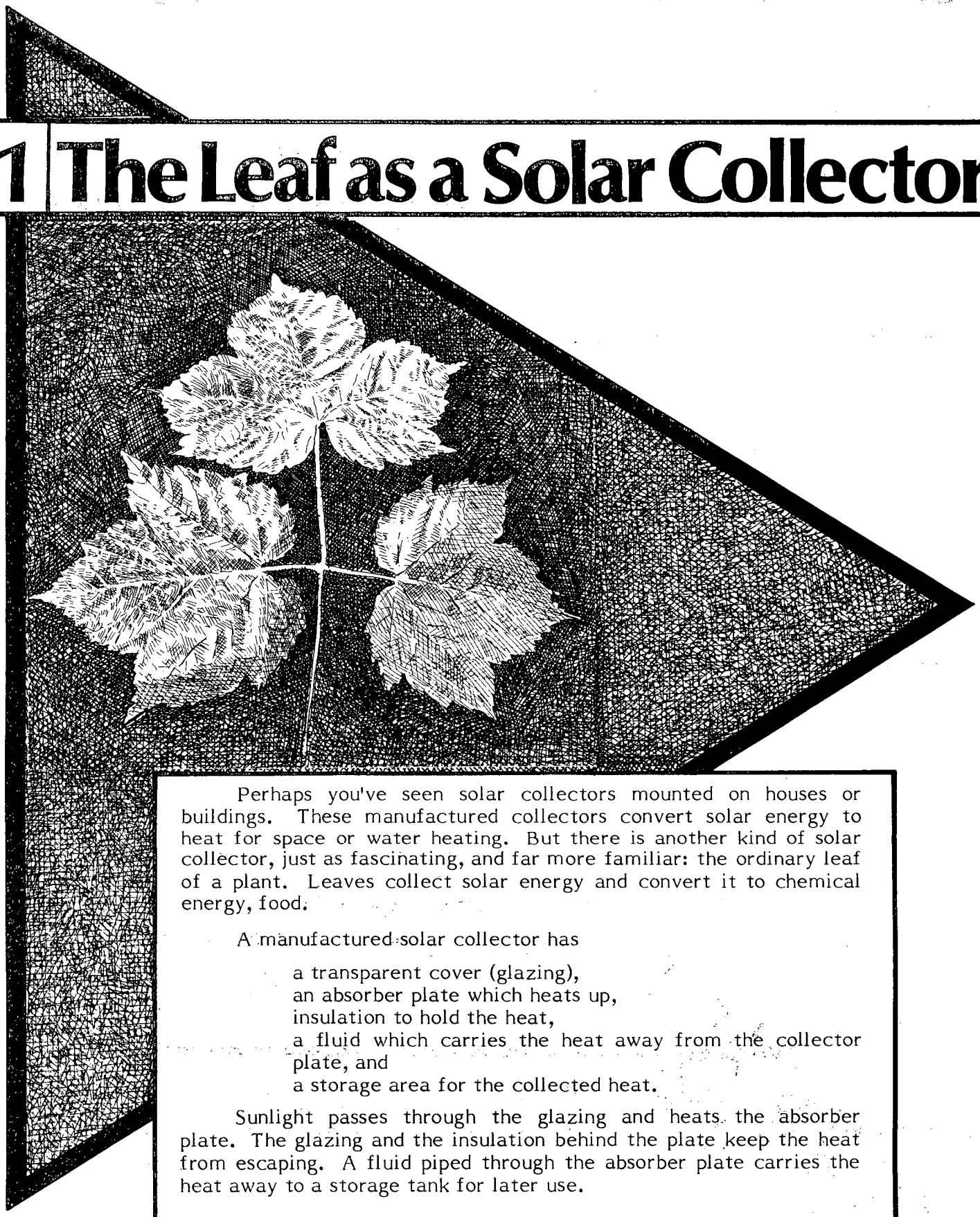
# 1 The Leaf as a Solar Collector



Perhaps you've seen solar collectors mounted on houses or buildings. These manufactured collectors convert solar energy to heat for space or water heating. But there is another kind of solar collector, just as fascinating, and far more familiar: the ordinary leaf of a plant. Leaves collect solar energy and convert it to chemical energy, food.

A manufactured solar collector has

- a transparent cover (glazing),
- an absorber plate which heats up,
- insulation to hold the heat,
- a fluid which carries the heat away from the collector plate, and
- a storage area for the collected heat.

Sunlight passes through the glazing and heats the absorber plate. The glazing and the insulation behind the plate keep the heat from escaping. A fluid piped through the absorber plate carries the heat away to a storage tank for later use.

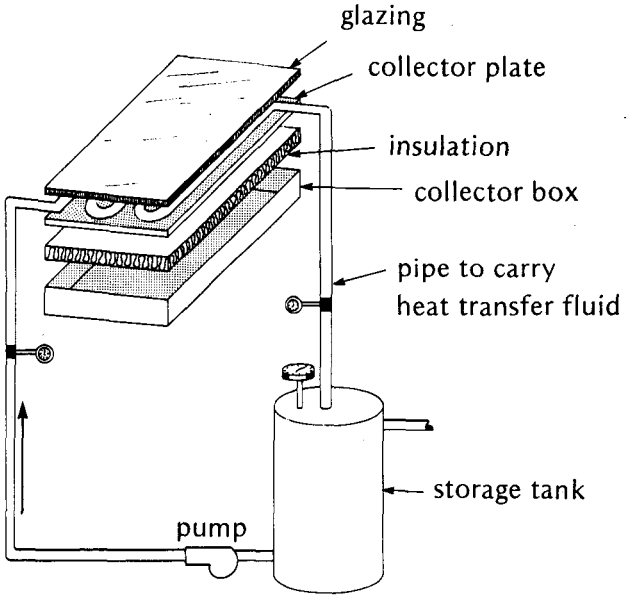
Can you see any similarities between a manufactured solar collector and a leaf? How about differences?

# objectives

At the completion of this activity, you should be able to

- recognize that leaves are natural solar energy collectors which transform light energy into chemical energy,
- describe the structure and function of the tissues which enable the leaf to be an effective absorber of sunlight, and
- identify similarities and differences between the leaf and a manufactured solar energy collector.

# skills and knowledge you need




Basic understanding of the functioning of a manufactured solar collector

Ability to use the compound light microscope

Ability to make drawings of microscopic observations

# materials

a fresh leaf from the plant Ligustrum (Privet)

one cover slip

three microscope slides

one single-edged razor blade

a compound microscope

drawing paper

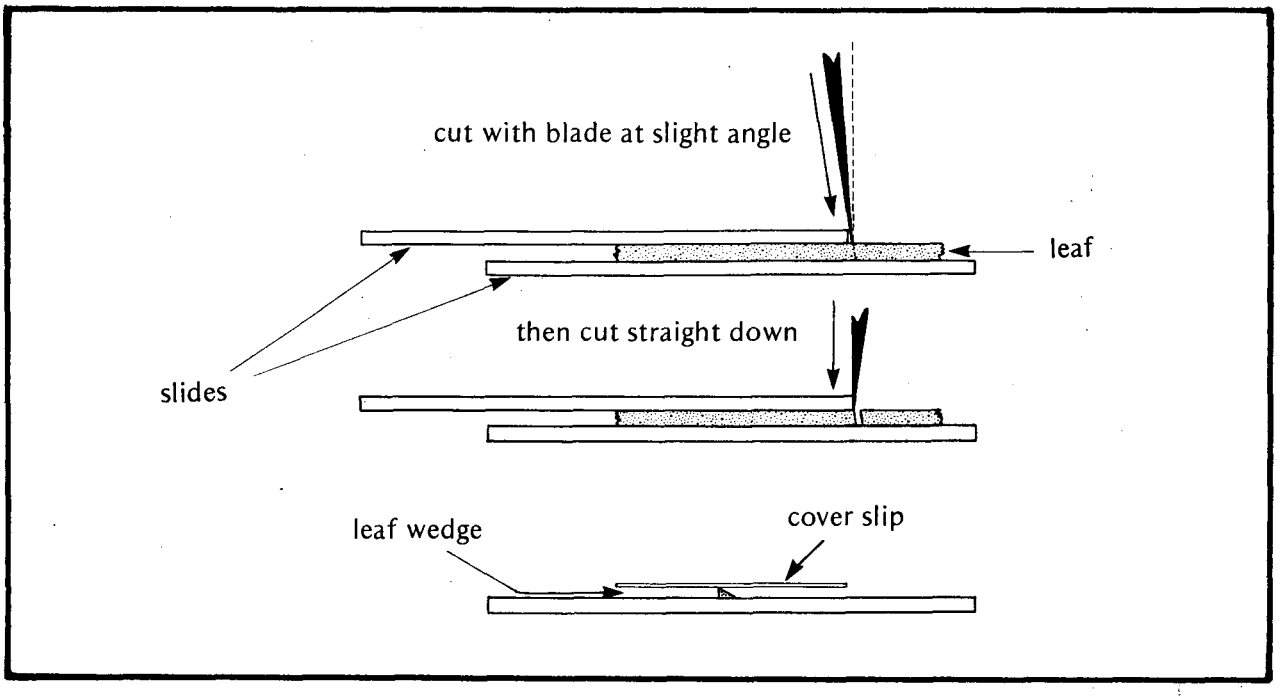
eyedropper

# procedure

1. Place your leaf between two microscope slides, as shown in the diagram. Move the top slide back so that part of the leaf is exposed.

2. Using your razor blade, slice a portion of the leaf along the edge of the upper slide at a slight angle.

*Caution: Use the razor blade carefully.*




3. Now make another slice perpendicular to the lower slide. This will produce a wedge of tissue suitable for microscopic observation.

4. Repeat Steps 2 and 3 several times in order to produce several wedge-shaped cross sections. Place these sections in a drop of water on the center of a third microscope slide. Add a cover slip to your wet mount.

5. Place your wet mount on the stage of a compound microscope and view under low power. Find part of a leaf section thin enough to study and center it in your field of view.

6. Under the microscope locate and draw the following tissues of the leaf.

   a. Upper Epidermis: These small, thick cells on the upper surface of the leaf protect the inner tissues from mechanical injury and help prevent the loss of water. In many plants a waxy cuticle covers the upper epidermis, further preventing water loss. The epidermis allows sunlight to pass through it.

b. Mesophyll: This tissue lies between the upper and lower epidermis and contains the cells which use sunlight to manufacture food by photosynthesis. There are two distinct layers. Palisade mesophyll cells are long and cylindrical, lying in a tightly packed layer just below the upper epidermis. Spongy mesophyll cells are irregularly shaped cells lying below the palisade layer in a more loosely packed arrangement with many air spaces between them. Both types of mesophyll cells contain chloroplasts, the small green bodies which contain chlorophyll and where photosynthesis occurs. Be sure to include these structures in your drawing.

c. Veins: Within the mesophyll tissue, you will see circular groups of smaller cells which lack chloroplasts. These are cross sections through the veins of the leaf. Veins contain cells which transport water and minerals to the leaf or transfer the food produced to other parts of the plant.

d. Lower Epidermis: Try to find openings in this lower surface layer where gases are exchanged between the leaf and the atmosphere.

## questions

1. Which leaf tissue serves as a natural glazing for light absorption? What properties help to make it an effective transmitter of solar energy?

2. In which tissue of the leaf is more of the light absorbed?

3. What is the color of the absorption layer of the leaf? What structures give this layer its color? What does this color indicate about the colors of light absorbed by the plant? What color of light is reflected by the plant?

4. In what way does the plant leaf use the energy from sunlight differently than does the manufactured solar energy collector?

5. The leaf usually remains cooler than a manufactured solar energy collector. What factors might be responsible for this difference in temperature?

6. What is the function of the open spaces in the leaf? How do these openings make the leaf different from the manufactured solar energy collector?

7. Both the plant leaf and the manufactured solar collector have an energy transfer system. Describe each system and indicate the similarities and differences existing between them.

8. Both the plant leaf and the manufactured solar collector have a storage system. In what form does each store energy? How does the plant call upon the stored energy when it is needed? What about the manufactured collector system?

# looking back

The plant leaf has been called the original solar collector. Like a manufactured collector, it has a transparent layer to transmit sunlight, an absorbing layer, and veins through which fluid transports the collected energy.

There are differences, however, between a leaf and a manufactured collector. The collector produces heat energy, and transports it to storage in tanks of water or bins of sand or other materials. The leaf produces chemical energy which is stored in the stem, root, or fruit of the plant. Finally, the collector is tight and insulated, to collect as much heat as possible. The leaf, on the other hand, has openings to the atmosphere where gases are exchanged, and escaping water vapor helps to cool the leaf.

# going further

Plant leaves seldom absorb all of the sunlight passing through them. Using a solar meter, you may wish to investigate how much solar energy different types of leaves absorb and transmit. What factors could account for the range of values obtained?

The mammalian eye also collects solar energy. Dissect a sheep's eye and compare and contrast its structures to the parts of a manufactured solar energy collector.

The efficiency of photosynthetic conversion has been placed at about 2-3%, while the daily efficiency of a manufactured collector may be as much as 45%. What factors might account for such a large difference in efficiencies?

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Teacher Information

# The Leaf as a Solar Collector

## Suggested Grade Level and Discipline

Science, grades 10-12
Life Science
Biology

## Skill Objectives

Preparing cross sections of plant leaves

Making wet mounts

Using the compound microscope

Drawing microscopic views of plant tissues

Developing scientific analogies and recognizing their limitations

## Major Understandings

The plant leaf is structurally adapted for the transmission and absorption of solar energy and has many functional similarities to a manufactured solar energy collector.

The plant leaf changes sunlight to chemical energy while the manufactured collector changes sunlight to heat energy.

Epidermal cells of the leaf are effective light transmitters, much like the transparent glazing of the manufactured collector.

Chlorophyll is the plant pigment responsible for the absorption of solar energy in the mesophyll layers. In the manufactured collector, the absorber is a metal plate.

Chemical energy is transported away from the leaf in the form of food molecules. The manufactured collector uses a fluid medium to transport heat energy.

The plant leaf is not as well insulated as a manufactured solar energy collector.

## Background

The leaf is a natural solar collector which shows several similarities to manufactured collectors. Its epidermis functions as a glazing, permitting sunlight to pass through to the underlying tissues. The epidermis also serves to protect inner structures from mechanical injury. The pores, or stomata, usually found in the lower epidermis, permit needed gas exchange.

The palisade and spongy mesophyll layers contain chlorophyll, a green pigment which absorbs red, blue, and violet wavelengths of light but reflects most of the green wavelengths. Rather than convert light energy into heat, the mesophyll cells perform a complex biochemical process, using sunlight as an energy source to synthesize sugars from water and carbon dioxide. The organic molecules produced may then meet the energy needs of cells throughout the rest of the plant. Thus the energy conversion occurring in the leaf is far more sophisticated than that which occurs at the collector plate.

Once energy conversion has taken place, systems exist in both the leaf and the manufactured collector to transport the chemical or heat energy to other areas for storage. In the leaf, veins contain cylindrical cells which transport sugars to the stem or roots where these sugars may be stored as starch granules until needed. The manufactured collector has pipes or ducts which carry hot water or air to tanks or rock bins for heat storage.

## Advance Planning

Prior to beginning this activity, be sure to give students preparation in using the compound microscope.

Instruction in making proper drawings of microscopic views may be needed.

Privet leaves should be fresh.

Have prepared slides of leaf cross sections available for student use.

## Suggested Time Allotment

One period to make, observe, and draw the leaf cross section

One period to answer and discuss the questions

## Suggested Approach

In order for students to view the leaf as a natural solar energy collector, it is imperative that they be acquainted with the components and operation of manufactured solar collectors. You might have them do Activities 1 and 2 in the Junior High/Middle Grades Activities book prior to beginning this investigation.

If sufficient materials and equipment exist, have students work individually. Otherwise, the activity may be performed in pairs.

As the students study their leaf sections under the microscopes, move around the laboratory and offer assistance as needed. Be sure that students are properly matching the structures described in the procedures with those they are viewing.

You might assign the questions for homework and lead an extensive discussion on the following day.

## Precautions

*Care should be used in working with the razor blades. They must be returned to the teacher once sections have been cut.*

## Points for Discussion

Why would it be disadvantageous for a leaf to contain light-absorbing pigments as dark as the collector plate in a manufactured collector?

Why do deciduous trees lose their leaves during winter rather than continue to collect and use solar energy?

What factors affect the rate at which plant leaves utilize the energy from sunlight?

## Typical Results

Students should not have difficulty making analogies between the leaf and the manufactured collector.

## Evaluation

Observe the care with which students make cross sections and wet mounts of leaf tissues.

Inspect students' drawings for accuracy and completeness.

Review answers to the questions for accuracy and depth of analysis.

Ask students to write a paragraph describing the similarities and differences between a leaf and a manufactured solar collector.

## Modifications

Sections of photosynthetic herbaceous stems can also be examined in order to determine how they are adapted for solar energy collection.

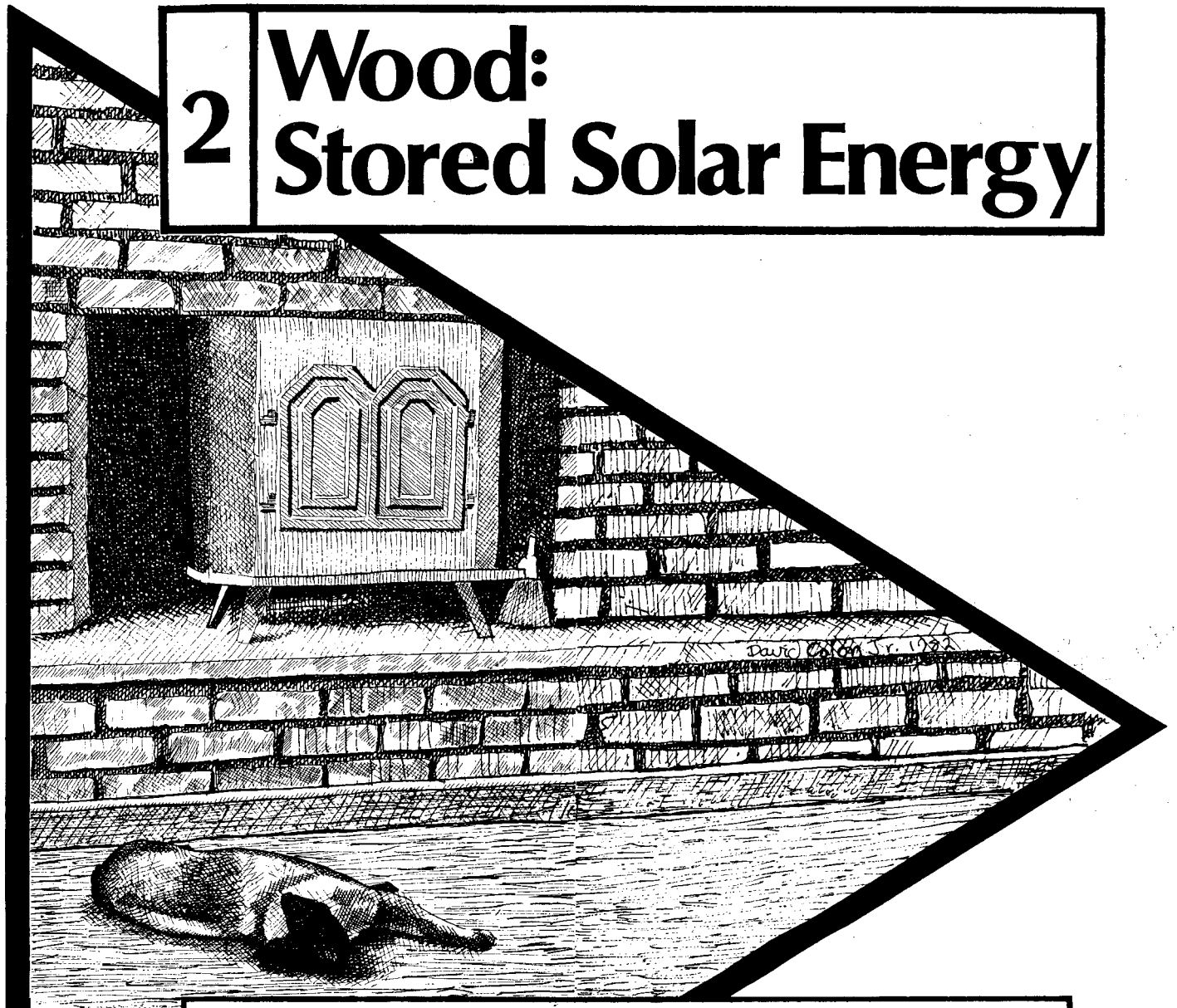
If some students have difficulty obtaining useful sections of fresh tissues, advise them to use the prepared slides.

## References

Laboratory Guide for Biological Science, William T. Keeton et al.
(W. W. Norton and Co., Inc., Norton College Division, 500 Fifth Ave., New York, NY 10036, 1968, $8.95/paper.)

The Solar Home Book: Heating, Cooling, and Designing with the Sun, Bruce Anderson and Michael Riordan.
(Brick House Publishing Co., 34 Essex St., Andover, MA 01810, 1976, $9.50/paper.)

# 2 Wood: Stored Solar Energy



In the days when wood was the only fuel and construction material for many houses, people knew a lot about various woods and their qualities. They didn't talk simply of "kindling," "firewood," or "boards." Instead, they spoke with discrimination about "pine chips," "birch logs," or "bird's eye maple."

Today wood is coming into its own again as an important fuel, but people need to know more about it before they adopt wood as a source of heat.

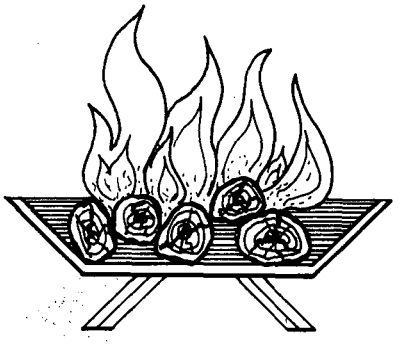
Fuel woods vary a good deal, depending on their moisture content, density, smokiness, and other qualities. As wood grows more and more popular and competitive as a fuel, a knowledge of woods and an ability to choose among them will be a useful skill.

# objectives

At the completion of this activity, you should be able to

- o calculate the number of cords in a stack of wood,
- o determine the cost/million Btu of various kinds of wood and select the best buy when sold by the cord,
- o determine the heat provided per cent for various fuels and compare these with the heat provided per cent by wood,
- o calculate the number of cords of wood that would be required to heat your home, and
- o compare other qualities of woods in addition to heat content and select the best woods for heating.

# skills and knowledge you need



The ability to solve simple mathematical equations

The knowledge of the cost of a cord of wood in your area

The knowledge of the costs of fuels in your area

The knowledge of the kind and amount of fuel required to heat your home

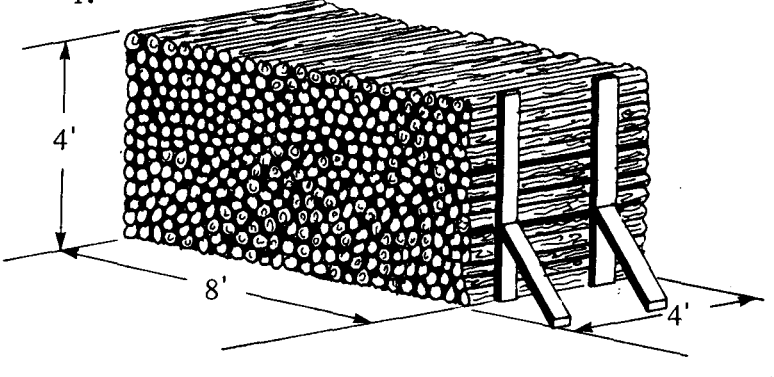
# materials

a calculator (optional)

# procedure

## Completing Data Table 1

1. Wood is commonly measured in a unit called the cord. A cord is a stack of wood measuring 4 feet high, 4 feet wide, and 8 feet long. Calculate the volume of 1 full cord of wood and enter the value in the appropriate space in Row A on Data Table 1.



2. Wood, however, is seldom stacked or delivered in full cords, even though it is standardly priced this way. To determine how many cords are in a stack of wood, use the following formulas.

Volume ($ft.^3$) =

Length (ft.) x Width (ft.) x Height (ft.)

$$\text{Number of cords in a stack of wood} = \frac{\text{Volume of stack } (ft.^3)}{\text{Volume of a cord } (128\ ft.^3)}$$

To practice calculating the number of cords in a stack of wood, use the formulas above to complete the rest of Data Table 1.

## Completing Data Table 2

3. Different woods have different densities. The denser a particular wood is, the more it weighs per cord. Data Table 2 lists the weight in pounds per cord of various kinds of wood. Also listed is the amount of heat available in Btu when a cord of each kind of wood is burned. (A Btu is the amount of energy required to raise the temperature of a pound of water $1^{\circ}$ Fahrenheit.) Calculate the heat content per pound for each wood in Data Table 2 by dividing the heat content per cord by the weight per cord. Remember to convert millions of Btu to Btu.

$$\text{Heat content (Btu/lb.)} = \frac{\text{Heat content (Btu/cord)}}{\text{Weight (lb./cord)}}$$

4. Find out the cost of a cord of wood in your area. Often the price will be the same no matter what kind of wood you're buying, but if the prices are different, note them. If your family cuts its own wood, try to figure out how much it costs to cut a cord: gasoline, depreciation on equipment, labor, and so on.

5. Calculate the cost per 1 million Btu of the woods listed in Data Table 2. The cost/million Btu will allow you to compare the woods to see which are the best buys.

$$\text{Cost/million Btu} = \frac{\text{Cost/cord}}{\text{Heat content (million Btu/cord)}}$$

## Completing Data Table 3

6. Find out the cost/unit for the fuels used in your area. Enter these values in the appropriate spaces on Data Table 3. Do not complete Data Table 3 for fuels not used in your area.

7. Column 3 of Data Table 3 lists the number of Btu per unit for some common fuels. To find the number of gross Btu provided per cent (¢) by each fuel, divide the Btu/unit by the cost/unit, in cents. (Remember to convert dollars to cents.)

$$\text{Gross Btu/cent} = \frac{\text{Btu/unit}}{\text{Cost/unit (cents)}}$$

This value is the number of Btu that each cent's worth of the fuel will provide <u>if</u> the fuel is burned completely and all the heat produced is used to heat your home. This value doesn't take into account the efficiency of the heating unit being used. Different heating units have different efficiencies.

8. In Column 5 of Data Table 3, the average efficiency of the most common method of heating with each fuel is given. No fuel burner is 100% efficient, since some heat is lost up the chimney or smokestack, and fuels are often incompletely burned. (The actual efficiency for any particular unit may differ greatly from the averages given.) To find the actual number of Btu (net Btu) provided per cent by burning each fuel, multiply the gross Btu/cent by the efficiency. (Remember to convert percentages into decimal form.)

Net Btu/cent = Gross Btu/cent x % efficiency

9. Find out what fuel is used to heat your home and how much of it is required in a heating season.

## Completing Data Table 4

10. Use the information in Data Table 3 to convert this amount of fuel into the Btu required in heating your home.

Btu/heating season =

Amount of fuel used in a heating season x Btu/unit x Efficiency of heating unit

11. Now calculate the number of cords of wood you would need to heat your home during a heating season.

Cords =

$$\frac{\text{Btu/heating season}}{\text{Btu/cord x Efficiency of heating unit}}$$

## Completing the Graph

12. Data Table 5 lists the relative densities of the woods in Data Table 2. On the graph provided, plot relative density vs. heat content (million Btu/cord) for each wood.

## questions

1. According to Data Table 3, which is the most inexpensive fuel (in net Btu/¢) in your area? How does the cost of wood compare with the cost of this fuel?

2. If you cut your own wood, will the cost/cord ever be zero? Explain.

3. A fireplace has a burning efficiency of about 10%. If you burned wood in a fireplace, what would be the net Btu/cent? How does this value compare with the value for an airtight stove?

4. High-quality airtight wood stoves have burning efficiencies as high as 75%. If an average home in the United States has an annual heating requirement of 121,000,000 Btu, how many cords would be required to heat this home using a 75% efficient stove?

5. Of the woods listed in Data Table 2, which is the best buy if sold by the cord? Why?

6. Of the woods listed in Data Table 2, which is the worst buy if sold by the cord? Why?

7. According to your graph, how is the relative density of a particular wood related to its Btu content per cord?

8. A face cord is the amount of wood in a stack that is 4 feet high and 8 feet long. Its width can range from 1 to 3 feet. If a face cord has a width of 2 feet, how many full cords is it equal to? If a face cord has a width of 18 inches, how many full cords is it equal to?

9. According to Data Table 2, which woods have the highest Btu values per pound? Are these woods hardwoods or softwoods? Why might they have such high Btu values per pound?

10. Of the remaining woods in Data Table 2, what is the most striking aspect of their Btu values per pound? Why might this occur?

11. How many cords of wood would be needed to heat your home during a heating season?

12. Data Table 6 lists some of the other qualities of wood to consider in addition to heat content when purchasing wood for home heating. What are some of these qualities? Taking heat content and these qualities into consideration, which wood(s) would you choose to heat your home with? Why?

## looking back

The series of calculations you have just carried out should have added to your knowledge of wood as a fuel. Your data should tell you how to determine the number of cords in a stack of wood, how to find the heat value and cost per Btu of the various woods, how wood burning compares with other ways of heating in terms of cost efficiency, and what desirable or undesirable qualities various fuel woods have. For a wood-heated household, this knowledge will have a high lifetime payoff in comfort, efficiency, cost, and safety.

# going further

Research some of the problems involved in using wood as a fuel source.

Research the many kinds of burning units available for heating with wood. Develop a chart of the relative merit of each kind of unit.

Research the environmental impact of widespread use of wood as a fuel.

Research the historical use of wood as an energy source.

Research the impact of increasing deforestation on the lives of many Third World peoples.

Research some of the possible future uses of wood as a large-scale source of biomass energy. What are some of the desirable characteristics of a biomass crop? Read about the various projections for wood's role as one of our future energy sources.

Research the many other uses for wood besides its use as an energy source. How would using wood as a large-scale source of energy affect these other uses?

Invite a wood stove dealer and/or a forester to speak to the class. From the information you learned in this activity, develop a list of questions for them to answer.

Identify woodlots in your area where wood is available to cut for fuel. Determine the size of the woodlot needed to furnish fuel wood for one house on a sustainable basis.

The values for heat content given in this activity assume air-dried woods with a low moisture content. To find out about the heat content of green woods, try Activity 3 in this book, "Burning Green and Dry Woods."

## Data Table 1

### Determining Cords

| Wood Sample | Length (ft.) | Width (ft.) | Height (ft.) | Volume ($ft.^3$) | Number of Cords |
|---|---|---|---|---|---|
| A | 4 | 4 | 8 | | 1 |
| B | 3 | 6 | 2 | | |
| C | 15 | 12 | 7 | | |
| D | 2 | 2 | 8 | | |
| E | 7 | 9 | 3 | | |
| F | 14 | 12 | 6 | | |

## Data Table 2

### Heating Value of Wood

| Type of Wood | Air-dried Weight (lbs./cord) | Heat Content (million Btu/cord) | Heat Content (Btu/lb.) | Cost/million Btu |
|---|---|---|---|---|
| Ash | 3440 | 20.0 | | |
| Aspen | 2160 | 12.5 | | |
| Beech | 3760 | 21.8 | | |
| Birch, Yellow | 3680 | 21.3 | | |
| Elm | 2900 | 17.2 | | |
| Fir, Balsam | 2100 | 11.3 | | |
| Fir, Douglas | 2400 | 18.0 | | |
| Hickory, Shagbark | 4240 | 24.6 | | |
| Maple, Red | 3200 | 18.6 | | |
| Maple, Sugar | 3680 | 21.3 | | |
| Oak, Red | 3680 | 21.3 | | |
| Oak, White | 3920 | 22.7 | | |
| Pine, Pitch | 3000 | 18.0 | | |
| Pine, Red | 2670 | 12.8 | | |
| Pine, Southern Yellow | 2600 | 14.2 | | |
| Pine, White | 2080 | 13.3 | | |

## Data Table 3
### Costs of Fuels

| Fuel | Cost/unit | Btu/unit | Gross Btu/cent | Average Burner Efficiency | Net Btu/cent |
|---|---|---|---|---|---|
| Wood | | | | 50%[1] | |
| Hardwood | /cord | 23,000,000 | | | |
| Softwood | /cord | 13,000,000 | | | |
| Oil | /gallon | 138,000 | | 65%[2] | |
| Electricity | /kWh | 3,413 | | 100%[3] | |
| Coal | /ton | 23,000,000 | | 60%[4] | |
| Natural Gas | /therm | 100,000 | | 75%[2] | |

[1] airtight stove
[2] typical system
[3] at the point of use
[4] coal stove or central heating system

## Data Table 4

| Fuel Used to Heat Your Home | Amount Required | Btu Required | Equivalent Cords of Wood |
|---|---|---|---|
| | | | |

## Data Table 5

| Type of Wood | Relative Density |
|---|---|
| Ash | .60 |
| Aspen | .38 |
| Beech | .64 |
| Birch, Yellow | .62 |
| Elm | .50 |
| Fir, Balsam | .36 |
| Fir, Douglas | .48 |
| Hickory, Shagbark | .72 |
| Maple, Red | .54 |
| Maple, Sugar | .63 |
| Oak, Red | .63 |
| Oak, White | .68 |
| Pine, Pitch | .52 |
| Pine, Red | .46 |
| Pine, Southern Yellow | .55 |
| Pine, White | .35 |

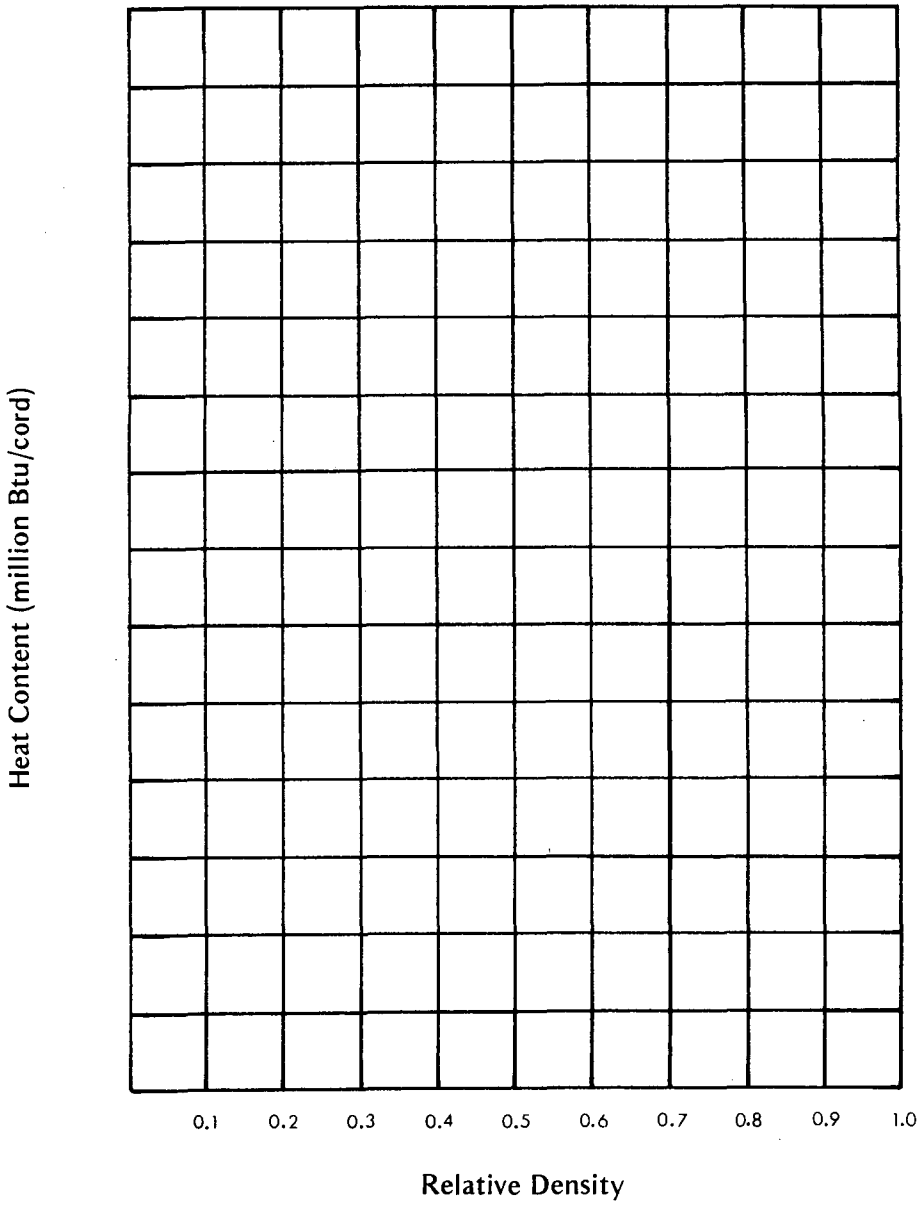
SOURCE: U.S. Forest Products Laboratory

## Data Table 6
### Firewood Ratings

| Species of Wood | Relative Amount of Heat | Easy to Burn | Easy to Split | Heavy Smoke | Coaling Qualities | General Rating and Remarks |
|---|---|---|---|---|---|---|
| **Hardwood** | | | | | | |
| Ash, red oak, white oak, beech, birch, hickory, sugar maple | high | yes | yes | no | excellent | excellent |
| Red maple | medium | yes | yes | no | excellent | good |
| Elm | medium | medium | no | medium | good | fair-contains too much water when green |
| Aspen, cottonwood | low | yes | yes | medium | good | fair-but good for kindling |
| **Softwood** | | | | | | |
| Southern yellow pine, Douglas fir | high | yes | yes | yes | fair-poor | good but smoky |
| Eastern white pine, western white pine, sugar pine, ponderosa pine, true firs | low | medium | yes | medium | fair-poor | fair-good for kindling |

SOURCE: U.S. Forest Products Laboratory

# Graph


Heat Content (million Btu/cord)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Relative Density

Teacher Information

# Wood: Stored Solar Energy

## Suggested Grade Level and Discipline

Biology, grades 10-12
Advanced Biology
Ecology
Environmental Issues and Problems

## Skill Objectives

Reading data tables and performing mathematical calculations

Calculating cord measures of wood

Calculating cost/million Btu for various woods

Comparing wood costs with other fuel costs

Calculating the amount of wood required to heat a home for one year

Determining the relationship between a wood's density and its heat content per cord

## Major Understandings

The cord is the standard unit in which wood is measured. A cord is a stack of wood 4 x 4 x 8 feet.

The factors of heat content and cost per million Btu determine how economical a given species of wood is for home heating.

With the exception of softwoods containing high proportions of resins, the heat contents per pound are virtually the same for different kinds of woods. Therefore, the denser woods (usually hardwoods) provide more heat per cord because they weigh more per cord.

By determining net Btu/cent for wood and other home heating fuels, one can compare the cost of heating with wood to the costs of other fuels.

The number of cords of wood that would be required to heat a home can be calculated by converting units of the actual fuel used to Btu and dividing by the heat content of wood.

Characteristics such as burnability, splitability, smokiness, coaling quality, and sparking also determine the value of a particular wood as fuel.

## Background

Over six million homes in the United States now have wood stoves, and wood stoves are being sold at the rate of over one million a year. Americans consume between 30 and 40 million cords of wood a year in heating their homes, more than double the amount consumed just a decade ago. In fact, some experts believe that wood now supplies more energy for the United States than nuclear power.

Wood has more energy uses than just home heating. In the Northwest, the wood products industry obtains half of its energy from wood waste, and in Vermont the largest wood-fired electricity generating plant in the country is now under construction. This plant will burn over 1500 tons of wood a day. Wood is on its way to becoming a transitional energy source for the United States.

Wood's appeal as an energy source is linked to its low cost and current abundance. America's private woodlots have been neglected for a century or more, and provide a convenient source of inexpensive energy. Wood's cost, when delivered close to where it is harvested, is competitive with the cost of oil and electricity. And the ease with which wood can be pelletized (converted into ½-inch diameter pellets) accounts for its rising popularity with industry.

In this activity students investigate the economics of wood for home heating. How attractive wood is as a home energy source depends on the amount of heat that can be captured when wood is burned. In the absence of hard data, this amount is greatly debated, and you may see other charts of Btu content which differ greatly from the one

presented here. The differences are traceable to the assumptions made in compiling the charts, the most important one being that of the wood's moisture content. The more water wood contains, the less the available heat, because some of the energy from burning is used to vaporize this moisture which then goes up the chimney. The heat content of a single species can vary also, depending on regional, seasonal, or even individual tree differences. But it is generally accepted that a cord of hardwood is roughly equivalent to one ton of coal, 200 gallons of fuel oil, 230 therms of natural gas, or 7000 kilowatt-hours of electricity.

Wood as a source of biomass energy has several advantages. Even when wood is purchased cut, delivered, and stacked, its price is relatively low. It is plentiful, storable, portable, and safe to handle. Wood contains less than 1/10th the sulfur content of coal. But there are drawbacks, too: wood is labor-intensive and wood stoves present a definite fire hazard unless properly installed and maintained. Other problems include the possibility of large-scale environmental effects from intensively-managed woodlots, the danger that wood will be diverted from such higher uses as lumber, and the lack of knowledge of the long-term health and environmental effects of the particulates released into the air when wood is burned at relatively low temperatures.

Throughout this activity the English system of measurement has been used because the literature on wood burning deals exclusively in Btu, feet, and pounds. For teachers who prefer the metric system, conversions can easily be made. One Btu equals 252 calories or 0.252 kilocalories.

## Advance Planning

Duplicate needed quantities of the data tables and graph. If desired, duplicate the teacher background section for use as a student reading.

Find out the costs of wood and other fuels in your area. Fuel wood dealers, home heating fuel dealers, coal suppliers, and your local utilities are likely sources.

## Suggested Time Allotment

Two to three class periods

## Suggested Approach

Introduce the activity by discussing how wood is a form of biomass energy. Define the term biomass conversion. Discuss photosynthesis as a means of capturing and storing solar energy.

Try to use this activity sometime during the heating season, when student interest in home heating will be higher.

Show students samples of the kinds of wood available for burning in your area.

Before students do Step 11 in the procedure, ask them to predict how many cords of wood their homes would require.

If necessary, help students with the math calculations required in the activity. You may want to complete the first row of each data table as an example.

Talk about burning unit efficiencies when you discuss results.

Encourage selection of a "Going Further" suggestion as a means of finding out more about wood as a source of biomass energy.

## Precautions

*Some parents may consider questions about fuel use in the home to be an invasion of privacy, and some schools may prohibit asking questions of this sort. We suggest that a note be sent to parents explaining the purpose of this activity and requesting permission for students to participate. Or consider presenting sample data for home Btu requirements, perhaps using your own home as an example. Sample data can also be used by students living in apartments who may not have access to heating bills.*

*Since charts of the Btu contents of woods vary so widely, Data Table 2 should only be supplemented when you are sure the assumptions underlying the additional data are the same. Substituting an entirely new chart is preferable.*

## Points for Discussion

What are some of the factors affecting the cost of wood as an energy source?

In what areas of the country would you expect the cost of wood for home heating to be competitive with other fuels? Why?

How do the efficiencies of different methods of burning wood vary? What are some of the features of an efficient wood burning unit?

What are some of the advantages and disadvantages of using wood to heat a home?

Would your family consider using wood to heat your home? Why or why not?

## Typical Results

Students who live in forested areas of the country or who already use wood to heat their homes will be interested in this activity and likely to discuss the results with their parents.

The net Btu/cent values will depend on the costs of the fuels in your region. Where wood is inexpensive and oil or electricity quite expensive, as in the Northeast, wood will compare favorably as an energy source.

Completed data tables are presented below. The cost assumptions are indicated, and represent average fuel costs in 1981.

Data Table 1

Determining Cords

| Wood Sample | Length (ft.) | Width (ft.) | Height (ft.) | Volume (ft.$^3$) | Number of Cords |
|---|---|---|---|---|---|
| A | 4 | 4 | 8 | 128 | 1.00 |
| B | 3 | 6 | 2 | 36 | 0.28 |
| C | 15 | 12 | 7 | 1260 | 9.80 |
| D | 2 | 2 | 8 | 32 | 0.25 |
| E | 7 | 9 | 3 | 189 | 1.48 |
| F | 14 | 12 | 6 | 1008 | 7.88 |

Data Table 2

Heating Value of Wood

| Type of Wood | Air-dried Weight (lbs./cord) | Heat Content (million Btu/cord) | Heat Content (Btu/lb.) | Cost/million Btu |
|---|---|---|---|---|
| Ash | 3440 | 20.0 | 5814 | 5.00 |
| Aspen | 2160 | 12.5 | 5787 | 8.00 |
| Beech | 3760 | 21.8 | 5798 | 4.59 |
| Birch, Yellow | 3680 | 21.3 | 5788 | 4.69 |
| Elm | 2900 | 17.2 | 5931 | 5.81 |
| Fir, Balsam | 2100 | 11.3 | 5381 | 8.85 |
| Fir, Douglas | 2400 | 18.0 | 7500 | 5.56 |
| Hickory, Shagbark | 4240 | 24.6 | 5802 | 4.07 |
| Maple, Red | 3200 | 18.6 | 5813 | 5.38 |
| Maple, Sugar | 3680 | 21.3 | 5788 | 4.69 |
| Oak, Red | 3680 | 21.3 | 5788 | 4.69 |
| Oak, White | 3920 | 22.7 | 5791 | 4.41 |
| Pine, Pitch | 3000 | 18.0 | 6000 | 5.56 |
| Pine, Red | 2670 | 12.8 | 4794 | 7.81 |
| Pine, Southern Yellow | 2600 | 14.2 | 5462 | 7.04 |
| Pine, White | 2080 | 13.3 | 6394 | 7.52 |

Data Table 3

Costs of Fuels

| Fuel | Cost/unit | Btu/unit | Gross Btu/cent | Average Burner Efficiency | Net Btu/cent |
|---|---|---|---|---|---|
| Wood | | | | | |
| Hardwood | $100/cord | 23,000,000 | 2300 | 50% | 1150 |
| Softwood | $100/cord | 13,000,000 | 1300 | 50% | 650 |
| Oil | $1.25/gallon | 138,000 | 1104 | 65% | 717.6 |
| Electricity | 8¢/kWh | 3,413 | 426.6 | 100% | 426.6 |
| Coal | $100/ton | 23,000,000 | 2300 | 60% | 1380 |
| Natural Gas | 50¢/therm | 100,000 | 2000 | 75% | 1500 |

## Evaluation

Collect and review students' data tables and graphs for accuracy and completeness.

Check students' answers to questions for degree of understanding.

Given sample data, ask students to calculate the number of cords in a stack of wood.

Ask students to determine the best buy when given a list of cost/million Btu for several woods.

Ask students to write a paragraph comparing the various qualities of several woods and to select the best wood for heating based on these qualities. Have them explain their choice.

## Modifications

In place of Data Table 2, substitute a chart of Btu content more representative of the woods in your region.

## References


The Complete Book of Heating with Wood, Larry Gay.
(Garden Way Publishing, Charlotte, VT 05445, 1974, $3.95/paper.)

Energy Future, Roger Stobaugh and Daniel Yergin, eds.
(Random House, 400 Hahn Rd., Westminster, MD 21157, 1979, $12.95.)

Energy Primer, R. Merrill and T. Gage, eds.
(Portola Institute, 485 Hamilton Ave., Palo Alto, CA 94301, 1975, $5.50/paper.)

Trees, Forest Products, and Forest Management.
(Subject Bibliography-086. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, free.)

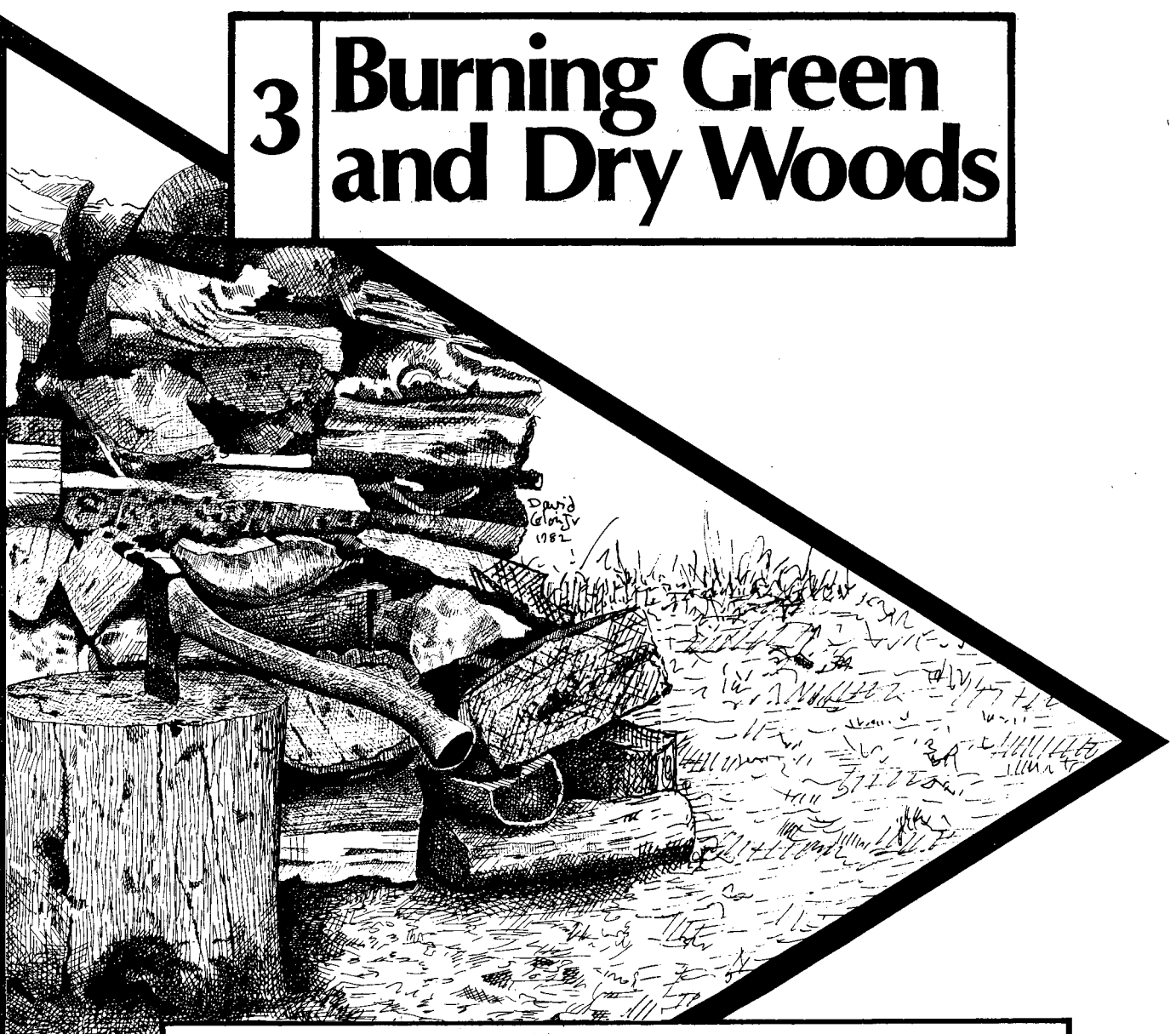
Wood Handbook: Wood as an Engineering Material.
(Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, $10.00.)

Wood Heat, John Vivian.
(Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049, 1978, $7.95/paper.)

The Woodburner's Encyclopedia, Jay Shelton.
(Dell Publishing Co., Inc., 245 E. 47th St., New York, NY 10017, 1980, contact the publisher for price.)

"Bioconversion," Factsheet #1, John and Kathryn Fowler.
(Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830, 1976, free.)

# 3 Burning Green and Dry Woods



Wood is such hard, solid stuff that we seldom think of it as containing water. But if you recall that until it is cut the wood is a living, growing plant, you will realize that it must contain water. In fact, many freshly cut woods contain as much water as they do wood itself.

As you can imagine, all that water could present quite an obstacle to burning. In this activity you will be comparing the heat contents of green and dry woods. You'll see which woods burn better and which provide more usable heat.

# objectives

At the completion of this activity, you should be able to

- o assemble and use a simple calorimeter,
- o calculate the amount of heat released by samples of different woods,
- o compare the amounts of heat released by green and dry hardwoods and by green and dry softwoods of the same species,
- o compare the amounts of heat released by equal masses of dry hardwoods and dry softwoods, and
- o determine which kind of wood and what condition of dryness provide the greatest amount of heat.

# skills and knowledge you need

Measuring metric volume with a graduated cylinder and a pipette

Using a metric balance

Performing simple mathematical calculations

# materials

a can calorimeter

a ringstand (or pegboard) and clamp

a 17 ml low-form crucible

a large test tube

tongs

a metric balance

a 50 ml graduated cylinder

a 1 ml pipette graduated in tenths

methanol

a thermometer ($-10^{\circ}$ to $110^{\circ}C$)

matches

samples of green and dry hardwoods and softwoods

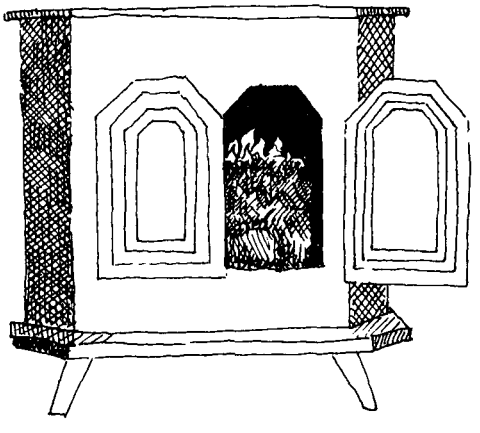
a knife or planer

a flask or beaker (for smothering embers)

a wax pencil

safety goggles and a lab apron

a calculator (optional)

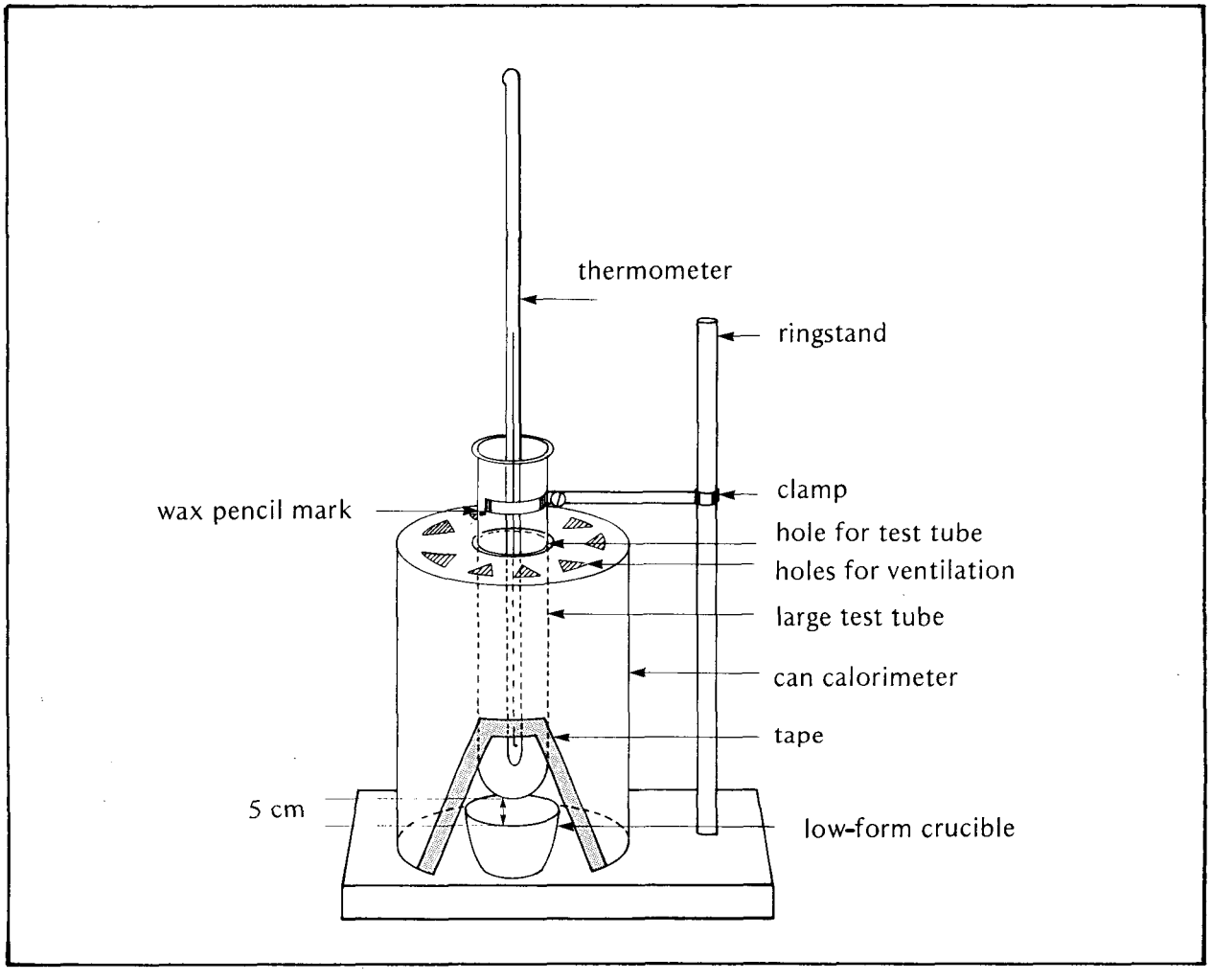


# procedure

1. Fill the test tube with 25 ml of room temperature water.

2. Adjust the ringstand, clamp, and can calorimeter so that the clamp is positioned directly over the hole in the top of the can. (See the diagram.) Place the test tube in the clamp so that it is suspended through the hole, approximately 5 cm above the crucible.

*Caution: Wear safety goggles and lab aprons when working through this procedure.*




3. With a wax pencil, mark the test tube where it touches the bottom of the clamp. This mark will allow you to keep the test tube's height above the crucible constant throughout the activity.

4. Place the thermometer in the test tube. When the temperature stops changing, record it in the appropriate space in the "Methanol" column of the data table.

5. As quickly as possible, pipette 0.5 ml of methanol into the crucible and place the crucible under the test tube.

*Caution: Perform this activity in a well-ventilated room only.*

6. Carefully ignite the methanol.

*Caution: A thermometer should not normally be used as a stirring rod, so stir the water very gently.*

7. Hold the thermometer away from the bottom of the test tube and stir gently for an even distribution of heat. This will prevent a falsely high temperature reading.

8. At the same time, use the tongs to move the crucible as needed to keep the flame directly under the test tube.

9. When the methanol has completely burned, read the final temperature of the water. Record this temperature in the appropriate space on the data table.

10. Determine the change in water temperature ($\Delta T$) caused by burning the methanol. Record this value in the appropriate space on the data table.

11. Mass the empty crucible and record its mass in the appropriate space at the top of the data table.

*Caution: Use the knife or planer carefully, as instructed by your teacher.*

12. Using the knife or planer, make shavings of the wood sample to be tested. Size of shavings is extremely important. The shavings should be thin and as uniform as possible from one sample to another. Add 1 gram of the shavings to the crucible.

    Record the combined mass of the crucible and wood sample in the appropriate space on the data table.

13. Clean the bottom of the test tube to remove soot and resins. Refill the test tube with 25 ml of room temperature water and replace it in the apparatus so that the wax pencil mark is at the bottom of the clamp. Record the temperature of the water in the data table.

14. As rapidly as possible, pipette 0.5 ml of methanol onto the shavings, move the crucible under the test tube, and ignite the shavings.

15. Again, move the crucible as needed to keep the flame under the test tube. Holding the thermometer away from the bottom of the test tube, stir gently until the flame goes out. Immediately read the final temperature of the water and record it in the data table.

16. Remove the crucible from the calorimeter with tongs and smother the embers by placing the bottom of the beaker or flask over the crucible.

17. Mass the crucible and wood residue and record the value in the data table. Dispose of the wood residue as directed by your teacher.

18. Determine the change in temperature of the water and record it in the data table. Then subtract that portion of the change in temperature caused by the burning methanol (found next to $\Delta$ T water in the "Methanol" column).

$$\Delta T \text{ (water)} - \Delta T \text{ (due to methanol)} = \Delta T \text{ (due to wood)}$$

The resulting value ($\Delta$T due to wood) is the change in temperature of the water caused by <u>just</u> the burning wood. Record this value in the data table.

19. Determine the change in mass of the wood ($\Delta$M) caused by burning and record it in the data table.

20. Repeat Steps 12-19 for each of the remaining wood samples.

21. Calculate the calories of heat released per gram for each wood sample. A calorie is the amount of heat needed to raise the temperature of one gram of water 1°C. In this activity the burning wood raised the temperature of 25 ml of water. Twenty-five milliliters of water have a mass of 25 grams. Use the following formula.

$$\text{Heat released by wood sample (calories/gram)} = \frac{\Delta T \text{ (due to wood)} \times 25 \text{ g}}{\Delta M \text{ (g)}}$$

The top line of the equation represents the number of calories of heat added to the water by the burning wood. The bottom line is the mass of the wood actually burned.

## questions

1. Which of the wood samples did you expect to have the highest heat content? Why?

2. Did your results support this expectation?

3. Did your results agree with those of other groups? If not, describe any factors which could have produced discrepancies.

4. Why was methanol used throughout the procedure? Why did you begin the procedure by burning just methanol?

5. According to your results, did green or dry hardwood of a particular species release the most heat? Explain.

6. According to your results, did softwood or hardwood of equal mass release the most heat? Explain.

7. What are the two independent variables in this investigation? Of the two, which accounts for the greater difference in the heat released by a sample of wood? Explain.

8. You may have found that for some green woods the $\Delta T$ due to wood was less than the $\Delta T$ due to methanol. What happened to the heat energy from the burning green wood?

9. Some wood stove owners prefer to use a mixture of dry and green wood in their wood stoves. Is there any advantage to this procedure? Explain.

10. Use your results from this activity to explain how you would select, prepare, and use a cord of firewood in order to receive maximum heat from burning it.

# looking back

When you are trying to save on fuel bills it may be very tempting to burn whatever wood you can obtain, even if it's rather green. This activity should have shown, however, that harvesting wood to allow plenty of drying time makes more sense.

When you burn green wood, you have to assume that part of its heat value is going up in vapor. With all the work of cutting, hauling, splitting, and stacking, you certainly ought to try to get the most out of every piece of firewood. Proper drying will help you to do just that.

# going further

If you performed the previous activity, "Wood: Stored Solar Energy," compare its results with the results of this activity. One Btu equals 252 calories. Convert units into one common unit.

Investigate other problems associated with burning green wood.

Investigate methods of drying wood which decrease the amount of time required for it to season (dry sufficiently for optimal burning).

Find out how a buyer of wood determines whether it's green or dry.

Investigate whether all species of wood have the same moisture content when freshly cut.

Conduct a survey of local firewood dealers. Determine species of wood sold, moisture content, degree of seasoning, heat content/cord, cords sold per season, prices, and average amount purchased per buyer.

Use the information in the table below to determine the number of calories in a cord of each of the dry wood species you tested.

Calories/cord = grams/cord x calories/gram

Calories/gram is the value you obtained in your tests. Which woods provide the greatest heat value per cord? Investigate the reasons for this.

| Type of Wood | Grams/Cord (air-dry) |
|---|---|
| Apple | 1,560,000 |
| Ash | 1,560,000 |
| Aspen | 980,000 |
| Beech | 1,705,000 |
| Birch, Yellow | 1,670,000 |
| Fir, Douglas | 1,090,000 |
| Elm, American | 1,315,000 |
| Hickory, Shag | 1,925,000 |
| Maple, Red | 1,450,000 |
| Maple, Sugar | 1,670,000 |
| Oak, Red | 1,670,000 |
| Oak, White | 1,780,000 |
| Pine, Eastern White | 945,000 |
| Pine, Southern Yellow | 1,180,000 |
| Poplar, Balsam | 945,000 |

## Data Table

Mass of empty crucible: _____g

| | Methanol | Dry Hardwood | Green Hardwood | Dry Softwood | Green Softwood |
|---|---|---|---|---|---|
| Final T (water) | | | | | |
| - Beginning T (water) | | | | | |
| $\Delta T$ (water) | | | | | |
| - $\Delta T$ (due to methanol) | | | | | |
| $\Delta T$ (due to wood) | | | | | |
| Beginning mass (crucible + wood) | | | | | |
| - Final mass (crucible + wood residue) | | | | | |
| $\Delta M$ (wood) | | | | | |
| Calories released/ gram of wood | | | | | |

Teacher Information

# Burning Green and Dry Woods

## Suggested Grade Level and Discipline

Science, grades 10-12
Biology
Chemistry
Advanced Biology

## Skill Objectives

Assembling and using a calorimeter

Measuring volume with a pipette and a graduated cylinder

Measuring mass with a metric balance

Practicing laboratory technique

Calculating heat content

Comparing, interpreting, and analyzing data

## Major Understandings

Green wood has a higher moisture content than seasoned wood.

Green wood provides less available heat (calories/gram) than dry wood because some of the heat energy released by burning green wood is absorbed when the moisture in the wood vaporizes. This vapor is generally lost up the chimney and is not available to provide heat energy when it condenses.

In general, nonresinous softwoods have lower heat contents than hardwoods, while highly resinous softwoods have higher heat contents. Most hardwoods have equivalent heat contents.

To provide the maximum amount of heat, firewood should be as dry as possible.

## Background

Over the last decade, wood has been rediscovered as a fuel. With the escalating cost of fossil fuels more and more homeowners have turned to wood as a primary or auxiliary source of energy for space heating. Since structural wood for building is the most important use of wood, we need to ensure that our forests and woodlots are managed for this higher use.

One way to manage wood effectively is to use only culls, scrub wood, dead trees, and waste industrial wood as firewood, and to burn this firewood as efficiently as possible. Yet a recent survey undertaken in Maine indicates that most consumers of cord wood are purchasing green wood. Burning wood in a green state results in a significant loss of its energy potential. Freshly cut wood may contain just as much water by weight as it does wood fiber. Each gram of water in wood will reduce the usable heat by 670 calories (1210 Btu/lb.), the heat energy required to vaporize a gram of water and heat it to the temperature of the flue gases.

The moisture content of wood is generally given as a percentage and is calculated in the following manner.

% Moisture Content =

$$\frac{\text{Original weight - Oven dry weight}}{\text{Oven dry weight}} \times 100$$

If a piece of firewood contains equal weights of wood and water, it will have a moisture content of 100%. The moisture content of firewood can be determined by the homeowner by weighing a piece on a bathroom scale and then drying it in the oven at 220°F until it reaches a constant weight.

Freshly cut firewood may contain between 45% (ash) and 120+% (sycamore) moisture, according to the species and time of year. When burned, this means that between 8 and 20 percent of its heating value is lost. Green wood should be seasoned (allowed to dry) for 3 - 9 months, depending on weather conditions, the location of the wood, and how

it is split and stacked. Firewood should be stacked so that sunlight and wind can remove the moisture, but at the same time should be protected from precipitation. If stored outside, firewood will season to a 15 - 19% moisture content. This decreases to a 12 - 14% moisture content for wood stored in a wood shed and 6 - 10% for wood stored indoors.

Besides decreased available heat, there are other reasons for not burning green wood. Water vapor in wood contributes to less complete combustion, poorly burning fires, difficulties in igniting the wood, and a cooling of flue gases that may lead to creosote build-up.

(For more information on the heat contents of hardwoods and softwoods, see the previous activity's teacher background section.)

## Advance Planning

Start collecting cans to make the calorimeters. One pound coffee cans and 46 oz. juice cans work well.

Construct the can calorimeters as shown in the student diagram. Use metal cutters to remove a triangular-shaped piece from the open end of the can. Tape with strapping tape to prevent cuts. Make ventilation holes in the top with a can opener. Cut a center hole just large enough to hold a test tube.

Cut green wood no sooner than 1 or 2 days before the activity.

Assemble ringstands, clamps, metric balances, and other needed equipment and supplies.

Determine how the wood residue will be disposed of.

If, for safety reasons, you hesitate to have students make their own shavings or if you wish to save class time, prepare shavings ahead of time and store them in an airtight container in a freezer.

## Suggested Time Allotment

Two class periods to perform the activity

One class period to answer questions and discuss results

## Suggested Approach

Try to perform this activity during the heating season, when student interest will be high.

Introduce the activity by discussing the growing importance of wood as a fuel. If appropriate, allow students to relate their own experiences with wood burning. Try to elicit from them some of the variables which affect wood burning.

Stress the importance of laboratory technique in this investigation. If necessary, demonstrate how to use a metric balance and give instruction in pipetting technique.

Students may work in groups of two or three.

If you have several different species of hardwoods and softwoods for students to test, consider giving different samples to different student groups and allowing students to share data later.

Before beginning the investigation, ask students to predict the heat contents of the various kinds of wood.

Work through a sample calculation as a demonstration, then help students with the calculations as needed.

Invite a forester to speak to the class about management of woodlots and forest resources for multiple uses.

## Precautions

*This activity should be performed under a hood or in a well-ventilated room.*

*Technique is crucial to the success of this activity. Make sure students follow all directions carefully.*

*Remind students to follow all safety precautions in the procedure, including the use of safety goggles and lab aprons.*

*Make sure students prepare shavings in a safe manner, as instructed.*

## Points for Discussion

In a wood stove, what is used instead of methanol to start a fire? To help green wood burn?

What are some of the safety hazards associated with burning green wood?

Why does a cord of green wood have a greater mass than a cord of dry wood of the same species?

If this activity were performed using equal volumes rather than equal masses of green and dry woods, how would the results have changed? Explain.

## Typical Results

Heat contents will be lower for green woods than for dry woods. Values for dry woods will be similar unless highly resinous dry softwoods have been tested. An accepted value for the heat content of hardwoods dried to a 20% moisture content is 3220 calories/gram (5800 Btu/lb.).

Values for heat content may vary among student groups because of differences in laboratory technique.

## Evaluation

Observe students' technique in using the calorimeter.

Check data tables for accuracy and completeness.

Review answers to questions for accuracy, completeness, and degree of understanding.

Give students sample data and ask them to identify the kinds of woods (green woods, dry woods, hardwoods, softwoods) based on a comparison of the values given.

Ask students to list kinds of wood in decreasing order of heat content.

## Modifications

If time is short, do the green wood portion of the activity as a demonstration, then provide dry wood shavings for students to test. Assign calculations and questions as homework.

## References


Burning Wood, Cooperative Extension, Northeast Regional Agricultural Engineering Service.
(Distribution Center, 7 Research Park, Cornell University, Ithaca, NY 14850, $1.00.)

Heating with Wood, U.S. Department of Energy.
(Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.)

The Woodburner's Encyclopedia, Jay Shelton.
(Dell Publishing Co., Inc., 245 E. 47th St., New York, NY 10017, 1980, contact the publisher for price.)

"Firewood Use and Misuse," E. W. Swain.
(Maine Audubon Quarterly, Winter 1978-79, Maine Audubon Society, Falmouth, ME 04105.)

"Seasoning Firewood," David W. Taber.
(Wood Utilization Service, SUNY College of Environmental Science and Forestry, Syracuse, NY 13210.)

"Tips for Firewood Users," David W. Taber.
(Wood Utilization Service, SUNY College of Environmental Science and Forestry, Syracuse, NY 13210.)

DO NOT MICROFILM
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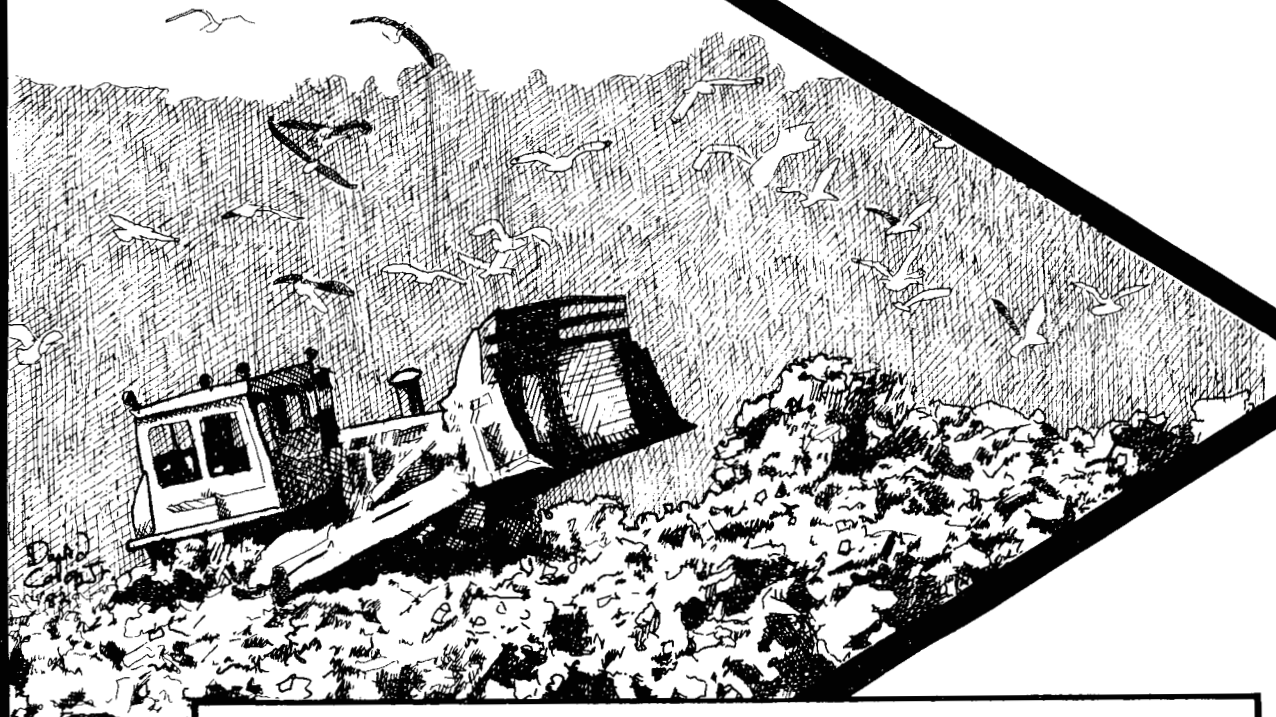
# 4 Fuels from Organic Wastes



All the fuels we use commonly today -- oil, coal, and natural gas -- came originally from living matter. They are called fossil fuels because they are the concentrated remains of long-dead plants and animals. What this tells us is that the physical components of today's fuels exist in organic matter also. Somehow, in plant and animal wastes, paper and scraps and sawdust, is the raw material for oil, coal, and gas, those precious fuels whose shrinking supplies we anxiously watch. For this reason, organic wastes are receiving serious attention today, as a potential fuel for the future.

# objectives

At the completion of this activity, you should be able to

- o assemble and use a laboratory apparatus that decomposes organic wastes,
- o determine the kinds of products produced by this decomposition,
- o define the term pyrolysis, and
- o explain why pyrolyzed organic wastes are considered a form of solar energy.

# skills and knowledge you need

The ability to use a bunsen burner

The ability to perform basic laboratory techniques safely

A knowledge of different fuels and their characteristics

# materials

a bunsen burner with wing tip attached

a ringstand and clamp

two pyrex test tubes

two stoppers fitted with glass tubing (as shown in the diagram)

wood splints

matches

a cold mirror or piece of glass (edges taped)

a watch glass

a crucible

a hot pad

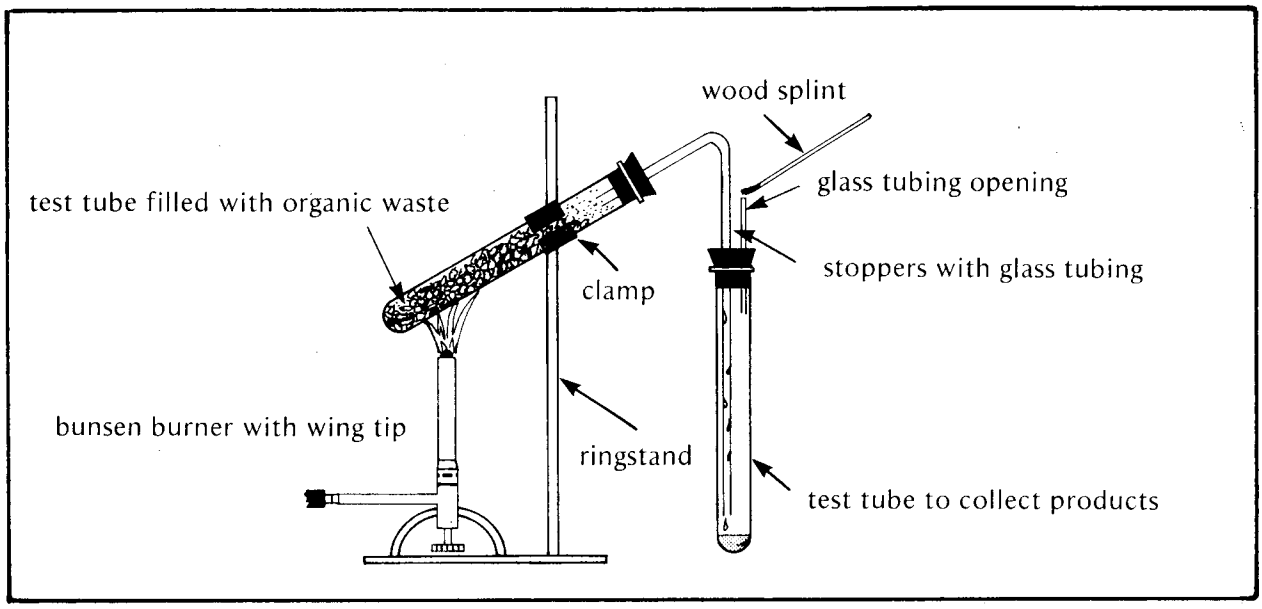
safety glasses and a lab apron

| | | |
|---|---|---|
| wastes: | paper | cardboard |
| | ice cream sticks | dried potato peels |
| | paper bags | shredded dry plant material |
| | sawdust | |

# procedure

*Caution: This activity may produce small amounts of harmful gases, so perform the activity only under a hood.*

1. Assemble the laboratory equipment as shown in the diagram.




2. Fill the left-hand test tube with one kind of waste and adjust the clamp so that the bottom of the test tube is 5 cm above the bunsen burner.

*Caution: Wear safety glasses and a lab apron throughout the activity.*

3. Have your teacher approve your set-up, then light the bunsen burner.

4. After one minute, place a glowing wood splint at the opening of the glass tubing. Record your observations in the data table. If nothing happens, use a hot pad to adjust the ringstand clamp and move the test tube slightly closer to the burner flame. Repeat this step until something happens and you can record your observations in the data table.

5. Place a cold mirror or piece of glass at the opening of the glass tubing. Observe what happens and record your observations in the data table.

6. Observe the material collecting in the upright test tube. Record your observations in the data table.

7. Observe the material collecting along the sides of the left-hand test tube. Record your observations.

8. Observe the material remaining at the bottom of the left-hand test tube. Record your observations.

*Caution: Disconnect the upright test tube before you turn the bunsen burner off, or distilled products may back up into the left-hand tube.*

9. Continue heating the waste for a total of at least 10 minutes, then disconnect the upright test tube and turn the bunsen burner off. Pour two or three drops of the liquid in the upright test tube into a watch glass. Try to ignite the liquid (this may or may not work). Record your observations in the data table. Dispose of the test tube and its remaining contents as directed by your teacher.

*Caution: Handle broken glass with extreme care.*

10. Remove some of the material from the bottom of the left-hand test tube. You may have to break open the test tube to collect this material. If so, to prevent flying glass, wrap the test tube in cloth or paper towel before hitting it with another object. Dispose of the broken glass immediately.

11. Place the material collected from the left-hand test tube in a crucible. Examine it and record your observations in the data table.

12. Place the crucible under the hood and ignite its contents. Record your observations.

*Caution: Do not try this procedure on plastic wastes. Hazardous gases will be produced.*

13. Repeat Steps 1-12 for other kinds of organic wastes.

# questions

1. What happened when you held the glowing splint at the opening of the glass tubing? Could you use the substance issuing from the opening as a fuel? Why or why not?

2. In what physical state (solid, liquid, or gas) was the substance issuing from the glass tubing? What kind of fuel does this substance resemble?

3. What happened when you held the mirror or glass to the glass tubing opening? What substance caused this?

4. In what state was the substance collected in the upright test tube? What happened when you tried to ignite it? What kind of fuel does this substance resemble?

5. If the substance in the upright test tube did not ignite, use your answer to Question 3 to explain why.

6. In what state was the substance collected at the sides of the left-hand test tube? What kind of fuel does this substance resemble?

7. In what state was the substance remaining at the bottom of the left-hand test tube? What kind of fuel does this substance resemble?

8. What happened when the substance from the bottom of the test tube was ignited?

9. When you repeated the activity with other organic wastes, how did the results differ?

10. Were the organic wastes heated in the presence or absence of oxygen? How do you know?

11. The scientific term for the laboratory process you have just completed is pyrolysis. From your knowledge of this process and your answer to Question 10, define pyrolysis.

12. Why are fuels obtained from organic wastes considered a kind of solar energy?

## looking back

You have just observed the breakdown of organic wastes to produce products very much like fossil fuels. Gaseous, liquid, and solid fuels can be generated from wastes by pyrolysis, a process like the one you carried out, where wastes are heated in the absence of oxygen.

Pyrolysis is not the only, or necessarily the best, way of using wastes for fuel. For one thing, as you probably noticed, the process of pyrolysis itself uses energy. You had to heat the test tube with a flame to break down the wastes into component fuels. Pyrolysis is just one of the many ways of getting energy from organic wastes that are being explored for their future energy potential.

## going further

Investigate the process known as destructive distillation. How are destructive distillation and pyrolysis similar? How are they different? Repeat the activity again, performing a destructive distillation of wood or coal. Find out the products of destructive distillation of wood and of coal.

Investigate the industrial processes used to make charcoal and coke. What are the uses of charcoal and coke? What are the by-products of charcoal and coke manufacture and how are the by-products used?

What are the advantages of turning organic wastes into fuels? The disadvantages?

Investigate direct combustion of organic wastes, another way to use organic wastes as fuel. Find out if any of your area municipalities burn organic wastes as fuel. If so, schedule a field trip to a plant to see how the process works.

Design and carry out an experiment to determine which wastes produce the largest amounts of gas.

For information on the heat content of wood wastes, try Activity 2 in this book, "Wood: Stored Solar Energy."

## Data Table

| | Observations |
|---|---|
| Upon holding a glowing wood splint to glass tubing opening | |
| Upon holding mirror or glass to tubing opening | |
| Of material collecting in upright test tube<br>a) while still in test tube<br>b) when removed and ignited | |
| Of material collecting on sides of left-hand test tube | |
| Of material remaining at bottom of left-hand test tube<br>a) while still in test tube<br>b) when removed and examined<br>c) when ignited | |

Teacher Information

# Fuels from Organic Wastes

## Suggested Grade Level and Discipline

Science, grades 10-12
Biology and Advanced Biology
Chemistry
Environmental Science

## Skill Objectives

Assembling laboratory apparatus

Using a bunsen burner properly

Making, recording, and interpreting observations

Practicing safe laboratory techniques

Classifying decomposition products from observed properties

## Major Understandings

Organic wastes can be converted into fuels through a process known as pyrolysis.

Pyrolysis is the chemical decomposition of organic wastes by heating them in the absence (or in very limited amounts) of oxygen.

The products of pyrolysis include a low Btu gas, alcohols, a heavy tar-like oil, and char. All of these products are combustible. Pyrolysis also produces water as a by-product.

Pyrolysis of organic wastes is a solar technology because the wastes are biomass, originally produced by the sun's energy through the process of photosynthesis.

## Background

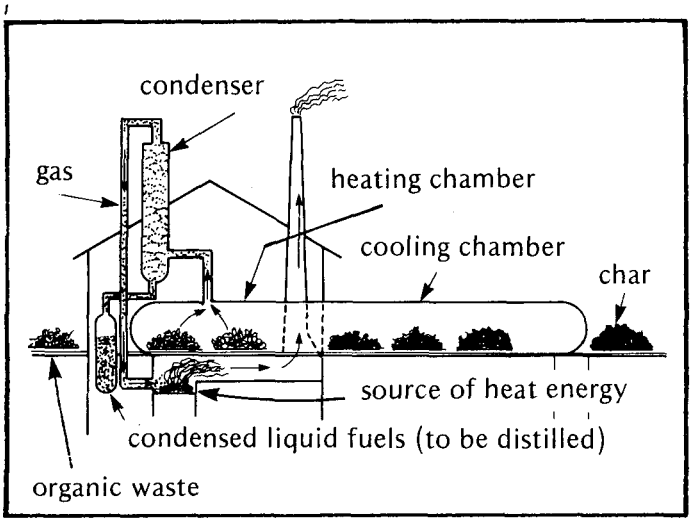
In the United States, the per capita production of trash and garbage is over 1 kilogram per day. Garbage and waste disposal is a major problem, especially in cities, where wastes become highly concentrated. However, much of this garbage consists of organic materials, which are combustible and can either be burned directly to produce energy or can be converted into fuels.

There are other sources of organic wastes also: manure, logging and wood residue, agricultural crop and food wastes, industrial waste, municipal sewage. In fact, it is estimated that the United States produces about 150 million dry tons of easily collectable organic waste every year, equivalent to almost 200 million barrels of oil.

While direct burning is the most common method of producing energy from organic wastes, pyrolysis is increasingly being considered as an alternative. Both methods currently have lower costs than conventional disposal methods. Pyrolysis is especially attractive as one portion of a total municipal waste disposal system in which wastes are both recycled and converted into fuel.

Pyrolysis should never be considered, though, as a preferred method of producing energy. Energy in the form of heat must be applied to cause pyrolysis, and the recovery of that energy from the raw wastes is only 75%. We can save more energy than we gain from pyrolysis by practicing conservation at the source, producing less trash in the first place and recycling what is produced. Using less highly-packaged goods and recycling paper are examples. We need to consider, too, other uses for organic wastes: livestock fodder, fertilizer, compost, anaerobic digestion to produce methane, fermentation and distillation to produce alcohols. Some of these processes may have higher economic value (such as the use of wood wastes in manufacturing particle board) and some may have higher environmental value (such as composting to replenish soil productivity).

However, pyrolysis has its place as one method of disposing of organic wastes, especially where wastes are highly concentrated, as in cities and feedlots, and would produce considerable pollution. Fuels derived from pyrolysis are also virtually sulfur-free. A simplified schematic of a possible commercial pyrolysis facility is shown in the diagram.




In this activity a standard laboratory experiment, the destructive distillation of wood, is changed slightly to demonstrate the pyrolysis of organic wastes. Destructive distillation is essentially the same as pyrolysis: both involve the chemical decomposition of organic substances through the application of heat.

## Advance Planning

Unless you wish to have students practice cutting and bending glass tubing, assemble the stoppers and tubing as shown in the student diagram. These can be reused from class to class. You may want to assemble the entire apparatus in advance of the activity.

Obtain samples of organic wastes. The cafeteria and custodial staffs should be able to provide wastes.

Students will need one copy of the data table for each waste tested.

If desired, duplicate copies of the teacher background section for student use.

Work through the procedure before students try it. Some wastes may not produce certain fuels, and students may not be able to make the observations required in some steps. Trying the procedure will allow you to vary the observations required in the procedure as needed. (For example, some wastes may have such high water contents that the liquid collected in the upright test tube will be mostly water and will not ignite. Other wastes may produce almost no alcohol at all.)

Provide for disposal of the pyrolysis products and broken test tubes. In most cases the heated test tube will not be reusable and must be discarded, unless strong solvents are used to clean it.

## Suggested Time Allotment

One to two class periods to introduce and perform the activity

One class period to answer questions and discuss results

## Suggested Approach

Introduce the activity by explaining how pyrolysis is a way to use biomass for energy and is thus a form of renewable, solar energy.

Students may work individually or in pairs on this activity.

If students will not have time to test more than one waste, assign different wastes to different students, then allow students to share data at the end of the procedure.

Ask students to predict the results of pyrolysis before they actually begin the procedure.

As students answer the questions, discuss the forms of our conventional fuels: gases, such as natural gas and methane; light, thin liquids, such as alcohols and gasoline; dark, heavy liquids, such as oil and tars; solids, such as coal and charcoal. Indicate the similarity of each product in the activity to the appropriate class of fuel, but stress that the procedure used does not allow positive identification of any fuels.

If necessary, help students to define pyrolysis.

## Precautions

*This activity should be performed only under a hood. The pyrolysis procedure will produce very small amounts of nitrous oxide and carbon monoxide.*

*Do not let students decompose plastic wastes. Hazardous gases will be produced from polyvinyl chlorides.*

*Remind students to wear lab aprons and safety glasses.*

*Use only pyrex test tubes in the heating process.*

*Make sure students ignite only a few drops of the distilled liquid.*

*Make sure students wrap test tubes in cloth or paper towel before breaking them. You may want to have students bring test tubes to you so you can break them yourself.*

*The test tube should be filled with organic waste. Otherwise, not enough liquid will collect in the upright test tube to be able to observe or test it.*

## Points for Discussion

What is the potential for use of organic wastes as fuel?

In what locations or situations might the best potential be found?

What are the advantages and disadvantages of using pyrolysis to produce fuels?

Did different organic wastes produce different forms of fuels? Why or why not?

## Typical Results

The gas issuing from the glass tubing resembles natural gas or methane fuel.

The liquids collecting in the upright test tube will be small in amount and will consist of water and oil-like, gasoline-like, and/or alcohol-like fuels.

The substances remaining in the left-hand test tube will be a heavy oil and/or a tar-like substance and char, a form of charcoal. All pyrolysis products, except the water, should support combustion.

## Evaluation

Check students' data tables for accuracy and completeness of observations.

Collect and review the answers to the questions to make sure students' conclusions are supported by their observations.

Ask students to list the kinds of fuels obtained from pyrolysis.

Have students define pyrolysis and explain why pyrolysis is a form of solar energy.

## Modifications

If you do not wish to have students perform this activity themselves, you can demonstrate it for them.

To speed condensation in the upright test tube, place it in a beaker of cold water.

Modify the apparatus to collect the gas by inverting a bottle in water and leading rubber tubing from the glass tubing into the mouth of the bottle.

## References


Energy for Survival: The Alternative to Extinction, Wilson Clark.
(Doubleday & Co., Inc., 501 Franklin Ave., Garden City, NY 11530, 1974, $12.50.)

Energy Primer: Solar, Water, Wind, and Biofuels, ed. by Richard Merrill et al.
(Portola Institute, 485 Hamilton Ave., Menlo Park, CA 94301, 1974, $5.50/paper.)

Introductory Physical Science, Uri Haber-Schaim et al.
(Prentice-Hall Inc., Box 500, Englewood Cliffs, NJ 07632, 1982, contact the publisher for price.)

"Biomass Energy," U.S. Department of Energy.
(Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830, 1980, free.)

"Biomass: Solar Energy from Farms and Forests," Solar Energy Research Institute.
(Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, contact GPO for price.)

"Fuels from Wastes: Bioconversion," Fact-sheet #2, John M. Fowler.
(Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830, free.)

# 5 Your Place in the Sun

There was a time when all the needs of life were met with biomass. Biomass -- the plant products of the earth -- fed, clothed, and sheltered the family, warmed them in winter, and sustained the animals that were their only form of transportation. Pine and oak, corn and potatoes, cotton and flax, hay and oats: the multitude of biomass products satisfied every demand.

What would happen if human beings were forced to return to the land as their only resource? Would biomass satisfy today's needs for today's population?

# objectives

At the completion of this activity, you should be able to

- o define the term biomass energy;
- o determine how much energy your family consumes in meeting its home heating and cooling, appliance operation, food, and transportation needs;
- o calculate your family's total energy use in millions of kilocalories/year;
- o estimate the amount of land your family would require if it were to meet all its energy needs from biomass energy alone; and
- o explain why the use of biomass energy would require this amount of land.

# skills and knowledge you need

The ability to perform simple mathematical calculations

Knowledge of your family's energy use patterns for space heating and cooling, appliance operation, and transportation

# materials

a calculator (optional)

# procedure

## Determining the Energy Used to Heat Your Home

1. Find out the kind of fuel used to heat your home or apartment. Determine how much of this fuel is used in a heating season by asking your parents or looking at your family's heating bills. (If you do not have access to this information, go to Step 3.)

2. Convert the amount of fuel used in a heating season to kilocalories by selecting the appropriate heat equivalent from the table and substituting it in the equation.

$$\text{Millions of kilocalories/year} = \frac{\text{Amount of fuel x Heat equivalent}}{1000}$$

| Amount | Fuel | Heat Equivalent (million calories) |
|---|---|---|
| 1 gallon | home heating oil | 34.78 |
| 1 cubic foot | natural gas | 0.252 |
| 1 kilowatt-hour | electricity | 0.86 |
| 1 cord | softwood | 3276. |
| 1 cord | hardwood | 5796. |

Enter this value in the appropriate space on Data Table 1. Now go to Step 4.

3. If you don't know how much fuel is used to heat your home or apartment, you may use the following table to obtain an approximate number for the kilocalories required per year.

| | Million Kcal/Year |
|---|---|
| Large house (4 or more bedrooms) | 42.3 |
| Medium house (2-3 bedrooms) | 35.3 |
| Small house or mobile home | 28.2 |
| Large apartment | 28.2 |
| Small apartment | 25.2 |

Enter the correct value in the appropriate space on Data Table 1.

## Determining the Energy Used to Cool Your Home

4. Use Data Table 2 to determine the number of kilocalories of energy consumed during a year in cooling your home or apartment. Enter this value in the appropriate space on Data Table 1. If your home is not air-conditioned, leave this space blank.

## Determining the Energy Used to Operate Appliances

5. Data Table 3 lists the average annual energy consumption for many common household appliances. Complete Data Table 3 by filling in the number of each appliance you have and the total energy consumed by each kind of appliance. If you do not have a particular appliance, leave the space blank.

6. Determine the total energy consumed by all appliances by adding the last column. Convert this value to millions of kilocalories by dividing by 1000 and enter the result in the appropriate space on Data Table 1.

## Determining the Energy Consumed in Food

7. To find out the approximate number of kilocalories of food each person in your family consumes every day, use the following table.

| | Kcal Consumed/Day |
|---|---|
| Adult Male | 3,000 |
| Adult Female | 2,200 |
| Teenage Male | 3,070 |
| Teenage Female | 2,310 |
| Child | 1,800 |

Use the equation below to find out how many kilocalories of food your family consumes per year.

Total kilocaries of food/year = (kcal consumed by Person 1 ...
+ kcal consumed by Person 2 ...
+ kcal consumed by Person N) x 365

8. Convert this value to millions of kilocalories by dividing by 1,000,000. Enter the resulting number in the appropriate space on Data Table 1.

## Determining the Energy Used in Transportation

9. (If your family does not own a car or other vehicle, go to Step 11.) Find out the distance each family vehicle is driven per year and its miles/gallon. If you are not able to obtain actual distance and miles/gallon figures, you may substitute the following approximations.

| | Yearly Mileage |
|---|---|
| If a one-way commute to work is 20 miles | 15,000 |
| If a one-way commute to work is 10 miles | 10,000 |
| If the vehicle is used only for errands or pleasure | 5,000 |

| Class of Car | Miles/Gallon |
|---|---|
| Subcompact | 34 |
| Compact | 24 |
| Intermediate-sized car | 19 |
| Luxury car | 17 |
| Pick-up truck (standard) | 18 |
| Pick-up truck (mini) | 27 |
| Van | 17 |
| Diesel-powered subcompact | 45 |
| Diesel-powered (any class) | 20% more than gasoline |
| Gasohol-powered car (any class) | about the same as gasoline |
| Methanol-powered car (any class) | slightly better than gasoline |

10. To determine the number of calories of energy consumed by each family vehicle per year, use the following equation.

$$\text{Million calories/year} = \frac{\text{Total miles}}{\text{miles/gallon}} \times 31.5 \text{ million calories/gallon}$$

(For diesel fuel, multiply by 34.8 million calories/gallon.)

Convert millions of calories to millions of kilocalories by dividing by 1000. Enter the resulting value for each vehicle in the appropriate space on Data Table 1.

## Determining Your Family's Total Yearly Energy Use

11. Find your family's total energy use per year (in millions of kilocalories) by adding the values in Data Table 1. Enter the total in the appropriate space.

## Determining the Land Required to Meet Your Family's Energy Need If the Only Source of Supply Is Biomass

12. Let's suppose your family had to receive its total energy requirement from biomass. How much land would your family need? One estimate for the amount of dry biomass that one square meter of land can supply on a sustainable basis is 250 grams. One gram of biomass, when simply harvested, dried, and burned, can yield as much as 4 kilocalories of energy.

But sometimes the biomass will have to be converted to another fuel, such as oil or gasoline, before it can be used. This conversion is not very efficient. Data Table 1 contains approximate conversion efficiencies for each category of energy use. The assumptions behind the conversion values are the following.

a. Wood is used to heat the home without processing to a second fuel, so the conversion factor is 1. The efficiency of wood burning is assumed to be the same as oil or natural gas.

b. Biomass is burned directly to produce electricity so the conversion factor is 1. The efficiency of conversion is equivalent to other methods of producing electricity.

c. All food energy comes from plants (no meat is eaten). On the average, about 40% of a plant is edible.

d. Biomass must be converted to gasoline before it can be used to fuel cars. The efficiency of this conversion is about 35%.

To find out, then, how much land your family would need to meet its energy requirement from biomass, substitute in the following equation for each category of energy use.

$$\text{Amount of land required } (m^2) = \frac{\text{Your family's energy requirement (kcal)}}{1000 \text{ kcal/m}^2 \times \text{conversion factor}}$$

Enter each value in the appropriate space in the last column of Data Table 1. Add the column to find the total land area required.

13. The table below will give you some idea of what this amount of land is equivalent to.

| | Square Meters |
|---|---|
| 1 small city block or a football field (100 m x 100 m) | 4,000 |
| 1 large city block (500 m x 500 m) | 250,000 |
| 1 small house lot (approx. 100 ft. x 100 ft.) | 930 |
| 1 large house lot (approx. ½ acre) | 2,000 |
| 1 acre | 4,047 |
| 1 small farm (approx. 100 acres) | 400,000 |
| 1 large farm (approx. 1000 acres) | 4,000,000 |
| 1 square mile | 2,590,000 |

## questions

1. For which category of energy use in Data Table 1 did your family require the most land? The least land?

2. How much land was required to meet your family's food needs?

3. How much land was required to meet your family's total energy need?

4. Do you live on a large enough plot of land to meet just your family's food needs? To meet your family's total energy requirement?

5. What is meant by the term biomass energy?

6. Why is so much land required to meet your family's energy need when biomass energy is the only source?

7. Why are fossil fuels so important as an energy source?

8. What are some ways in which you could reduce your family's total energy requirement?

9. The purpose of the assumptions made in Step 12 was to simplify the calculations in this activity. In what ways are each of these assumptions inaccurate or misleading?

## looking back

A close look at the energy demands of today's typical American family, or your own family, reveals one central fact: most Americans use a staggering amount of energy. Even the things that we regard as the bare necessities of life have become "energy-intensive."

Today many people in developing countries still meet most of their needs with direct use of biomass: wood for fuel and homegrown food and cloth. But their lives tend to be much harder and less comfortable than ours.

What conclusion did you draw about the amount of land required to meet your family's needs? Did it seem like a reasonable amount of land for every family in the country to own? In the world? The calculations you have just done should raise a number of questions in your mind about the amount of energy we use, and where our future energy will come from.

## going further

How much land would be required to meet the energy needs of your class members? Your school population? Your village or city population?

World population is now estimated at 4.5 billion persons. If each person consumed 3000 kcal of plant food per day (1.1 million kcal/year), the dietary requirement for an active adult, how many square meters of land would be required to meet this demand? (Use the values given in Step 12.) If half of the required calories were obtained from meat, which requires at least 10 times the amount of land, how much land would be required? If the earth's total of potential arable land is 32,000 billion square meters of cropland and 32,000 billion square meters of grazing land, how many people could the earth support?

Biomass may be used to provide food, textiles, construction products, chemicals, and fuels. Investigate what has been called the "food vs. fuel" controversy surrounding the use of biomass for fuels. Report to the class on your findings.

The U.S food industry is highly mechanized and energy intensive. In fact, for every calorie of food eaten at the table at least 9 calories of energy are required to put it there. Investigate the many ways in which energy is used in producing and processing our food and delivering it to our tables. What are the implications of this energy-intensive food production for the future?

Biomass is the main soil nutrient. Investigate the meaning of this statement. If biomass was collected and converted to fuel, and not recycled to the soil, what would happen to soil productivity?

One readily available source of biomass energy is organic waste disposed of in landfills or dumped at sea. For more information on how organic wastes produce biomass energy, try the previous activity, "Fuels from Organic Wastes."

## Data Table 1

### Your Family's Yearly Energy Use in Millions of Kilocalories

| | Million Kcal/Year | Conversion Factor | Land Area Required to Provide This Energy ($m^2$) |
|---|---|---|---|
| 1. Energy used to heat your home | | 1.0 | |
| 2. Energy used to cool your home | | 1.0 | |
| 3. Energy used to operate appliances | | 1.0 | |
| 4. Energy consumed in food | | .4 | |
| 5. Energy used in transportation | | | |
| Vehicle 1 | | .35 | |
| Vehicle 2 | | .35 | |
| Vehicle 3 | | .35 | |
| | | | |
| Total | | | |

# Data Table 2

## Annual Energy Requirements for Cooling

Directions:

1. Select either the city nearest your home or the city whose climate is most nearly like that of your own area.

2. Multiply the number given next to that city by the number of rooms in your home which are air-conditioned.

3. The resulting number will be an estimate of how many million kilocalories are consumed in cooling your home during the cooling season.

| City | Estimated Million Kilocalories Consumed/Year for Each Room Cooled |
|---|---|
| Albuquerque, NM | 0.740 |
| Atlantic City, NJ | 0.444 |
| Birmingham, AL | 1.035 |
| Boston, MA | 0.444 |
| Burlington, VT | 0.222 |
| Charlotte, NC | 0.592 |
| Chicago, IL | 0.518 |
| Cleveland, OH | 0.370 |
| Cincinnati, OH | 0.814 |
| Columbia, SC | 0.961 |
| Corpus Christi, TX | 1.553 |
| Dallas, TX | 0.961 |
| Denver, CO | 0.370 |
| Des Moines, IA | 0.518 |
| Detroit, MI | 0.592 |
| Duluth, MN | 0.296 |
| El Paso, TX | 0.814 |
| Honolulu, HI | 1.257 |
| Indianapolis, IN | 0.592 |
| Little Rock, AR | 1.183 |
| Minneapolis, MN | 0.370 |
| New Orleans, LA | 1.183 |
| New York, NY | 0.518 |
| Newark, NJ | 0.444 |
| Oklahoma City, OK | 0.961 |
| Pittsburgh, PA | 0.740 |
| Rapid City, SD | 0.666 |
| St. Joseph, MO | 0.888 |
| St. Petersburg, FL | 1.257 |
| San Diego, CA | 0.740 |
| Savannah, GA | 0.961 |
| Seattle, WA | 0.444 |
| Syracuse, NY | 0.296 |
| Trenton, NJ | 0.666 |
| Tulsa, OK | 1.257 |
| Washington, DC | 0.666 |

Based on data from the ASHRAE Handbook and Product Directory, 1976, and from Edison Electric Institute's "Annual Energy Requirements of Electric Household Appliances" and "Air-Conditioning Usage Study."

## Data Table 3

## Annual Energy Requirements of Household Appliances

| Appliance | Million Calories Consumed/Year | Number of Appliances | Total Energy Consumed |
|---|---|---|---|
| Electric blanket | 126.4 | | |
| Clock | 14.6 | | |
| Clothes dryer | 854.0 | | |
| Coffee maker | 120.4 | | |
| Dishwasher | 312.2 | | |
| Fan (attic) | 250.3 | | |
| Food freezer | 1,565.2 | | |
| Food mixer | 1.7 | | |
| Food waste disposer | 6.1 | | |
| Frying pan | 0.4 | | |
| Furnace fan | 559.0 | | |
| Hair dryer | 21.5 | | |
| Heater (portable) | 151.4 | | |
| Hot plate | 77.4 | | |
| Iron | 51.6 | | |
| Lighting | 831.6 | | |
| Microwave oven | 163.4 | | |
| Radio | 74.0 | | |
| Radio/Record player | 93.7 | | |
| Range | 602.0 | | |
| Refrigerator (automatic defrost) | 1,935.0 | | |
| Sewing machine | 9.5 | | |
| Shaver | 0.4 | | |
| Television (black/white) | 86.0 | | |
| Television (color) | 275.2 | | |
| Toaster | 33.5 | | |
| Vacuum cleaner | 39.6 | | |
| Washer (automatic) | 88.6 | | |
| Water heater (electric only) | 4,137.5 | | |
| Total | | | |

Source: Edison Electric Institute. Data from "Annual Energy Requirements of Electric Household Appliances" used with permission.

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Teacher Information

# Your Place in the Sun

## Suggested Grade Level and Discipline

Science, grades 9-12
Biology and Advanced Biology
Ecology
Environmental Issues and Problems
Mathematics

## Skill Objectives

Determining family energy use

Converting energy use to millions of kilocalories/year

Estimating land requirements to meet family energy needs through biomass energy

Interpreting and analyzing data

## Major Understandings

Biomass is plant material, derived from solar energy through the process of photosynthesis.

Biomass energy is the energy released when biomass is eaten, burned, or converted into fuels.

A typical American family consumes an enormous amount of energy per year (the equivalent of over 200 barrels of oil). The land required to meet this energy need through biomass alone would be substantial.

The amount of land required to meet just a family's food requirement is relatively small.

Biomass energy converted to uses other than food will be able to meet only a small portion of world energy needs. However, this potential will be significant in the world's future energy mix.

## Background

Solar energy produces biomass through the process of photosynthesis. This process is extraordinarily inefficient: only about .1% of the solar energy striking a plant is actually converted into plant tissue.

Traditionally, biomass has been a major source of energy for meeting human energy needs. It has, of course, supplied all our food and, until the advent of fossil fuel use, was our primary fuel. But biomass alone, without those vast stores of "fossil biomass" — coal, oil, and natural gas -- accumulated over millions of years, could not begin to meet the modern world's energy needs. If the total yearly U.S. agricultural production, including food, wood, and fiber, were used for energy, it would meet only 25% of the nation's annual energy need. However, crop residues, animal wastes, and crops grown for fuel can make a significant contribution, perhaps as much as 10% of U.S. energy consumption.

The biomass fuels are several: ethanol, a liquid fuel which can be derived economically from corn, sugar cane, and sorghum; methane, a gaseous fuel derived from animal wastes; methanol, a liquid fuel derived from the destructive distillation of wood in the absence of oxygen; and fuel oil and char, derived from the pyrolysis of organic wastes. The advantages of biomass energy include its renewability as a resource, the well-developed technologies for producing it, and its reduction of polluting wastes in such places as landfills and feedlots.

A major concern about using biomass as a source of fuel is whether food crops will be diverted to fuel. This problem is compounded by the fact that almost 90% of U.S. cropland is used to produce livestock feed, in the highly inefficient process of producing meat for the family table. In fact, a healthy vegetarian diet for the U.S. population could

be produced on only 9% of present cropland, or 30 million acres. And the land in livestock feed production could adequately feed 1.4 billion of the world's people.

The values used in this activity for biomass productivity per square meter were based on values taken from Pimentel, Bio-Science, 1978. It should be stressed that for the purpose of this activity, these values were just conveniences, and you may see other, widely differing values reported in the literature. The values reported for kilocalories of energy/gram of dry matter are remarkably consistent over the many kinds of biomass crop, with the actual values reported generally ranging from 4-5 kilocalories of energy/gram (7000-9000 Btu/lb.).

## Advance Planning

Calculators will make this activity much simpler. They are often available from math classrooms.

Duplicate needed quantities of data tables.

Use the references listed to gain additional background information on biomass energy.

## Suggested Time Allotment

One-half class period to introduce the activity and to explain what data students will need to collect from home

One to two class periods to perform the calculations

One to two class periods to answer questions and discuss results

## Suggested Approach

Introduce the activity by defining biomass and discussing energy uses for biomass. Also define calorie and kilocalorie.

Emphasize the purely theoretical nature of this activity as an exercise in estimating the land necessary to meet a family's energy needs through biomass alone. Stress that any answers will be only very rough approximations.

Help students work through the calculations.

Use the approximate data for energy use only when students are unable to obtain data on their own families. Being able to use their own data should increase students' interest in the activity.

In the discussion of results, point out the enormous difference in the amounts of land required to meet just food needs and to meet total family energy needs. Provide time to discuss the reasons for this difference, some of which may include the diffuse nature of solar energy, the inefficiency of energy captured in photosynthesis, the rapid increase in residential energy consumption after World War II, and the current dependence on fossil fuels to meet energy needs.

You may want to enlist the aid of a math teacher when performing this activity in the classroom.

## Precautions

*Remind students that this activity is just an exercise to help them relate their fossil energy use to the traditional practice of obtaining energy from the land.*

*Make sure students understand that the values given for dry weight/m$^2$ and calories/gram are rough approximations only. These values vary with the type of land under consideration and the reference quoted.*

*Some parents and school authorities may consider questions on family energy use an invasion of privacy. We suggest a note to parents explaining the purpose of the activity and requesting permission for their child's participation. However, the activity has been designed so that it may be completed without obtaining data from home. This may be particularly useful to students who live in apartment houses and may not have access to heating and cooling data.*

## Points for Discussion

Why has energy use increased out of all proportion to the land base which could meet this need?

How is biomass an indirect form of solar energy?

How are such fuels as gasoline, home heating oil, natural gas, and coal related to the land base?

How could biomass energy replace the fuels mentioned above?

What are the advantages and disadvantages of biomass fuels?

## Typical Results

For most families, energy consumption will range between 50 and 100 million kilocalories/year. The land required to meet this need will be between 75,000 and 200,000 square meters.

## Evaluation

Check students' data tables and answers to questions for completeness and accuracy.

Determine if students correctly calculated the land required to meet their family's energy needs.

Ask students to define the term biomass energy.

Ask students to explain why such a large amount of land would be required to meet their family's energy need through biomass alone.

## Modifications

The activity may be simplified substantially by selecting only certain sections for use. For example, you may just want to have students calculate how much land would be needed to meet their family's appliance operation requirements.

If you do not wish to have students calculate Step 10 in the procedure, you may substitute the data table on the next page.

## References


Solar Energy Education Reader
Part III: "Biomass Energy: The Promise and the Problems," p. 290.
"Thought Snacks," p. 294.
"Gasohol: A Choice That May Buy Grief," p. 297.
(Solar Energy Education Project, NYS Education Department, Albany, NY 12234, 1981, contact the project for price.)

Energy Primer: Solar, Water, Wind, and Biofuels, edited by Richard Merrill et al.
(Portola Institute, 485 Hamilton Ave., Menlo Park, CA 94301, 1974, $5.50/paper.)

Fundamentals of Ecology, Eugene P. Odum.
(W.B. Saunders, Inc., W. Washington Square, Philadelphia, PA 19105, 1971, $17.95.)

Plant Science: An Introduction to World Crops, Jules Janick et al.
(W.H. Freeman & Co., 660 Market St., San Francisco, CA 94104, 1974, $21.00.)

"Biological Solar Energy Conversion," David Pimentel et al.
(BioScience, American Institute of Biological Sciences, 1401 Wilson Blvd., Arlington, VA 22209, June 1978.)

"The Energy Cycle of the Biosphere," George M. Woodell.
(Scientific American, 415 Madison Ave., New York, NY 10017, September 1970.)

"The Flow of Energy in the Biosphere," David M. Gates.
(Scientific American, 415 Madison Ave., New York, NY 10017, September 1971.)

"Fuels from Biomass: Integration with Food and Materials Systems," E.S. Lipinsky.
(Science, 1515 Massachusetts Ave., N.W., Washington, D.C. 20005, February 10, 1978.)

"Fuels from Plants: Bioconversion," Factsheet #1, John M. and Kathryn Fowler.
(Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830, free.)

"Solar Biomass Energy: An Overview of U.S. Potential," C.C. Burwell.
(Science, 1515 Massachusetts Ave., N.W., Washington, D.C. 20005, March 10, 1978.)

| Miles Driven Per Year | Miles Per Gallon (mpg) 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|
| 5,000 | 32.8 | 16.4 | 10.8 | 8.3 | 6.6 | 5.5 |
| 10,000 | 65.5 | 32.8 | 21.7 | 16.4 | 13.1 | 10.8 |
| 15,000 | 98.3 | 49.1 | 32.5 | 24.7 | 19.7 | 16.4 |
| 20,000 | 131.0 | 65.5 | 43.6 | 32.8 | 26.2 | 21.9 |
| 25,000 | 163.8 | 81.9 | 54.2 | 41.1 | 32.8 | 26.0 |

Millions of Kilocalories Per Year

# Metric Conversion Table

| Unit of Measure | English Unit | Multiply By ► <br> ◄ Divide By | Metric Unit | Symbol |
|---|---|---|---|---|
| Length | inches | 2.54 | centimeters | cm |
| | feet | 30.0 | centimeters | cm |
| | feet | 0.3 | meters | m |
| | yards | 0.91 | meters | m |
| | miles | 1.61 | kilometers | km |
| Area | square inches | 6.5 | square centimeters | $cm^2$ |
| | square feet | 0.09 | square meters | $m^2$ |
| | square yards | 0.8 | square meters | $m^2$ |
| Mass (Weight) | ounces | 28 | grams | g |
| | pounds | 0.45 | kilograms | kg |
| Volume | gallons | 3.8 | liters | l |
| | cubic feet | 0.03 | cubic meters | $m^3$ |
| Temperature | degrees Fahrenheit | 5/9 (after subtracting 32) <br> 5/9 plus 32 | degrees Celsius | $^oC$ |
| Heat | Btu | 252 | calories | c |
| Speed | miles per hour | 1.61 | kilometers/hour | km/hr |

# Energy Units

barrel: a liquid volume equal to 42 gallons or 159 liters. One barrel of crude oil has about the same heat energy as 350 pounds of bituminous coal, $5.8 \times 10^9$ joules or $5.5 \times 10^6$ Btu or $1.39 \times 10^6$ kcal.

Btu: British thermal unit, a unit for measuring heat; a Btu is the quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit, about one-fourth of a kilocalorie (252 calories).

calorie (also: gram calorie): a metric unit of heat energy; the amount of heat needed to raise the temperature of one gram of water one degree Celsius. It equals 0.0039 Btu. One thousand calories make one kilocalorie (kcal), sometimes called a Calorie or food Calorie.

kilowatt: a measure of power, usually electrical power or heat flow; equal to 1,000 watts or 3,413 Btu per hour.

kilowatt-hour: the amount of energy equivalent to one kilowatt of power being used for one hour; equals 3,413 Btu, or about 860 kcal.

watt: a unit of measure for electrical power equal to the transfer of one joule of energy per second. The watt is the unit of power most often associated with electricity and is determined by multiplying required volts by required amperes. One horsepower = 746 watts.