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ABSTRACT

This guide, one component of the Resource Recovery Education Kit (see SO 007 866 for a description), contains ideas and activities for teaching about solid waste disposal in secondary level science classes. Among the course objectives are the following: (1) to understand that sufficient technology exists to recover a greater segment of the resources than we are now extracting; (2) to learn about improved methods for reducing waste volume and disposing of the residue; and (3) to develop an understanding of how we can conserve depletable resources for the future. Teaching strategies include constructing models, conducting laboratory experiments, research, and classroom discussion. The guide consists of three major study units: (1) Solid Waste: A Growing Problem; (2) Disposal; and (3) Resource Recovery. Objectives, student activities, questions for discussion and research, basic understandings to be developed, and instructional resources are provided for each unit. A special projects section provides visual and print instruction for constructing a model landfill site simulating the waste conditions that lead to water pollution, identifying the microorganisms responsible for the process of composting, and recycling glass. (Author/RM)

Teaching resource recovery in SCIENCE

RESOURCE RECOVERY EDUCATION PROGRAM

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I. SOLID WASTE: A GROWING PROBLEM

A. OBJECTIVES

1. To emphasize that everything in our environment is related to everything else and that, at least ecologically speaking, everything we do has an effect on someone or something else.
2. To lead students to realize that everyone contributes trash and garbage to our communities' solid waste stream and that, when properly managed (collected, transported, processed, and disposed of), these discards do not pollute. Improperly managed, these waste products represent what has been called the third pollution (after air and water).

B. STUDENT ACTIVITIES*

1. Observe a balanced aquarium or terrarium environment over a two-week period. Keep a log of conditions of the soil and water and of the plant and animal life, doing whatever tests the class thinks necessary to determine the conditions. Then create an open garbage dump, made of ordinary household wastes, in a small section of the system. What effect does the presence of wastes have on the balanced environment? How many types of pollution are created?
2. Construct a model landfill site simulating the waste conditions that lead to water pollution. (See the Project Section.)
3. Test the effect of carbon dioxide on groundwater. (See the Project Section.)
4. Simulate the air pollution created by open burning or by improper incineration. (See the Project Section.)
5. Prepare a simulation of an open dump, an incinerator, a sanitary landfill, and a composting operation. The students' manual describes these systems in detail. Compare the four systems, considering the following: space requirements; capacity; potential air, water, soil, noise, odor, and visual pollution; potential health hazards; and resource recoverability.
6. Based on the information gathered from the previous activities, develop a method that allows garbage to be properly integrated into the aquarium/terrarium environment.
7. Accumulate for several weeks all the trash (wastepaper, pencil shavings, lunch bags, etc.) created in your classroom. Your classroom thus becomes a miniature "spaceship earth." How can you safely dispose of or reuse this solid waste?
8. Burn equal amounts of different types of common waste materials in a closed container. Measure the heat generated by each type. Which materials have the best potential for use as a fuel?
9. Repeat the preceding activity, concentrating on accomplishing the most complete combustion by varying the amount of oxygen used in the burning.
10. Simulate an electrostatic precipitator. (See the Project Section.)

*A number of the activities in this guide refer to the Project Section, which is at the end of this guide and which contains a detailed description of the activities.

C. QUESTIONS FOR DISCUSSION AND RESEARCH

1. Why is it important that essential world mineral resources be conserved and recycled?
2. What kinds of resources can be conserved through the process of resource recovery?
3. How does solid waste disposal affect water pollution? What happens when the runoff from a dump flows into the public water supply? What is the leachate problem?
4. What types of air pollutants are generated by outmoded incinerators? How can technology reduce these pollutants? Can technology reduce the discharge of gases and particulates from a pollution-causing facility without shutting it down?
5. What are the air quality standards of your community?
6. Why is there concern over the generation of methane gas in many landfills?
7. Now that health and pollution considerations have made dumping and burning unacceptable, what are some acceptable alternative methods for disposal? What would be the most environmentally sound method for your community?

D. BASIC UNDERSTANDINGS TO BE DEVELOPED

1. Loss of valuable resources

As government officials, scientists, and conservationists search for ways to conserve the nation's natural resources, public interest turns increasingly to resource recovery. Every year Americans throw away over 125 million tons of trash, much of which could be reclaimed and reused for its resource and energy value. Efforts to recover materials from waste are on the upswing, but there is still much work to be done.

The refuse now disposed of in our city dumps and incinerators contains over a billion dollars' worth of valuable resources—iron, aluminum, zinc, lead, copper, glass, paper, rubber, and plastics. Although we are recovering some of these resources, it is obvious that we must begin to "mine" much more of this "urban ore." In so doing we will protect our environment, conserve our resources, and reduce the mounting cost of collecting, processing, and disposing of our solid waste.

2. Water pollution from solid waste disposal

The third pollution, solid waste, often contributes to the more publicized problems of unclean water and air. Improper solid waste disposal, as in open dumps and landfills that are poorly designed or operated, adds to existing water pollution. This pollution becomes particularly severe when landfills or dumps are located at a lower elevation than their surroundings. For example, water runoff that collects at the disposal site may become contaminated. In the same way, considerable water pollution occurs if the disposal site contains soil with a high capacity to retain water or is located where the groundwater table is high. In either case there is a high water content in the decaying waste. The runoff from the site can then carry bacteria, fungi, and decomposed products into streams, lakes, and reservoirs.

Another water problem arises from the carbon dioxide (CO_2) formed during the decomposition of waste at a disposal site. The carbon dioxide dissolves in the groundwater, making it weakly acid. The resulting acidic water dissolves limestone and other rocks, thereby increasing the mineral content of the water.

3. Air pollution from solid waste disposal

a) Although unlawful in most states, open burning of waste is still a widespread problem. Open burning often results in incomplete burning, thereby generating high levels of undesirable gases along with other air pollutants.

b) Another frequent source of air pollution is incineration, which is controlled, enclosed burning. Without question, several modern incinerator systems do their job cleanly and safely. (See Topic III, Disposal, for a description of incineration.) Unfortunately, a majority of existing municipal incinerators were built before 1960, and they lack the equipment needed to reduce particulate emissions to a level considered safe by today's air quality standards. A ton of refuse burned in conventional municipal incinerators produces an average of 24 pounds of particulate emissions, including combustible particles—mainly soot, char, and aerosol—and incombustible mineral particles swept along through the stack. More efficient burning consumes the combustibles, and controlling the rate of flow helps reduce the incombustible particle content. Collecting devices in the stacks trap both types of particles. Incombustible gases, mainly the oxides of sulfur and nitrogen, are a relatively minor problem. Combustible gases, such as hydrocarbons and carbon monoxide, can be reduced by more efficient burning.

The earliest attempts at cleaning stack gases involved the use of settling chambers, but they removed only the larger or heavier particles. A more promising solution now appears to be the use of wet scrubbers and electrostatic precipitators. Electrostatic precipitators, which use an electric charge to collect unwanted particles, are slightly more efficient and slightly more expensive than wet scrubbers, which use a spray of liquid to remove dust particles from the air. Wet scrubbers have the added advantage of removing water-soluble gaseous pollutants but have the disadvantage that the contaminated water must be purified. Both types of devices are less expensive and more efficient when constructed as part of a new system, as is now being done, than when added to an outmoded incinerator.

c) Incineration is not the only source of undesirable gases in solid waste disposal; in fact, it is a minor contributor compared with several other sources. Methane (CH_4), the major component of natural gas, is produced when a landfill operates under anaerobic (without oxygen) conditions rather than the desired aerobic (with oxygen) conditions. (See Topic III, Disposal, for a description of composting conditions.)

E. INSTRUCTIONAL RESOURCES

1. Read Topic I, on resource recovery in the section "A Survey of Resource Recovery" in the students' booklet.
2. Refer to the report "Municipal Refuse Disposal," Chapters 4 (pp. 91-146) and 5 (pp. 147-207), listed in Instructional Resources.

II. COLLECTION AND TRANSPORTATION

Because this topic is dealt with in detail in the guides for social studies and industrial arts, it is not included in this guide.

III. DISPOSAL

A. OBJECTIVE

1. To learn about improved methods for reducing waste volume and disposing of the residue (sanitary landfill, controlled incineration, pyrolysis, etc.).

B. STUDENT ACTIVITIES

1. Identify the microorganisms responsible for the process of composting. (See the Project Section.)
2. Compare the biological activity in three different waste-disposal systems. (See the Project Section.)

3. Compare the biodegradability of several common waste materials. (See the Project Section.)
4. Make a study of heat generation in composting. (See the Project Section.)
5. Make a collection of the various types of cans found in the home, leaving them in their original shape. Determine the average number of cans used per week by the family of each student in the class, and compute the volume of these cans. Then estimate the total volume of cans used in a week by your community. Now flatten the same number of cans, measure their volume when flat, and estimate the community's total volume of flattened cans. How do the two totals compare? List the benefits gained by reducing the volume of cans, boxes, and similar containers before disposal.

C. QUESTIONS FOR DISCUSSION AND RESEARCH

1. What are biochemical reactions? What is their role in solid waste disposal?
2. What do the terms *aerobic* and *anaerobic* mean? In decomposition of solid waste, which of these conditions is preferred and why?
3. What is meant by *biodegradable?* Discuss the biodegradability of the components of typical waste.
4. Discuss the advantages of applying compost to soil. What may happen to soil when incompletely decomposed compost is applied?
5. How does composting differ from conventional disposal methods? Should it be considered a disposal method or a recovery method?
6. Compare the advantages and disadvantages of various methods of waste disposal.

D. BASIC UNDERSTANDINGS TO BE DEVELOPED

The two most acceptable methods of solid waste disposal are sanitary landfill and nonpolluting incineration. Sanitary landfill and composting (which are included in this section as another means of disposal) use the process of biochemical degradation. Nonpolluting incineration uses the process of thermal decomposition.

1. Biochemical degradation methods

a) In biochemical degradation, the decomposition of organic matter occurs through biochemical reactions—chemical transformations involving living organisms. *Organic* does not necessarily refer to matter from living sources, since organic compounds— more correctly defined as carbon-containing compounds—include over 95 percent of all known chemicals.

The major organic materials found in solid waste are foods, paper, and plant materials. For biochemical degradation to take place, there must be an environment in which microorganisms can rapidly decompose organic matter. The microorganisms involved are indigenous ones, including flora, fungi, bacteria, and actinomycetes. Biochemical decomposition can occur by aerobic reactions or by anaerobic reactions. Aerobic decomposition is preferred because decomposition proceeds rapidly and does not produce excessive odor. The products of aerobic decomposition of organic matter are carbon dioxide (CO_2) and water (H_2O), whereas the products of anaerobic decomposition are methane (CH_4), carbon dioxide, and water.

Aerobic decomposition also generates heat—enough, for example, to raise the temperature of a compost pile to 150°F or higher and to destroy pathogenic organisms, fly ova, and weed seeds. Anaerobic decomposition is not only slower and more odorous than aerobic digestion, but its relatively low temperatures do not kill pathogens, larvae, and seeds.

Not all organic matter is biodegradable—that is, having the capacity to be broken down into basic elements by bacteria. For example, plastics (most of which are organic compounds), glass, and metals are nonbiodegradable; many other common waste components, such as paper and food, are biodegradable.

b) The most widely used disposal method involving biochemical degradation is the sanitary landfill. Sanitary landfills utilize natural or man-made depressions or trenches. In a properly designed fill site, refuse is spread in thin layers and compacted. When the refuse builds to a depth of about ten feet, a layer of compacted soil is added to provide a seal. This process continues until the desired depth of fill is achieved. Since air does not readily penetrate a properly sealed landfill, the oxygen in the fill is rapidly depleted through the decomposition of organic matter by aerobic microorganisms. With the depletion of oxygen, anaerobic microorganisms take over the decomposition process. Current research efforts are providing insights into possible improvements for landfills. For example, pumping air into landfills could assist aerobic decomposition, which is more efficient than anaerobic decomposition.

A comparison of the major disposal methods shows the many advantages offered by sanitary landfills. For example, a carefully managed landfill eliminates burning and scattering, does not encourage vermin, does not spread foul odors, and often results in open land ready for use. Since landfills can eventually be converted into recreation and building sites, this form of disposal may even be regarded as a form of resource recovery.

c) . Composting is the biochemical degradation of waste organic material—such as food, paper, and plant materials (leaves, grass clippings, etc.)—into an inert, humuslike substance. The process is carried out under controlled conditions of aeration, temperature, and moisture.

Composting recycles organic wastes back to the soil without significant pollution. Moreover, the final product is a soil conditioner that makes tilling easier and improves retention of water and nutrients. Although compost contains small amounts of the three most important fertilizer elements (nitrogen, phosphorus, and potassium), its nutrient content is too low fc · it to qualify as a fertilizer. The fertility of soil is related to the amount of organic matter and nitrogen present. When soil is cultivated without being fertilized to replenish its nitrogen, its yield and organic content decrease with time. One way to maintain high yields is to add fertilizer along with compost.

Since composting results in a useful product, as well as being a method for waste disposal, it should also be viewed as a form of resource recovery.

2. Thermal decomposition methods

Thermal decomposition involves conversion or destruction of waste through the application of heat. One thermal decomposition method is incineration, a process in which wastes are reduced in volume by controlled burning. The ideal incinerator should provide combustion in which organic compounds combine chemically with oxygen from the air to produce carbon dioxide and water and thus not contribute to air pollution.

An incinerator operating at temperatures of 1300°F. to 2000°F., with time allowed for complete combustion, will reduce refuse to an inert, sterile, inorganic residue containing metal, glass, and ash. With proper cleaning and filtering of the stack exhaust, air pollution will be almost nonexistent, in contrast to conditions in most old-style incinerators, which either have been poorly designed or are improperly operated, pouring noxious gases and particulate matter into the atmosphere. (See Topic I, Solid Waste: A Growing Problem, Section D, for a description of air pollution caused by incineration.)

E. INSTRUCTIONAL RESOURCES

1. Read Topic III on disposal in the section "A Survey of Resource Recovery" in the students' booklet.
2. Refer to the report "Municipal Refuse Disposal," Chapters 4 (pp. 91-146) and 5 (pp. 147-207), listed in Instructional Resources.
3. Refer to the article "Incinerator Guidelines," listed in Instructional Resources.
4. Refer to the document "Sanitary Landfill Facts," listed in Instructional Resources.

IV. RESOURCE RECOVERY

A. OBJECTIVES

1. To develop the understanding that through resource recovery from the solid waste stream we can utilize materials from solid waste and thus conserve depletable resources for the future.
2. To understand that municipal solid waste is a vast national resource of materials and energy and that sufficient technology already exists to recover a much greater segment of these precious resources than we are now extracting.

B. STUDENT ACTIVITIES

1. Recycle glass. (See the Project Section.)
2. Accumulate a wastebasket full of typical household waste. What methods, such as screening, magnets, etc., can be used to automatically separate the mixed materials?
3. Create thermal energy from waste material. (See the Project Section.)
4. Simulate the pyrolysis of waste. (See the Project Section.)
5. Determine whether the gases generated in Activity 4 are suitable as a fuel.
6. Develop uses for each of the materials recovered in the activities. Make as many of these products as is feasible in the classroom.

C. QUESTIONS FOR DISCUSSION AND RESEARCH

1. Discuss the possibilities for recycling the solid waste components of glass, metals, paper, plastics, and rubber.
2. What are the technological advantages of using waste glass in the production of new glass? Of using waste rubber in the production of new rubber?
3. How can the mechanical and physical properties of solid waste components be utilized in making new materials?
4. Discuss the possibilities for chemically converting waste cellulose into useful chemicals.
5. Discuss the benefits of biochemical conversion as a resource recovery method.
6. How can the energy value of solid waste be recovered from incineration? In pyrolysis how can the heat energy from solid waste be best utilized?

D. BASIC UNDERSTANDINGS TO BE DEVELOPED

1. Resource recovery by recycling

In recent years protecting our supply of natural resources has become a matter of growing concern. Not long ago the United States enjoyed an abundance of essential natural resources. This is no longer the case, as our growing dependence on imported raw materials indicates. One way of protecting our resources is to reuse material as fully as possible. Many valuable materials—such as glass, paper, plastics, rubber, and metals—can be recovered from solid waste and reused as new products.

Glass. Glass—especially the glass container—is one of the most easily recyclable of all waste products. Throughout its history the glass industry has reused various amounts of crushed glass, called cullet, as a major part of the raw materials needed to make bottles, jars, and other containers.

Because glass cannot burn, it does not pollute the air in the incineration process. Because it cannot corrode, rot, putrefy, or otherwise degrade, it does not pollute land or water when disposed of in dumps and landfills. In fact, waste glass that is crushed or ground will mix with soil to become a firm landfill without causing disease or giving off noxious gases.

Container glass is about 73 percent silica (sand), but it also contains limestone and soda ash in precise amounts to make a product of uniform quality and color. Glass color is determined by the addition of small amounts of metallic oxides: cobalt is used to achieve a blue color, chromium or sulfur for yellow, iron for brown and green, and manganese or nickel for purple.

After blending in a mixer, this "batch" of ingredients rides to a glass furnace on belts or in buckets. The furnace is a huge pot or tank, with flames that soar across the top of the batch and temperatures that reach 2700°F. Following the melting process, the glass flows into a refining chamber before dropping to automatic feeders, where it is finally formed into the desired shape.

Glass bottle makers recycle their own glass. In the manufacture of glass, cullet has traditionally been used to lower the melting temperature of the glass mix. When cullet is added, less heating fuel is required. Since one batch of glass can consist of up to 30 percent or more of cullet, this is a significant amount conserved.

To obtain waste glass for cullet, and as the first step toward complete salvage-recycling, glass manufacturers have set up reclamation centers at production plants all across the country. Still other centers are being organized by soft-drink and brewing companies and by community and environmental groups. The most immediate and also one of the potentially largest markets for salvaged glass is the bottle-making industry itself.

Used glass containers are also capable of being recycled into many other useful products. One potential secondary use for cullet is as an aggregate in "glasphalt," a product in which glass is substituted for crushed limestone in asphalt for paving streets.

Other secondary uses of old glass containers employ [illegible] physical properties of glass in such applica[illegible] as the production of sewer pipes, spun-glass insulation, the use of tiny beads of glass in the reflective center strip of highways, the manufacture of glass bricks and blocks, and even as a substitute for sand along eroded beaches.

Meanwhile, the glass industry is sponsoring research to develop the means of mechanically separating the various components of solid waste, including glass bottles, so that they may be more readily salvaged and recycled in greater volume. For example, the glass industry has cosponsored with the federal government an investigation of the air classification process, which utilizes forced air currents to separate the components of solid waste.

The industry is also working with other private and government organizations to refine glass obtained from various recycling processes for reuse in bottle making. As part of this effort, it is supporting research to develop a means of optically sorting according to color the container glass reclaimed from solid waste. Similarly, glassmakers have been working closely with the U. S. Bureau of Mines, which is experimenting with a technique to separate small pieces of clear and colored glass by means of high-intensity magnetic forces. Since iron content is related to color, colored glass pieces with the highest iron content are attracted more strongly in the magnetic field.

Finally, in cooperation with the Black Clawson Company and the city of Franklin, Ohio, the glass industry is providing funds and technical assistance to supplement a grant from the U.S. Environmental Protection Agency for incorporating a subsystem of waste-glass recovery into a waste recovery plant in Franklin. In addition to recovering glass, the subsystem will provide an opportunity to study various air and mechanical separators as well as new optical sorting equipment.

Paper. Paper—especially wastepaper—is another important recoverable resource. Paper can be reused as a raw material in the manufacture of new paper products, as a source of energy, and as a meduim for either a sanitary landfill or a composting operation. The fact that over 13 million tons of paper were recycled in 1972 indicates the success of recycling.

Paper is composed of cellulose molecules. These molecules are originally formed in plants, where they arrange themselves in elongated cell walls that form semicrystalline threads. The largest plant of all—the tree—contains the longest, most abundant, and most easily extractable supply of cellulose threads. Cellulose fibers contain an unusual amount of tensile strength; they can be separated from both wood pulp and paper pulp more than once. Their strength, however, is limited, and they can be recovered from scrap pulp only a certain number of times.

The repulping of wastepaper is usually done by mechanical action involving water. For example, in one mechanical reclamation process the repulping begins with a mixture of 3 parts of paper to 97 parts of water at 100°F. A hydrapulper* —like a giant eggbeater—then stirs the mixture until the fibers are separated in a slurry. Numerous refining and cleaning operations and, if necessary, de-inking take place to prepare the fiber for re-forming and to remove foreign particles. The pulp produced in this way is then used in manufacturing new paper products.

Cost is a major factor in determining the extent of wastepaper recycling. Since new technology has greatly improved the harvesting and processing of pulpwood trees, recycling mills must have, in order to compete, a dependable supply of uncontaminated wastepaper. Another factor in recycling paper is the technical capability of paper mills to repulp the various grades of wastepaper. And even if the technical capability exists, recycling cannot improve the original physical characteristics of the paper fiber. For example, the short fibers used to make newsprint cannot be repulped and used in writing paper, since writing paper requires fibers of greater strength.

There are some problems in the recovery of wastepaper. Some paper products are laminated to metals and coated or extruded with plastics. Others are printed with durable inks that resist de-inking, thereby posing problems for reuse. However, the bulk grades of wastepaper—such as old newspapers, used corrugated boxes, and mixed office waste—can be repulped to make recycled paperboard (known in the industry as combination paperboard) and building products. Many of the packages found in supermarkets, drugstores, and other stores—cartons for soaps, cereals, crackers, and hundreds of other products—are made from combination paperboard.

To encourage the recycling of wastepaper, the federal government, through the General Services Administration (GSA), has changed its specifications for certain types of paper and paperboard products it buys for government agencies—mostly packaging papers, paperboards, and tissues. The GSA now requires the inclusion of varying percentages of waste fibers in such products. This is expected not only to aid the purchase of a wider variety of recycled paper products but also to help stimulate the market demand for papers containing repulped material.

A number of cities are also involved in voluntary separation and collection efforts. There, centers have been set up where wastepaper is segregated and collected, usually in three categories—corrugated paper, newsprint, and mixed paper (which includes magazines).

Currently, those cities with successful recovery programs are concentrating on recovering newspapers from households for established markets. One such paper collection program is operating in Madison, Wisconsin, where sanitation department trucks collect bundled newspapers put out by residents on a voluntary basis. Similar municipal recovery programs are taking place in Hempstead, New York, and Louisville, Kentucky.

Another use for wastepaper is as a component in conventional incineration. Paper is desirable not only because of its combustibility but also because it absorbs the moisture found in other components of municipal waste. Despite the problems in recycling, paper is being recycled on a large scale, and ways to improve and develop new technology are being strongly pursued.

Plastics. The word *plastics*, referring to another component of solid waste, includes a whole range of materials, just as the terms *metal* and *wood* do. One plastic is as different from another as oak is from pine or as gold is from silver. Technically, plastics are polymers, as are synthetic rubber and man-made fibers. The major constituents of plastics are carbon and hydrogen, although some also contain nitrogen and oxygen as basic ingredients.

The first step in producing all plastics is the formation of monomers, the small molecules that combine chemically to form the large molecules of a polymer. The type of polymer is determined by the monomer used. For example, for polyethylene and polypropylene, ethylene and propylene are the respective monomers.

There are about 40 basic groups of plastic material, many of which can be modified and combined to provide additional ranges of plastics.

All plastics, however, are either thermoplastic or thermosetting. Thermoplastics—such as polyethylene, polyvinyl chloride, and polystyrene—can be melted and re-formed if they are clean and uncontaminated by foreign materials. On the other hand, thermosetting plastics, once formed, cannot be remelted and reworked. They will retain their shape until decomposition temperatures are reached. Currently, research is being done on the use of a flux or binder to aid the combining of different types of thermoplastics.

Although plastics are used in many different ways, the actual volume of plastics in the solid waste stream is not very large, being estimated at about 2 percent. At present, the large-scale recycling of plastics salvaged from municipal solid waste poses some special problems. Technologically, most plastics can be recycled; more than 1 billion pounds were reground and re-formed into finished goods last year. This, however, was scrap generated in the industry's manufacturing processes, where the materials can be kept unmixed and uncontaminated. Collecting, separating by type, and marketing recycled plastics waste are considerably more difficult. For one thing, plastics raw material costs are so low that sorting and reprocessing plastic waste cannot as yet be justified economically.

One particularly encouraging use of waste plastic is as a fuel for incinerators. Since plastics have a high BTU (heat) content, the incineration of such refuse as wet garbage, grass, and leaves is helped by the presence of plastics. This fuel use can also be applied to driving steam-power generation facilities, thereby providing heat and light for the nation's cities. A further use for plastic waste is incineration in new pyrolysis systems that break plastics down into basic gaseous chemicals and recover the gases. The gases can then be recycled as fuel or as low-cost chemicals to make new plastics.

Rubber. Rubber is a material that can be recovered and reused very effectively. There are two major types of rubber—natural and synthetic. In 1971 nearly twice as much synthetic as natural rubber was consumed in the United States. Of the finished products made from this synthetic rubber, tires and tire products accounted for about three-fourths of all uses. Discarded rubber products—mostly discarded tires and used inner tubes—usually contain natural and synthetic rubber in combination.

The three processes used to reclaim rubber are digesting (wet), devulcanizing (dry), and mechanical methods. Although the processes and equipment may vary from company to company, the end result is usually softened rubber scrap ready for reuse in other products. Known as "reclaimed rubber," this material can be recycled in combination with new rubber. There are significant economic incentives for using reclaimed rubber. This material costs about half as much as styrene-butadiene rubber (SBR), the major synthetic rubber. And even though reclaimed rubber is of lower quality, containing only about 50 percent rubber hydrocarbons, this is not considered to be a major problem in its use as reclaimed rubber. Reclaimed rubber actually offers definite advantages, such as being more rapidly masticated and better adapted to filler absorption than synthetic or natural rubber.

Several new applications for reclaimed rubber point to further recycling potential. The Goodyear Tire and Rubber Company, for example, is active in developing new uses and markets for scrapped tires. The company is installing a new furnace at its Jackson, Michigan, tire plant that will use worn-out tires as fuel to generate steam for new tire production. Pound for pound, tires are recognized as delivering about 50 percent more BTU value than conventional coal fuel. The tire destruction furnace will consume and utilize some 1 million tires annually.

Scientists at Rutgers University have developed three new methods for utilizing scrap rubber. These methods—using discarded tires to produce high-protein food, to condition poor-quality soil, and to purify water—can all help in solving the tire disposal problem. The researchers are careful to point out, however, that although these discoveries indicate exciting potentials, more studies will be needed to determine their practical values.

According to a report developed by the director of research for Firestone Tire and Rubber Company and a sponsor of the project, the scientists at Rutgers were able to grow a yeast-based food on rubber taken from scrap tires. Although tasteless, the food is nutritious and suitable for human and animal consumption.

In another part of the Rutgers project, scrap rubber was shredded, reduced to a powder with fungi, and then mixed with such unproductive soils as sand and clay. The powder improved the ability of the sand to retain water and reduced the water penetration density of the clay. As further proof that poor quality soil could be improved in this manner, the scientists grew kidney beans in sand mixed with the powder.

Another experiment proved that scrap rubber may be useful in purifying polluted water. The experimenters found that when water was mixed with the powder made of scrap rubber, certain impurities in the water were removed through an ion exchange process. Other experiments showed that scrap rubber could be used in producing several different organic chemicals. One of these chemicals, a polysaccharide, can be used to obtain a certain type of sugar.

Metals. Metals, another vital container material, can be divided into two categories—ferrous (containing iron) and nonferrous (containing no iron). The use of scrap ferrous metal is traditional in steelmaking. In the last 30 years recycled scrap has accounted for more than 50 percent of the raw material used to make new steel. The majority of this scrap is produced in the mills; the rest is purchased from outside sources. The major ferrous item in household municipal waste is the "tin" can. Actually, the tin in cans is only a coating about 1/10,000 inch thick, placed on steel to guard against rust and corrosion. Tin cans are salvaged from municipal waste in an increasing number of localities throughout the United States. Because of the magnetic quality of steel, it can be separated out by giant magnets that lift great bunches of scrap from municipal garbage at landfill sites, transfer stations, and incinerators.

There are four basic uses for reclaimed steel cans—reuse in copper extraction, detinning, remelting in steel mills, and reuse in the production of ferroalloys. For use in copper extraction, steel scrap recovered by recycling is shipped to the copper industry in the western states. There, some 600,000 tons of shredded cans are used every year as "precipitation iron" to recover copper from low-grade ore. Approximately 200,000 tons of the copper mined domestically is processed by a leaching/cementation process involving a chemical exchange of the copper and iron ions. The resulting precipitate is a reddish sludge containing more than 80 percent copper, which is sent to a smelter for refining. Approximately one to two pounds of iron are required to produce one pound of copper by this process. Since nearly 15 percent of our output of copper is produced in this way, this process is of great importance in conserving our limited copper resources.

Another significant market for steel scrap is detinning, an industrial process for recovering tin from cans rejected in the manufacturing process, from municipal solid waste (when cans are separated before incineration), or from other sources. Since the United States has no deposits of tin, all of this metal used here must be imported. Detinning presently uses industrial tinplate scrap for recovering tin. The most common technique employed is an alkaline chemical process in which tinplate is treated with a hot solution of caustic soda and sodium nitrate or nitrite, causing the tin to be dissolved into sodium stannate. The tin recovered through either a crystallization, an electrolysis, or a neutralization process is purer than the metal produced from ore.

Although there are some technical problems in using tin cans in the various steelmaking processes, such use is possible. Detinned scrap can be utilized in conventional steel processing in open-hearth furnaces. The problems caused by high levels of impurity in the cans can be overcome either through a preburning process or through dilution with other furnace charges.

Still another market for tin-can scrap is in the production of ferroalloys, in which the iron is combined with carefully controlled amounts of such elements as silicon and manganese. The material is then used as a part of the "melts" for alloy steel or castings in foundries.

Still another source of recyclable metals is junked automobiles—outside the normal waste channels, perhaps, but still a municipal disposal problem. Discarded cars are typically collected by wreckers and salvagers and usually end up providing two kinds of products—salvaged auto parts that can be reused or rebuilt and ferrous scrap metal that can be remelted to make new metals.

The major problem in recycling a junked car is finding economical ways to turn the 3000 pounds of steel, nickel, zinc, aluminum, and copper in it into cleanly separated scrap.

There are two distinct types of salvage operations for junked cars. Auto wreckers primarily strip wrecked and abandoned cars of their parts and then sell the remaining hulks to scrap plants for processing. Scrap processors, on the other hand, have much more heavily equipped operations and are capable of producing cleanly separated scrap for mills, refineries, and foundries. Processing usually includes stripping the engine block, windows, seats, etc., and then crushing the hulk in a large press or shredding it in an enormous hammer mill. Automobile shredding produces fist-size chunks of steel that can be sold at a higher price than that normally received for automobile hulks. Burning is often performed instead of stripping.

To help speed up the scrap cycle, the U.S. Bureau of Mines is working on a method to produce clean ferrous scrap from junked cars by the physical or chemical removal of nonferrous material. This research will help the nation's smaller scrap dealers, who cannot afford to buy extremely expensive processing equipment.

Although automobile hulks have accumulated faster since 1950 than the industry has been able to process them, the outlook for automobile recycling is promising. Approximately 85 percent of all junked cars are now entering the automobile scrap cycle, and this percentage is increasing.

The recycling of nonferrous metals is also important in conserving our resources. More than 3 million tons of nonferrous metals are recovered and reused in this country annually. Among these metals are such resources as lead, copper, zinc, nickel, chromium, brass, gold, silver, platinum, palladium, rhodium, and aluminum. Many of the materials recovered are scrap left over from the manufacturing process.

Recycling has always existed in the aluminum industry. Because of its long life in such products as airplanes, ships, and buildings, much of the aluminum produced in previous years is still in use today. Because of its high scrap value, nonbiodegradability, and nonrusting characteristics, even this aluminum will ultimately be recycled and appear as new products serving new applications. More than 20 percent of all the aluminum used today was once in some other form. And that percentage could grow with new applications of the recycling idea.

The copper industry is another major user of scrap metal. During the Depression of the 1930's more copper scrap was reused than was mined. Today about 45 percent of the copper used in this country eventually finds its way back to manufacturers for reuse.

Secondary lead has also proved itself satisfactory for use as a raw material. Most secondary lead is recovered from spent flashlight and car batteries. Other sources of lead are solder, lead pipes from old buildings, and lead wastes from the manufacture of chemicals. In many cases scrap lead is the preferred metal because it has already been combined with such necessary elements as antimony and tin.

Because the proportion of nonferrous metals found in solid waste is lower, their recovery is feasible only in large-scale operations. Feeding 1000 pounds of solid waste into a conventional incinerator may yield only 2 percent nonferrous metal. Yet, proportionately more silver and gold could be recovered from waste than from the commercial mining of the minerals. Each ton of burned trash, for example, yields from 1 to 9 ounces of silver and .05 ounce of gold, compared with .08 and .004 ounces, respectively, found in natural sources. The precious metals that can be retrieved from photographic supplies, old and new coins, electronic solder, computer boards, and sparkle dust on greeting cards can be used not only by jewelers but also by the computer, electronics, and aircraft industries. In fact, secondary precious metals invariably claim a higher price than the original ore because they are free from contaminants that originally had to be refined out of the ore that came directly from the mine.

2. Resource recovery by conversion

It is not necessary in every case to return the materials of trash and garbage to their original use in order to recapture some value. The utilization of recovered materials through biochemical conversion and energy conversion is an important aspect of resource conservation, comparable to the recycling of resources back to their original use.

Biochemical conversion. Scientists are continually seeking new uses for biochemical conversion in solving environmental problems and meeting new ones. The value of compost as a soil conditioner has long been recognized. (See Topic III, Disposal, in this guide.) An emerging purpose for compost is its use as an antipollution agent. According to one recent study, for every ton of compost sprayed on an ocean oil slick, 19 barrels of crude oil are promptly soaked up. The resulting cohesive masses can then be either collected or burned on the water. Even if not removed, these cohesive masses do not adhere to living creatures and vessels; if the masses are washed ashore, the compost helps to decompose absorbed oil.

Other experimental conversion processes now under study include the conversion of cellulose into ethyl alcohol and into single-cell proteins. Since cellulose is the major chemical component of municipal waste, methods utilizing waste cellulose could be of enormous value. As for the possibility of use as a source of protein, several research projects are investigating methods for converting waste cellulose into livestock feed.

Still another intriguing experiment uses a bacteriological process that experts say will convert one ton of municipal refuse into 13,000 cubic feet of natural gas. The conversion is made by placing a 10-to-1 mixture of garbage and sewage sludge in a sealed cylinder. In the absence of air, anaerobic bacteria—which breed in a closed environment—grow and finally decompose the garbage, reducing its volume by 90 percent. After 15 days clean methane gas that can heat a home or cook a meal is produced

Energy conversion. The growing shortage of fuels for the production of electricity has prompted a number of cities in our country to consider using a most unlikely source of energy— garbage. The theory, which is currently being experimented with, is that if local trash and garbage are burned as a supplemental fuel in power company boilers, less fossil fuel will be required and less refuse will have to be disposed of through costly conventional means.

By about 1975, 27 buildings in downtown Nashville, Tennessee, will be heated and cooled with the steam energy obtained by burning 700 tons of refuse a day. Although the process of converting garbage into heat is still in the pilot stage, a few cities are saving enough by this method to help defray the cost of garbage collection and disposal—a major expense for most local governments.

A similar program has been working in St. Louis for more than a year in a pilot program sponsored jointly by the city, the Union Electric Power Company, and the U.S. Environmental Protection Agency. In this operation as much as 300 tons of refuse a day is shredded and ferrous metals are magnetically removed before the remaining mixed refuse is combined with coal for burning in a modified boiler.

On the average, municipal refuse contains 5000 British thermal units (BTU's) per pound. The following table gives an idea of the considerable heat value of solid waste materials.

Heat Content of Waste Components

Material	BTU's/lb.	Percent Inert
Plastics	15,770	0
Wood	7,783	1.9
Paper	7,551	3.3
Textiles	7,232	2.8
Metals (organics only)	668	81.4
Glass	80	93.5

Source: E. R. Kaiser, University of California—Davis, September 1969, page 181.

Some waste components, such as plastics, have extremely high heat content. And since increasing proportions of dry combustible wastes have steadily replaced the soggy garbage of the past, there is a definite increase in the fuel value of household refuse.

Another energy-yielding process, and one gaining increasing attention, is pyrolysis, a method in which organic material is heated to high temperatures (1000°F. to 2000°F.) in either an oxygen-free or a low-oxygen atmosphere. Through a method called destructive distillation, the pyrolysis of solid waste results in a chemical breakdown of the organic matter into three classes: gases—mostly hydrogen, methane, carbon dioxide, and carbon monoxide; a liquid, or "tar," that contains such organic chemicals as acetic acid, acetone, and methanol; and a solid, or "char," consisting of almost pure carbon plus such inert materials as glass, metals, and rocks. Pyrolysis has been adapted to treat solid waste; the process yields energy-rich oils and other potentially useful material.

The U. S. Department of the Interior's Bureau of Mines, which has been researching pyrolysis as a resource recovery method since 1929, reports that a ton of municipal solid waste pyrolyzed at about 1600°F. yields close to 18,000 cubic feet of gas, 114 gallons of liquid, 25 pounds of ammonium sulfate, 0.5 gallon of tar, and 154 pounds of solid residue. The proportions of the products vary somewhat with the pyrolysis temperature.

The gas mixture produced by pyrolysis is an efficient low-sulfur fuel. Gas from a ton of municipal solid waste has between 5 and 8 million BTU's of available heat. Since about 2 million BTU's per ton of refuse will sustain the process, the gas output alone can fuel the plant and leave ample heat for other uses.

The liquid resulting from pyrolysis is more than 90 percent water, in addition to a mixture of numerous organic compounds. This mixture is so complex that it is not likely to be useful, except perhaps as a wood preservative or an insecticide. The tar obtained by pyrolysis adds another 736,000 BTU's to the heat yield of a ton of refuse. The light oils are a potential source of benzene and toluene.

The solid residue from pyrolysis is a lightweight, flaky, carbonaceous material. The char from a ton of residue has a fuel value of from 10 to 17 million BTU's; the sulfur content is very low. The residue can easily be screened to remove bottle caps, aluminum, etc., and briquetted with a starch binder. Briquettes can be used as fuel, as a filter for sewage sludge, or as a good filter medium for removing the organic substances from the liquid residue. The substances can then be burned.

Interest in pyrolysis as a technique of solid waste management will probably grow. Although research has not yet resulted in a full-scale facility, pyrolysis offers most of the advantages of incineration and the added advantages of nonpollution, resource recovery, and lower operating costs.

E. INSTRUCTIONAL RESOURCES

1. Read Topic IV on resource recovery in the section "A Survey of Resource Recovery" in the students' booklet.
2. Refer to the article "Bottlenecks," Part 1, listed in Instructional Resources.
3. Refer to the article "Machinery for Trash Mining," listed in Instructional Resources.
4. View and discuss the film "Recycling," listed under Audiovisual Materials.

PROJECTS SECTION

This section was developed to encourage students to set up and carry out activities without teacher assistance. Detailed instructions are given for starting each activity, but the data gathering and the final interpretation of the data require student input. The activities in the Appendix are an extension of those described in the preceding guide and are indicated in the guide by a cross-reference to the Appendix. To locate a specific activity in the guide, refer to the general heading and then to the specific numbered activity in that group.

I. SOLID WASTE: A GROWING PROBLEM

B. STUDENT ACTIVITIES

2. Construct a model landfill site simulating the waste conditions that lead to water pollution.
Step 1: Cover the bottom and sides of a tray or box with a sheet of plastic.

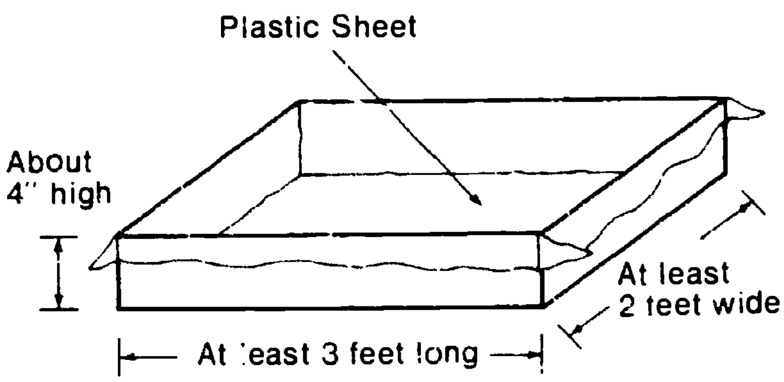

Figure 1

Step 2: Add sand or dirt. Then establish a grade by having a greater depth of sand at one end. A grade from 3 inches to 1 inch is adequate.

Figure 2

Step 3: Construct a water stream by digging out a channel from the higher elevation to the lower. Add enough clear water to fill the channel. As an optional feature, the stream can be made to flow by continuously running water through the channel as shown.

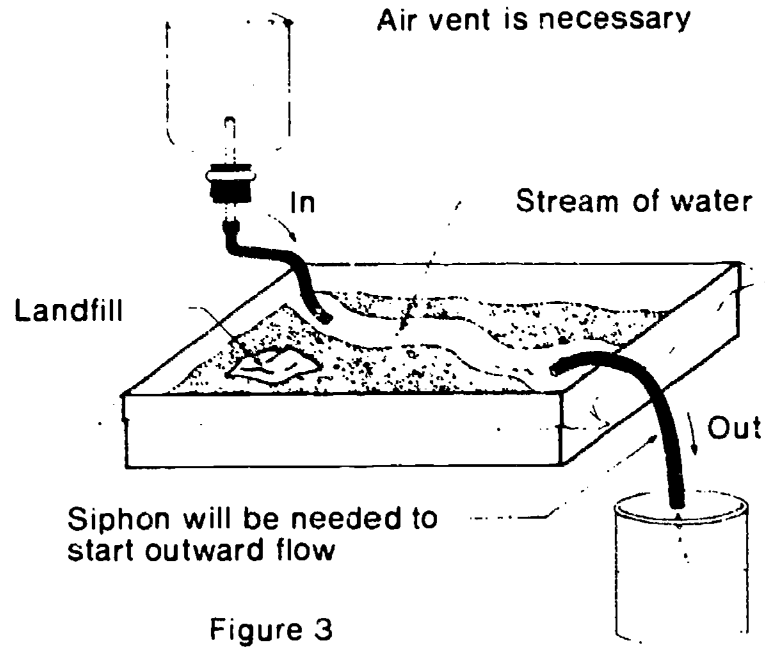

Figure 3

Step 4: Prepare a miniature landfill site at an elevation above the stream, as shown in the preceding illustration. To trace the flow of groundwater through the landfill, bury a few crystals of potassium permanganate ($KMnO_4$) at a depth of 1 inch in the sand. (If potassium permanganate is not available in your laboratory, it can be purchased at almost any drugstore.) Potassium permanganate is soluble in water, producing a solution that is purple when concentrated and pink when diluted.
Step 5: Simulate rain over the landfill by adding water. Observe the stream to see if the color of potassium permanganate appears. Appearance of a pink or purple color indicates that the stream has picked up the undesirable groundwater from the disposal site.

3. Test the effect of carbon dioxide on groundwater.
Step 1: Add small pieces of limestone to about 5 ml. of water in a test tube. If limestone is not available, it can easily be prepared from calcium hydroxide ($Ca(OH)_2$) and carbonic acid ($CO_2 + H_2O$) according to the following procedure. Prepare a saturated solution of limewater by adding carbonic acid to water. Shake vigorously to dissolve as much of the calcium hydroxide as possible. Allow the solution to stand until the solution above the undissolved calcium hydroxide is clear. Pour about 2 ml. of the clear limewater into a test tube. Add carbonic acid by adding clear soda water from a freshly opened bottle until limestone formation is no longer observed. The formula for the reaction that takes place is $Ca(OH)_2 + H_2CO_3 = CaCO_3 + 2H_2O$.

Step 2: To the test tube containing limestone in water, add small portions of soda water while stirring. Observe the action of the carbonic acid. Continue the addition of soda water until all the limestone has reacted. An alternative to using carbon dioxide (CO_2) from soda water is to collect the carbon dioxide from decomposing organic waste and to bubble it into the water suspension of limestone.

4. Simulate the air pollution created by open burning or by improper incineration.

Step 1: Place some moth flakes (the two common commercial products are naphthalene and p-dichlorobenzene) into a porcelain or deflagrating spoon. Observe the whiteness of the material.

Step 2: Burn the material in the flame of a Bunsen burner. Note the large quantity of soot that is formed. Two other compounds that are readily usable in this experiment are aspirin and Styrofoam (polystyrene).

10. Simulate an electrostatic precipitator.

Step 1: Burn a 2-inch-by-2-inch piece of paper. Crumble the burnt piece into several small particles.

Step 2: Take a small piece of clear plastic kitchen wrap and rub it with a paper towel or between your hands. This puts an electrostatic charge on the plastic film.

Step 3: Hold the plastic about 3 inches away from the ashes and observe what happens to the ashes. You have placed an electrostatic charge on the plastic, which then attracted the ashes. This is the basic concept of an electrostatic precipitator, a device that collects unwanted particles from a solution in an incinerator. The charge in a precipitator can be turned on and off. While it is off, the collecting surface can be vibrated, the accumulated particles being shaken into a container for proper disposal. In incineration the electrostatic precipitator is used to trap the burnt particles before they go out the chimney.

III. DISPOSAL

B. STUDENT ACTIVITIES

1. Identify the microorganisms responsible for the process of composting.

Step 1: Two trays will be required for this activity. Fill one with dry soil and the other with soil containing about 5 percent organic matter. Prepare the latter by thoroughly mixing ground-up organic matter with dry soil. Make a slit in the soil and insert a clean microscopic slide. Press the soil against the slide. Following this procedure, insert six slides into each container, as in Figure 1.

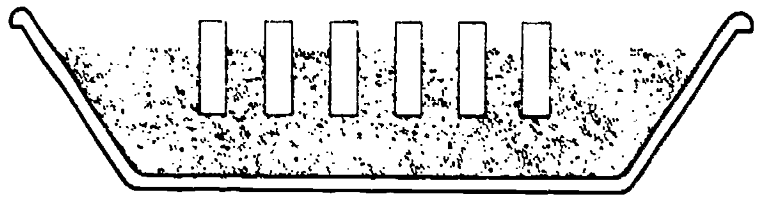

Figure 1

Six slides in each container will permit observation of each sample at the end of one week, two weeks, and three weeks. Each observation requires two slides, one stained dark and one stained light. Adjust the moisture content to about 20 percent water by adding a volume of water corresponding to about one-fifth of the volume of soil. Keep the moisture content as constant as possible by adding water as needed. After one week, two slides from each container will be studied according to the following procedures:

Step 2: *Slide removal.* To properly remove a slide from the tray, dig soil away from one side of the slide; then tilt the same slide toward the hole and lift it out, as in Figure 2.

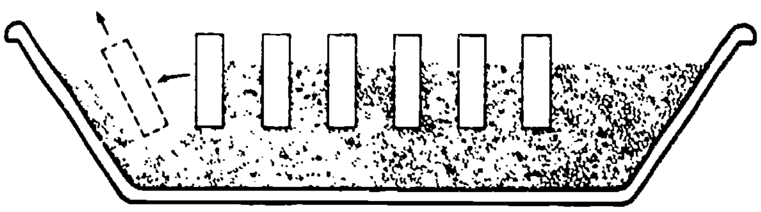

Figure 2

The slide will now have a film of soil and microorganisms on one side. Clean the other side with a cloth. Label the slide with a wax pencil. Prepare a second slide in the same way.

Step 3: *Slide fixation.* The preparation on the slide is fixed by passing the slide over a flame. One or two passes should be sufficient.

Step 4: *Slide staining.* Stain one slide dark, using gentian violet or methylene blue.

Stain the other slide light, using erythrosine or eosine.

Step 5: *Microscopic observation.* Examine each slide with the low and high powers of a microscope for the presence of bacteria. If present, spirilla will probably not be seen unless the field is darker. Sketch your observations.

Step 6: *Bacteria identification.* Using Figure 3, identify the morphological class of the bacteria on the slide.

Cocci Bacilli Spirilla Actinomycetes

Figure 3: Common Morphological Classes of Bacteria

Step 7: *Experimental conclusions.* From your observations determine whether there are differences in the number and types of microorganisms in the two samples.
Step 8: *Validation.* At the end of the second week repeat the procedures with another pair of slides from each sample. Have the number and types of bacteria in the samples changed significantly? If so, account for the changes.
Step 9: *Final conclusions.* At the end of the third week repeat the procedures and make further observations. Relate your observations and conclusions to composting.

2. Compare the biological activity in three different waste-disposal systems.

In your simulation of the different disposal systems the same batch of soil should be used for all systems. Also, for comparisons to be meaningful, the same types of waste material should be used in each system.

(a) Open Disposal (aerobic conditions):
Step 1: Place a thin layer of rich soil (about 2 inches) in a glass beaker. Add to the surface small samples of several different garbage components. You may choose to set up more than one container in order to observe the behavior of a variety of different waste materials. (Although you should choose representative organic waste materials, for the sake of avoiding odors do not include such proteins as meat and dairy products.) Add water until the soil is moist; then cover the container as shown in the following illustration. A cover of clear plastic wrap will allow better observation of the samples.

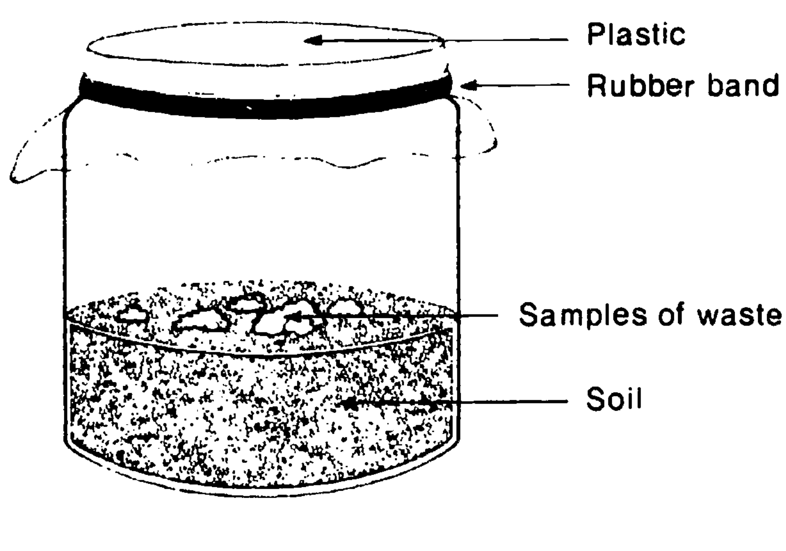

Figure 4

Step 2: To maintain your culture, add water as needed to keep the soil moist but not waterlogged. Also, after each two or three days, remove the cover for a few minutes to ensure that ample air is present. Each day observe your samples and record your observations. Note not only disintegration but also mold formation.
Step 3: Although, as you know from the previous activity, there are many different microorganisms present, those which are observable to the naked eye are molds. Molds are a type of fungi composed of many filaments known as hyphae (or hyphae massed together are called molds). Note the colors, shapes, and sizes of the molds. The colors of the molds are due to spores.

(b) Properly Managed Landfill (partially aerobic conditions)
Step 1: Create a landfill in a beaker or glass by adding soil to within 2 inches of the top of the container. Insert small samples of waste into the soil. To facilitate observations, position the samples near the outer surface, as in Figure 5.

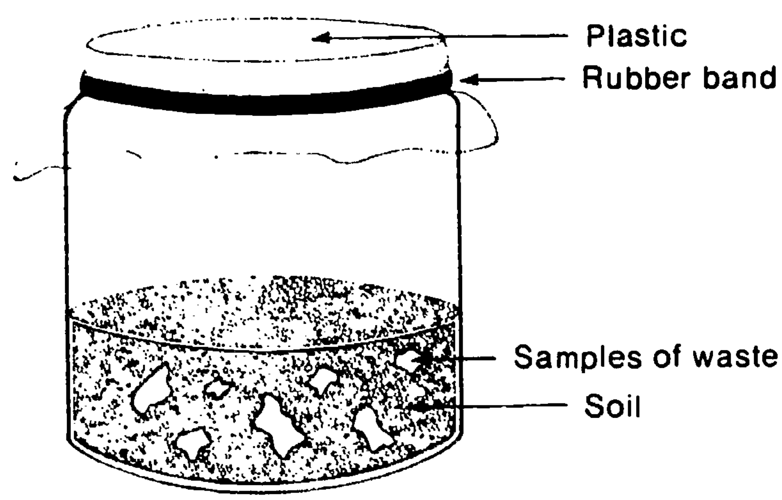

Figure 5

Step 2: Add water until the soil is moist but not waterlogged; then cover the container. Throughout the experiment keep the soil moist. Each day observe your samples and record the observations. Rates of mold formation and decomposition represent significant data.
Step 3: Compare your observations with those from the open disposal in which more air is available.

(c) Improperly Managed Landfill (anaerobic conditions)
Step 1: Create a waterlogged landfill in a beaker or glass by adding soil until the container is half filled. Then add samples of waste, and stir until a slurry of mud is obtained. Add water to within 2 inches of the top of the container, and then cover tightly.

Step 2: Each day observe the mixture, noting whether any odor is formed and whether there is observable evolution of gases. Methane, a product of anaerobic decomposition, is a water-insoluble gas; therefore, its evolution will produce an occasional bubble through the water. Compare your observations with those obtained from the two aerobic decomposition experiments.

3. Compare the biodegradability of several common waste materials.

Step 1: Prepare a miniature landfill in a glass container according to the directions in Topic III, Activity 2b. Place in the landfill a small sample of each of the following waste materials: food scraps, glass, paper, plastic, iron, and aluminum. Be sure the samples are properly positioned for observation. Keep the landfill moist.

Step 2: Periodically observe the samples and record your observations. From your observations establish which waste materials are biodegradable.

4. Make a study of heat generation in composting.

Step 1: Form a compost mixture in a bucket by adding alternating layers of organic material and soil. The organic layers should be about 3 inches deep and the soil layers should be about 1 inch deep. Use any available organic matter—such as food scraps, dry leaves, and paper. Keep the compost mixture moist but not waterlogged. Excessive water will block aeration, creating anaerobic decomposition, which in turn leads to undesirable odors. To provide aeration, the mixture should be turned every four or five days by transferring the mixture to another bucket.

Step 2: Each day insert a thermometer into the center of the compost pile and record the temperature. Record the temperatures on a graph, with the temperature plotted against time in calendar days.

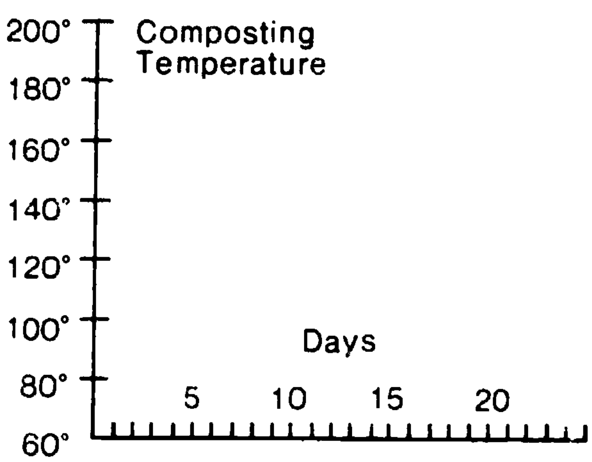

Figure 6

Step 3: After three weeks it may be more convenient to record your results as temperature plotted against time in weeks.

IV. RESOURCE RECOVERY

B. STUDENT ACTIVITIES

1. Recycle glass.

Step 1: To obtain powdered glass for this activity, enclose pieces of broken glass or a glass bottle in a heavy cloth. Carefully shatter the glass into small pieces with a hammer. Transfer the pieces of glass to a mortar. Using a pestle, grind the fragments into a powder.

Step 2: Place about 1 gram of the powdered glass in a crucible.

Step 3: Heat the crucible at the maximum heat of a Bunsen burner.

Step 4: After ten minutes observe the resulting clear glass that has formed in the bottom of the crucible.

3. Create thermal energy from waste material.

Step 1: As shown in Figure 1, construct a crude calorimeter by placing a small test tube (about 18 mm. x 200 mm.) in a metal can containing air vents, with large cuts along the bottom and small holes in the top. Using a rigid wire, construct a stand on which waste materials such as paper and plastic can be mounted. Place a thermometer in the test tube.

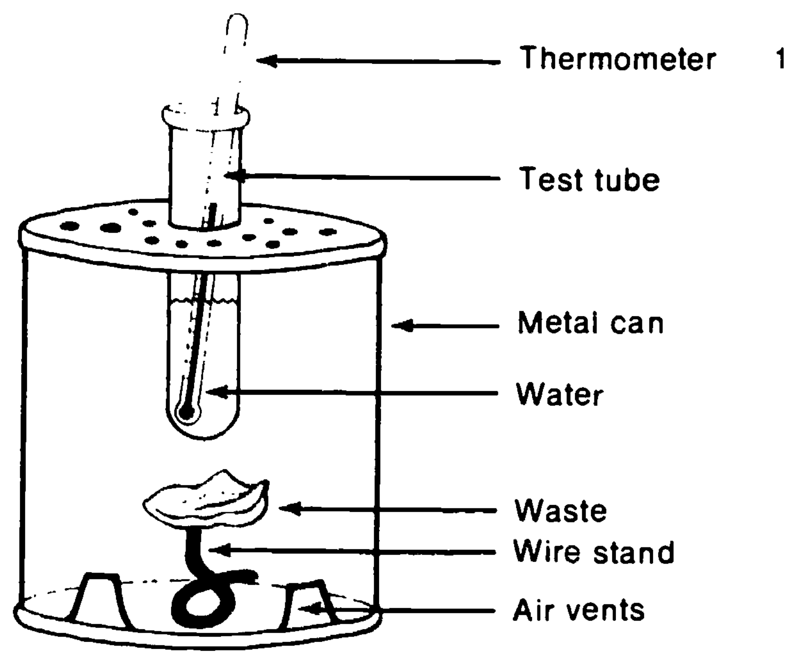

Figure 1

Step 2: Add 3 ml. of water to the test tube and record the temperature. Then remove the thermometer.

Step 3: Mount 0.5 gram of paper on the wire stand and position it so that the flame almost contacts the test tube.

Step 4: Using a match, ignite the paper and allow it to burn. As soon as the burning is completed, place the thermometer in the water. Measure and record the temperature of the water.

Step 5: Repeat this procedure, using 0.5 gram of a plastic that will ignite from the flame of a match. Be sure that a small quantity of water is present in the test tube.

Step 6: Compare the temperature changes observed for the different waste materials. Your observations are relative, since the heat loss from the crude calorimeter prevents exact quantitative measurements of heat content. Other combustible waste materials, such as dried vegetation, may also be compared. Note the thermal properties, such as melting or noncombustibility, of the various waste materials.

4. Simulate the pyrolysis of waste.

Step 1: Pack into a large test tube (about 25 mm. x 200 mm.) crushed dry leaves or other organic waste until the tube is about two-thirds full. As shown in Figure 2, mount the test tube at a 45° angle.

Step 2: Using rubber tubing, connect this reaction tube to a smaller test tube (about 18 mm. x 150 mm.). The connection from the reaction tube should be extended halfway into the collection tubes by means of a glass tube. The collection tube *must* have an exhaust tube. (CAUTION: WITHOUT THE EXHAUST TUBE THERE WILL CERTAINLY BE AN EXPLOSION.) Place the collection tube in a beaker of ice water.

Step 3: After placing a safety shield in front of the apparatus, heat the reaction test tube, using the maximum heat of a Bunsen burner. Within minutes the pyrolysis will produce gases. Periodically hold a lighted match at the exhaust opening and observe the flammability of the gas. (If too much moisture is present, several attempts will be needed before the gas ignites.)

Step 4: After all the gases have been liberated (about 10–15 minutes), turn off the heat. Examine the collection test tube for oils and the reaction tube for char. Record your observations. Relate your results to those obtained in research on pyrolysis of solid waste.

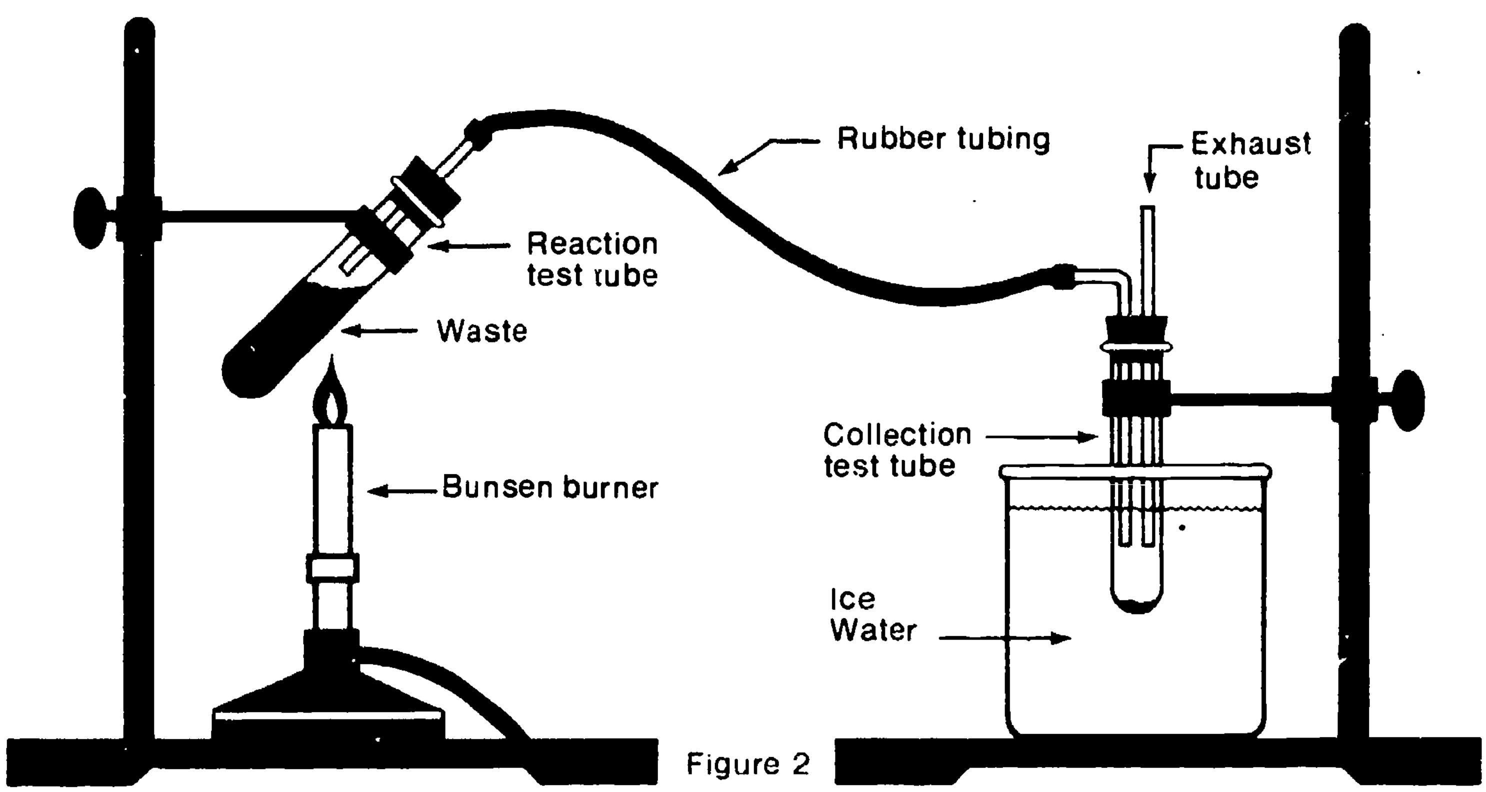

Figure 2