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ABSTRACT

The materials in this curriculum supplement, developed for middle school or high school science classes, present solid waste problems related to plastics. The set of curriculum materials is divided into two units to be used together or independently. Unit I begins by comparing patterns in solid waste from 1960 to 1990 and introducing methods for plastics identification. The 11 lessons in the unit explore the raw materials of plastics, leads observations of what happens to plastic litter, and introduces alternatives to dumping, including incineration, reuse, and recycling. A community survey is proposed as a basis for developing a plan for recycling and waste reduction for the community. Biodegradable and photodegradable plastics are studied in unit II as the factors that cause degradable plastics to break down in the environment are explored. The unit describes several degradation tests that allow students to set up projects that monitor the rate of degradation for a variety of plastics. The lessons are specific to Illinois classrooms but may be adapted for other states. (MCO)

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September 1991

Plastics in Perspective

Illinois Department of
Energy and Natural Resources

University of Illinois
Center for Solid Waste
Management and Research

Plastics in Perspective

Plastics: Waste Reduction/Recycling

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Degradable Plastics and the Environment

Part of the Solution or Just More Pollution?

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FOREWORD

Plastics in Perspective

Many of the most troubling aspects of the solid waste problems facing our society center around plastics, that versatile family of substances developed from petroleum—a nonrenewable resource—that does not readily recycle through the natural ecosystem. The materials in this curriculum supplement have been developed for use with students in middle school or high school science classes.

This set of curriculum materials is divided into two units, each developed and written by a different author. It is not essential that both sections be taught. However, the writers and reviewers feel that the two sections complement each other and when presented together provide an in-depth picture of the plastic waste dilemma facing us all. It is hoped that this material will help our young people become better informed citizens and decision makers, prepared to improve our record of resource use.

Unit I begins by comparing patterns in solid waste from 1960 and 1990. It introduces the plastics used in our everyday lives and gives methods for identifying the various kinds of plastics through laboratory work. The unit explores the raw materials of plastics and leads observations of what happens to plastic litter. Alternatives to dumping, including incineration, reuse, and recycling, are explored. A community survey is proposed as a basis for developing a plan for recycling and waste reduction for the community.

Unit II explores the factors that cause degradable plastics to break down in the environment. Two main types of degradable plastics are studied: biodegradable and photodegradable. The unit describes several degradation tests which allow the students to set up projects that monitor the rate of degradation for a variety of plastics.

The authors used several sources for the statistics used in their units. These sources do not always agree and small differences exist. It is important to note the source of information. You might have the students discuss why these numbers are different.

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Plastics: Waste Reduction/ Recycling

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Introduction

PLASTICS: WASTE REDUCTION/RECYCLING

Plastic is by far the fastest growing portion of the solid waste stream in America, and it will likely increase by another 50 percent in the next 10 years. Plastic seems to be destined for the junk heap—but why? What is plastic made of? What is it used for? How much plastic is manufactured? How much plastic is discarded? What happens to it after it is thrown away? What is in the future for plastic? What are the costs in a society with plastic? What are the costs in a society without plastic? How long can we ignore the issue?

Without doubt, Americans are part of a throwaway society, and according to data published by Franklin Associates for the U.S. EPA, we are rapidly becoming more wasteful. In the 30 years from 1960 to 1990, the weight of trash produced in our cities and towns has nearly doubled. While this in and of itself may not seem alarming (amounts of trash would probably grow with population—though our population has not doubled in that same time), what is more striking is the behavior of the individual. Over this same period, the pounds of trash per person per day grew from 2.48 to 3.27 (almost one-third more). In other words, in 1990, everyone in the United States is personally responsible for almost 1,200 pounds of trash per year, a total of more than 300 billion pounds of garbage.

We literally create a mountain of trash every year that should become an obvious mountain range on our landscape. However, rather than leaving this refuse where it might be seen, we have buried it. Once out of sight it is out of mind. But placing trash in landfills has not solved the problem of solid waste. In fact, landfill space is rapidly declining, and many operating landfills have problems with leaching and gas production, among others. Entombing our waste has merely postponed addressing the real issues and in the meantime we have buried billions of tons of potentially valuable resources.

Burying our trash is a waste both materially and economically. In dollars, a typical community spends more of its municipal funds to operate a landfill and dispose of trash than it does to support social programs. The cost of landfilling trash has risen significantly in our country, and the cost is passed on directly to the customer by raising pickup fees.

Material resources present in our discards include metals, glass, paper, yard waste, food waste, plastic, wood, rubber, leather, and textiles. When analyzing these various components of solid waste, some patterns become clear. Though the amount of most constituents of trash actually decreased, remained level, or marginally increased, two have changed quite dramatically. In our modern information age, the average person discards almost two-thirds more paper and paperboard than someone in 1960. But even more astounding is the fact that the amount of plastic discarded is 25 times more in 1990 than in 1960!

The problem of solid waste is rapidly becoming a crisis, but garbage is a social as well as economic and ecological problem, and though it will require technical solutions, engineering alone is not sufficient to solve it. Although some experts believe that the necessary technology is "on the shelf," the final remedy must involve all parties in a concerted effort. It can be done, but it must be chosen.

In this unit, you and your students will have a chance to investigate the problem of solid waste as it relates to plastics. You will begin by comparing patterns in solid waste from 1960 and 1990. You will hunt for plastics in your everyday life and learn to identify some of them through laboratory work. You will find out what plastics are made from and how they are formed. You will observe what happens to plastic litter. You and your students will analyze your own trash and see what plastics are contained there. You will visit a landfill and find out what happens to plastic that is discarded. You will consider alternatives to dumping such as incineration, reuse, and recycling. You will look at case studies of plastics being recycled. You will survey your community and develop a plan for recycling and waste reduction in your area.

A complete guide for teaching this unit and an extensive bibliography has been included for your convenience.

An Overview

The goal of this curriculum unit is to convey the importance of plastic waste reduction and recycling. As a result of the following outcomes, students will not only have an opportunity to learn about plastic waste, they will also obtain the knowledge, skills, and perhaps the motivation to do something about it.

Many communities across the nation lack the markets and facilities to support plastic recycling. However, momentum is gaining in the recovery, processing and remanufacturing of plastic into various useful products. If children in schools can be informed of the problem and given the ability to address it, perhaps these barriers can be overcome.

This project will take from three to four weeks to complete if all of the activities are included. You will also need to do a fair amount of preparation in the organization and reviewing of the references listed for the lessons. Some of the lessons also require material preparation.

Outcomes, timing, and materials for each lesson are summarized below. Each lesson includes: background information, detailed preparation and teaching plans, discussion questions, and a bibliography. At the end of the unit, you will also find a complete bibliography and a mailing list with contacts for free videos, books, brochures, samples, etc.

LESSON ONE

1) Students will become aware of the amount of trash produced by the average American each day.
2) Students will analyze trash using mass, volume, and percent.
3) Students will make comparisons between trash in 1960 and 1990.
4) Students will also draw conclusions from trends in graphs over the same period.

This lesson should take only one period. However, you will need to take time to prepare the trash samples in advance. You can use "clean" items for the trash—most of the materials can be saved to use again.

Create the trash samples using the chart in Table 1 as a materials guide.

LESSON TWO

1) Students will recognize that plastic is a common material for everyday uses, especially packaging.
2) Students will become aware that plastic has many specialized and technical applications.
3) Students will group plastic items by general physical characteristics or functions.
4) Students will realize that most ordinary plastic items are meant to be disposable.

This lesson should take one to two class periods depending on how many items are brought in and the length of discussion. You need to take plenty of time for students to handle, observe, and classify the plastics.

You should begin saving plastic bottles, tubs, containers, bags, etc., well in advance to expand the collection if necessary. Be sure to look at the Society of the Plastics Industry brochure on container coding. Some products are already coded so it will be easier for you to identify them by resin type.

LESSON THREE

1) Students will be able to carry out a variety of simple laboratory tests on plastic items.
2) Students will be able to develop a flow chart for identifying unknown samples.

The laboratory experiment may take more than one period, depending on the abilities of your students and the number of unknowns that are tested.

See the lesson for safety information and the student procedure. The Dow guide for identifying rigid plastic containers is a useful summary of properties.

Also, see the lesson for sample preparation. You will need to cut or chip two or three pieces of each of the six plastics listed for every group doing the experiment. Each group will need a pair of forceps, a candle, and a container of water for the tests.

LESSON FOUR

1) Students will be aware that plastics are formed from chemicals found in petroleum.

2) Students will recognize that plastics are based on a nonrenewable resource.

3) Students will understand the basic processes of polymerization by simulating the formation of polyethylene.

This lesson should take only one period. You may want to duplicate or make a transparency of the diagrams for polymer formation. This is meant to be only an introduction to polymers, and the lesson can be easily expanded using the resources listed in the bibliography.

If you do the simulation activity, you will need a large open space for the students to move in and link together.

LESSON FIVE

1) Students will observe the effect of nature on various items in typical litter.

2) Students will compare the behavior of degradable vs. other plastics.

This lesson can take one or two periods, depending on how much you do before to the activity. If you set up the "litter" area or compost heap several months early, you could photograph the items periodically for comparison in class. Or if you have students create the site you will need to continue observing it for many weeks into the future.

The audio tape and many excellent articles are well worth discussing. Students can be assigned readings before this period, and the tape can be played as a catalyst for discussion.

LESSON SIX

1) Students will understand their own personal involvement in the solid waste problem.

2) Students will measure mass and calculate percent for the components of trash.

3) Students will consider ways to reduce their contribution to waste.

For this lesson you will need one or more periods, depending on how many students bring in trash for analysis. It will take a whole period for a group of students to go through one person's trash.

You will need to come prepared to cover the floor or tables to protect them from the mess, and you will need a plan for disposing of the trash at the end of the activity.

LESSON SEVEN

1) Students will realize where most of their trash goes.

2) Students will be more aware of the mounting problem of solid waste, both in terms of space and cost.

The tour itself may take more than one period so you will need to make arrangements for taking students out of classes for a field trip. Arranging the tour should be done in advance with a backup plan in case of bad weather.

If you plan to use the video tape, be sure to order it early and have it copied.

LESSON EIGHT

1) Students will acquire a broader and deeper knowledge of solid waste management alternatives.

2) Students will become aware of the need for an integrated approach to solid waste management.

3) Students will apply this learning specifically to plastic in solid waste.

4) Students will create an integrated approach to address this problem.

This lesson can take one to two periods. Students need enough time to make their presentations to class.

Also, if class time is used for preparation (which is reasonable), you may need to take two or three more days. This is an important learning experience for the students.

The materials required are, for the most part, the suggested readings, but students will also need some items for visual aids, such as poster board or overhead transparencies, etc.

LESSON NINE

1) Students will be introduced to the fundamental ideas and procedures involved in plastics recycling.

2) Students will consider steps for initiating a plastics recycling project in the community.

If you use the videotape and discuss the readings, you will need two periods for this lesson. Be sure to book the videotape in advance.

LESSON TEN

1) Students will administer a survey to community members.

2) Students will assess the results of the survey.

3) Students will draw conclusions concerning attitudes and participation from the results of the survey.

4) Students will devise a plan for initiating plastics recycling in the community based on their conclusions.

From start to finish—having students take the survey for practice, doing the survey in the community, analyzing the responses, and discussing the results—this activity may require more than a week. You may wish to begin working with it in class before starting lesson eight so that class time will not be lost while you are waiting for surveys to be returned.

Be sure to duplicate enough copies for each student to distribute.

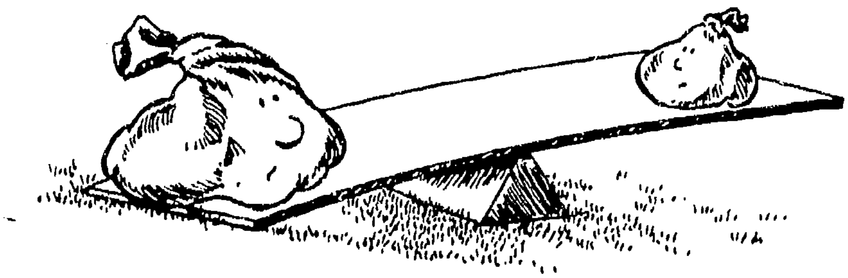
LESSON ELEVEN

1) Students will create an integrated plan for action based on the information gathered in this unit.

2) Students will test the feasibility of the plan by submitting it for consideration to the municipal governing board. (optional)

If you choose to use this final lesson and its outcomes, you may need several days to put your plan into action. While this may be too much to take from a class schedule, the result could be important to the students. They may even be willing to get more involved outside of the classroom on their own time.

Lesson One
HANGING IN THE BALANCE



On this first day, it is important to impress the student with the immensity of the problem of solid waste. A vivid demonstration using real garbage will initiate a thoughtful discussion on the issue of personal involvement and responsibility.

OUTCOMES:

1) Students will become aware of the amount of trash produced by the average American each day.
2) Students will analyze trash using mass, volume, and percent.
3) Students will make comparisons between trash in 1960 and 1990.
4) Students will also draw conclusions from trends in graphs over the same period.

PREPARATION:

For the demonstration, you will need two bags of trash. One will represent average 1960 discards, and the other will represent average 1990 trash. Use information from Table 1 to create these sample bags. In looking at the data, it should be obvious that the most dramatic change has been in the segment of plastic trash. By mass, plastic discards in 1960 were equivalent to three or four plastic sandwich bags. The 1990 figure is 25 times greater, and this could include plastic bottles, bags, candy bar wrappers, food containers, etc.

The components of the trash samples should be placed in clear plastic bags for convenience. Then each of the components should be placed in the appropriate 1960 or 1990 trash bag. Except for the food waste and yard waste, the separate bags of paper, glass, metal, etc., for each sample can be saved for future use so it is worth trying to be fairly accurate in the amount of each present. (For the "inorganic miscellaneous," you might just put some table salt in the bag to represent these materials that end up in trash. This can include batteries, mineral waste, etc.)

You will also need a hand spring scale or pan balance for finding the mass of the trash and its components. These can probably be borrowed from a science classroom if you do not have one yourself.

You might choose to dress up as a garbage collector to set the mood for the unit. These people play a key role in one of the most important AND expensive problems we face today.

TEACHING PLAN

Place the two sealed bags of trash on the table, and let the students pick them up and handle them. Ask them what they might do to find out more about the difference between the two bags. This should lead to a decision to weigh them and look at their contents.

Weigh the two trash bags and have the students record their masses. Spill out the contents of the bags; have the students describe the various components weigh; and record each of their masses as well.

Using the mass of a particular component (for example, glass) and the total mass from the year (say 1960), have the students calculate the percent of that component in the trash for the year:

$$\frac{\text{Mass of glass}}{\text{Mass of trash}} \times 100 = \%\ \text{glass in trash}$$

It is possible to make some rough visual comparisons of volume of each component of trash. This can be accomplished by placing the components from each year in rank order of which appears the largest down to the smallest. It should be quite obvious that at least some of the volume in the bags is due to the empty space in rigid containers. But unless they are thoroughly crushed, these empty spaces also contribute to volume in landfills.

Using the data from Table 1 on an overhead transparency or a handout, have students make bar graphs of the trends in discards for each of the categories. The students can be split up into groups for this part, and each group can do one graph. For example, one group would deal with paper and paperboard, one with glass, metal, etc. The resulting growth curves should make it quite clear that the accelerated climb by plastics is unusual and of great consequence.

Based on these growth curves, have the students project to the year 2050 (most of them will be retiring by then). From these graphs, the students can determine the amount of each component in trash and total trash discarded in that year.

DISCUSSION

These questions can help to guide a discussion of the previous activities:

1) What changes have taken place in the last 30 years?
2) Have all segments increased?
3) Have all the increases been at the same rate?
4) How have percentages of each segment changed over the years?
5) How has the volume of each segment changed over the years? (Does it seem to be in proportion with the change in mass?) For this question, it is important to note that for plastics—which have exceptionally small mass for their size and which tend to trap air even when crushed—the volume increase may seem more dramatic. Plastics are about 8 percent of trash by mass but can be more than 30 percent by volume.
6) What do the graphs of the separate segments over time suggest concerning patterns of waste disposal?
7) What factors might explain some of these changes since 1960? (For example, glass and metals are still used extensively in packaging and disposable items, but advances in technology have led to lighter weight materials; paper waste has grown rapidly in our "information age"; disposable plastic containers have become very popular since the mid-1960s.)
8) In what time period did plastic in waste increase the most?
9) Why are plastic containers and packages so popular?
10) Why has the amount of plastic in waste increased so much while other materials have increased only slightly?
11) The metal, glass, and plastic in a person's daily trash have about the same mass. Why does it look like there is more plastic present?
12) Can you draw any general conclusions about our society from these patterns of waste disposal?

At this point, it should be obvious that plastic waste is rapidly increasing. Let students ponder whether they think something should be done about this, why they feel that way, and what could be done.

If they are not sure that the issue of discarded plastic is so important, reinforce the magnitude of the problem by doing the following calculations. Multiply the number of pounds of plastic discarded per day per person by the number of days in a year and by the number of people in the U.S. (0.26 X 365 X 250,000,000 = 23.7 billion lbs.). This is an incredible amount of material. This can lead to other questions like:

1) From what is plastic made, and can we afford to throw it away?
2) Where does trash go, and what happens to the plastic in it?
3) How much does all of this cost us?

These issues will be addressed in later lessons.

BIBLIOGRAPHY

1) Thayer, Ann M., *Plastics recycling,* Chemical and Engineering News, Jan. 30, 1989. (This is an excellent general resource that will be useful throughout the unit.)

2) Franklin Associates, *Characterization of municipal solid waste in the United States 1960 to 2000,* (1988 update). Prepared for USEPA. Franklin Associates, LTD. Prairie Village, KS.

3) *Methods to manage and control plastic wastes: report to Congress,* United States Environmental Protection Agency, Office of Solid Waste, Office of Water, Feb. 1990. (This comprehensive report to Congress gives a broad overview and detailed description of the problem as it now exists and current efforts toward solutions.)

FURTHER STUDY

1) Students could do some research on trends in personal waste by interviewing adults who lived in the 1950s, '60s, and '70s. Find out how products changed, why they changed, and if people were aware of a need for change.

2) A new field in archeology—garbology—examines what the characteristics of household waste say about a community and its social values. Much of this work has been headed by William Rathje of the University of Arizona. His project was called *Le Project du Garbage*, and he presented a paper before the Forum of the Association of State and Territorial Solid Waste Management Officials on Integrated Waste Management in 1988 that was titled *Source Reduction and Landfill Myths*.

TABLE 1

Discards of Municipal Solid Waste By Individuals, 1960 to 2000

(In pounds per person per day)

Materials	1960	1965	1970	1975	1980	1985	1990	1995	2000
Paper and Paperboard	0.74	0.91	0.98	0.87	1.01	1.12	1.20	1.20	1.27
Glass	0.19	0.24	0.33	0.33	0.34	0.28	0.27	0.26	0.25
Metals	0.32	0.30	0.36	0.34	0.31	0.28	0.29	0.29	0.29
Plastics	0.01	0.04	0.08	0.11	0.18	0.22	0.26	0.29	0.32
Rubber and Leather	0.05	0.06	0.08	0.09	0.10	0.08	0.08	0.08	0.08
Textiles	0.05	0.05	0.05	0.06	0.06	0.06	0.07	0.07	0.07
Wood	0.09	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.12
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL NONFOOD PRODUCTS	1.46	1.71	2.00	1.92	2.13	2.16	2.29	2.37	2.48
Food Wastes	0.37	0.35	0.34	0.34	0.29	0.28	0.27	0.26	0.25
Yard Wastes	0.61	0.51	0.62	0.64	0.64	0.64	0.65	0.65	0.65
Miscellaneous Inorganics Wastes	0.04	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.07
TOTAL WASTE DISCARDED	2.48	2.71	3.01	2.95	3.11	3.14	3.27	3.35	3.45

Details may not add to totals due to rounding.

Source: Franklin Associates, Ltd.; Characterization of Municipal Solid Waste in the United States, 1960 to 2000 (Update 1988); page 24, table 9

Note: All numbers past the 1985 date are projections made in 1988.
Students may wish to get current numbers to check the accuracy of those projections.

Lesson Two
THE SCAVENGERS

We are certainly all familiar with the many forms that plastic can take in packaging—bottles, bags, films, cartons, padding, etc. However, this is only one part that plastics plays in our lives. Innovations in formulas and preparation of plastics have made them some of the most versatile materials for space travel, construction, automotive, health care, electronics, and many other technical applications.

The very high strength-to-weight ratio of plastics has made them important in the construction of energy-saving jets and space vehicles. And their "invisibility" to radar has made plastics extremely important in the development of the stealth bomber.

In our modern society, it is nearly possible to construct an entire house out of plastic building materials and trim, from plastic pipes for water, plastic lumber for decking, and plastic foam for insulation to plastic siding and window frames, bathroom fixtures, and molded trim pieces for a decorative touch. Use of plastics in construction is second only to use of plastics in packaging and is continuing to increase at a rapid pace. Low cost and high strength and durability of the materials make them attractive substitutes.

In transportation, plastics again play the role of weight-saving for fuel efficiency, but they have become a material of choice and not just necessity. Every car made today has some plastic in the exterior body parts, interior passenger compartment, and engine components. There are a few cars that have all-plastic bodies (such as the Pontiac Fiero), and there are plans for an all-plastic car in the future.

Amazing advances have taken place in the fields of medicine and health care because of plastics. Blood vessel replacements, artificial kidneys, and even artificial hearts are made almost entirely of plastic. Sterile plastic gauze and adhesive strips are used to cover wounds, and plastic devices can be implanted to deliver doses of a medication on a timed-release schedule.

The light weight, water and corrosion resistance, and electrical insulating abilities of plastics have made them ideal for uses in both consumer and highly technical electronic components. Plastic is used for the ases of most computers, stereos, TV's, etc. Plastics also are an important part of the circuit boards for computer chips, disks for data storage and retrieval, devices to protect from dust and humidity, and fiber optic cables that transmit telephone calls.

Plastic is all around you right now. Can you find anything that is plastic that has not been mentioned yet? In the next section, you will have a chance to think about these innovative uses of plastics. What has brought them about? What materials have they replaced? And what does the future hold for plastics?

Though it is apparent that plastic is important in all aspects of our lives, by creating a collection of plastic items it should become clear that most plastic seems to be destined for the trash.

OUTCOMES

1) Students will recognize that plastic is a very common material for everyday uses, especially packaging.
2) Students will become aware that plastic has many specialized and technical applications.
3) Students will group plastic items by general physical characteristics or functions.
4) Students will realize that most ordinary plastic items are meant to be disposable.

PREPARATION

This list of common plastic items can be used to create a scavenger hunt or classroom display. The list has been organized by material type for easy identification, but the student should not be told this beforehand. This activity should allow students to explore and classify based on their own observations. The six most common plastics included here are:

High-density polyethylene (HDPE)
dairy product containers, detergent and cosmetic bottles, antifreeze containers, motor oil bottles, milk and water jugs, 2-liter soft drink bottle base cups, margarine tubs, and bleach bottles.

Low-density polyethylene (LDPE)
films (like food wrap), trash bags, sandwich bags, grocery sacks, dry-cleaning bags, mustard containers, flexible bottle caps, coffee can lids, and food storage containers.

Polypropylene (PP)
cellophane-like snack food bags and wrappers (glossy and crinkly), candy wrappers, squeezable catsup bottle, linings of disposable diapers, aerosol can caps, rigid caps on soft drink bottles, deli tubs, and some plastic cutlery.

Polystyrene (PS)
high-impact — plastic cutlery, disposable razors, prescription and vitamin bottles.

semi-rigid — lids; single-service mini-containers for cream, jelly, butter pats; and cottage cheese tubs, clear deli carryout containers; cookie package trays; cellophane-like films.

foam — packing and insulation materials, food trays, egg cartons, carryout containers, hot cups, "clam shell" containers for fast foods.

Polyvinyl chloride (PVC)
durable construction products (pipes, siding, conduits, cables, gutters, flooring, paneling), luggage, foot wear, upholstery, brief cases, clothing, camping gear, beach rafts, vegetable oil bottles, imported mineral water bottles (Evian), household cleaner bottles, bottle cap liners.

Polyethylene terephthalate (PET)
soft drink bottles, liquor bottles, microwave freezer containers.

Some plastic containers already have been imprinted with the plastic container codes described in the SPI brochure. Using this guide, you can quickly identify the plastic resin used in a particular item that has been coded. See the bibliography for details.

The students should have an opportunity to handle and observe the items very closely. The purpose is to classify the materials by similarities in properties or uses. Examples of groups might be:

a. colored - uncolored
b. opaque - translucent - transparent
c. rigid - flexible
d. food - non-food container
e. disposable - durable

By letting students know that six different plastics are represented here, students can become more particular in their grouping. It is not likely they will be completely accurate, but they should begin to realize more subtle differences and similarities between the items.

At this point, further work can be carried out in the laboratory to determine other physical and chemical properties of the plastics.

Several other interesting observations may be made here as well. Some items contain two or more different plastics, e.g., the 2-liter soda bottle is PET with an HDPE base cup and possibly a PP cap with a PVC liner. The squeeze catsup bottle is not pure PP: it actually has five to seven layers of plastics and adhesives, though PP is a major component. The variety of PVC products clearly demonstrates the diverse properties that can be obtained with additives such as colorants, plasticizers, stabilizers, fillers, etc.

Plastics are also used more frequently in highly technical and engineering applications. Some of these are discussed in a series of articles from *Modern Plastics* (a set of brochures and pamphlets produced by Society of the Plastics Industry) and an article from *U.S. News and World Report*. (See bibliography for complete reference.)

TEACHING PLAN

Using this information, organize a scavenger hunt for plastic items in the home. Be sure to get a good representative sample of ordinary items, but also challenge students to bring in "exotic" items made of plastic or items that only recently have appeared on the market.

Create a display that the students can handle and group according to characteristics or functions. It might be nice to keep the display intact for the next few days as you continue to study plastics. Some of the items may also be tested in the laboratory activity to follow.

DISCUSSION

1) What desirable characteristics make plastics so good for these many uses?
2) Are plastic items meant to be durable or disposable? Give examples.
3) How many of these items do you throw away in one day? (The average person discards about five plastic packages per day.)
4) How long have plastics been in use compared to paper, metals, wood, ceramics, glass, etc.?
5) Are plastics used mainly to replace other materials, i.e., metal, wood, glass, or for unique applications? Give examples.
6) Is the use of plastics increasing or decreasing? If increasing, what are some of the new uses?
7) Predict new uses for plastics in the next year, 10 years, your lifetime.
8) Americans used to sneer at "cheap plastic" products, especially imports. Are plastics "cheap" either economically or materially?
9) What happens to discarded plastics? Do they break down or burn or otherwise "disappear"? (This will be studied later.)

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3) Sheets, Kenneth R, *The new high-tech world of plastics*, U.S. News and World Report, Feb. 24, 1986.
4) *Typical container materials*, Plastics Group, The Dow Chemical Company, 1989.
5) *Plastics: A.D. 2000 production and use through the turn of the century*, Chem Systems, 1987. (This is a comprehensive look at plastic authorized by SPI. It is available through interlibrary loan.)
6) *SPI's Voluntary plastic container coding system* brochure.
7) *Polymers, the material of choice today, tomorrow, and thereafter*, The Polymer Group of the University of Illinois, 1304 W. Green St., Urbana, IL 61801.

FURTHER STUDY

1) Someone could do more research into the future of plastic products. One good resource would be *Plastics: A.D. 2000*, an industry guide to the trends in applications and markets. Another good source would be the industry publication *Modern Plastics*. These may be available through interlibrary loan. The pamphlets from SPI are also good summaries of plastic's future.
2) A student could investigate what process accompanied the replacement of glass soda bottles with plastic. How was this initiated? Was there a consumer demand? Was there a public debate? How was the glass industry affected?

Lesson Three
PLASTIC IN THE LABORATORY

If plastic is to be recycled, and that is our ultimate goal, consumers must know which plastic is which. However, that can be very complicated today with so many different resins as well as composite, or layered, plastics. One way to find out what a plastic is made of is bring it into the laboratory and perform the following experiment. A simpler answer for the consumer will be introduced later.

OUTCOMES

1) Students will be able to observe or carry out a variety of simple laboratory tests on plastic items.

2) Students will be able to identify unknown samples.

PREPARATION

This is a laboratory experiment and it requires full attention to safety. This means wearing goggles, having fire extinguishers nearby, and having good ventilation and water available. It is possible to work safely in a regular classroom or even outside, but it might be preferable to be in a science laboratory.

The Dow guide (see Bibliography) to identifying rigid plastic containers provides a useful summary of properties to be observed in this experiment.

A. Safety

Due to the potential safety hazards involved with this particular experiment, we request that teachers only conduct these procedures as demonstrations under proper safety considerations (i.e., hooded ventilation, etc.)

While burning, the plastic could spatter and drip.

Also, use great care when handling the burning plastic as it can drip and cause burns, or it could ignite other combustible materials.

Caution students about inhaling the vapors. The PVC does release hydrochloric acid gas when burned or heated. In a large quantity, this could be harmful. But in this experiment, the amount of HCL produced is small and should not be dangerous. However, a well-ventilated room or open window is advised. Test the ventilation for yourself to decide. You may feel it inappropriate for students to do the burning and may choose to do it as a demonstration.

Be sure to tr: ne procedure yourself first. Pellets, chips, or small sheets cut from each material will work in these tests. Just be carefui of the amount. Keep pellets and chips to the size of a pea or sheets about 1 inch square.

B. Materials and equipment

Safety goggles, forceps, a container of water and a candle with matches are the only equipment. The samples of the HDPE, LDPE, PP, PS, PVC, PET may be supplied as pellets in a kit or can be obtained from the following consumer items.

HDPE—milk jugs, LDPE—coffee can lids, PP—some deli-tubs or plastic cutlery, PS—aspirin bottles or plastic cutlery, PVC—Evian mineral water bottles, PET—2-liter soda bottles

C. Procedure

This part of the procedure is related to laboratory work with known plastic samples. The purpose is to observe and record the behaviors and properties of the six most common consumer plastics. The results of this work with known samples will lead to the development of a scheme for working with unknown plastic samples.

1) Be sure that the plastic is not just suspended on the surface tension of the water.
2) Encourage students to develop precise descriptions of various levels of transparency, translucence, etc.
3) Again encourage precision in de: iption.
4) Caution students about flying plastic. It should be pointed away from other people when it is being bent.
5) There are dangers related to dripping and spattering as well as smoke and vapors (see above). To be done correctly, the plastic must be removed from the flame within one or two seconds or it will simply burn up.
6) Students should be able to use the procedure to work with unknown materials.

D. Unknown

These unknowns can be chips or cuttings from some of the household products listed previously. You may also want to encourage students to test their own samples. This is really what the experiment is all about. In a short time students can become "experts" on the composition of plastic household products.

A word of safety is important here though. When burned, polyurethanes (mostly as foams in upholstery cushions, rigid foam insulation, or wood coatings) can release isocyanate, which in small quantity will sting and burn the eyes and nose. Greater quantities of the gas (from samples larger than a pea) could be dangerous. Working outside or under a hood is recommended if polyurethanes are to be burned.

DISCUSSION

1) Why do some plastics float and some sink?
   (density of material: LDPE = 0.92 g/ml; HDPE = 0.96 g/ml; PP = 0.90 g/ml, PS = 1.05 g/ml, PVC = 1.39 g/ml, PET = 1.35 g/ml—those with a density greater than water at 1 g/ml will sink)
2) How are the characteristics of the various plastics matched with their uses as containers, e.g., rigid bottles, flexible bottles, thin sheets or bags, etc?
   (holding soda under pressure, squeezability, tight food wrap, light weight puncture resistant bags)
3) What is the benefit of a flow chart when identifying unknowns?
   (makes work efficient, eliminates possibilities by negative result)
4) Do all of the plastics have the same properties?
5) Why might it be important to separate different plastics if they are to be recycled?
6) Are the methods we used suitable for the consumer at home? Are they reasonable?
7) Think of ways to assist the consumer in easy but accurate identification and separation of different plastics.

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1) *Identifing Rigid Plastic Containers*, Plastics Group, The Dow Chemical Company, 1989.
2) *SPI's Voluntary Plastic Container Coding System*, SPI.

FURTHER STUDY

Look carefully at the container coding system for the plastic container industry. What are its advantages? Are there shortcomings? Who benefits from the recycling of plastic containers? What are some other factors involved in making recycling of plastics work? Does this coding system make recycling of all plastics much more likely to happen?

Plastic Identification Laboratory Procedure

A. Safety

1) Plastic materials will be burned in this experiment. Some may drip or splatter hot or flaming residue. Use caution, burn only the amount indicated (burning larger amounts is an extreme fire hazard), keep a container of water nearby to extinguish the burning plastic, and wear goggles at all times.
2) Vapors from some heated or burned plastics can be noxious. Use only the amount indicated, and do not breathe directly over the material.

B. Introduction

In this experiment you will investigate the properties of six different plastics. You will record your observations of their appearance, test their densities, and burn samples. The results of these experiments should allow you to identify an unknown material consisting of one of these plastics.

Of course, there are many more plastics than these six, and some of them may appear or behave similarly to these. However, this simple procedure is sufficient to identify the plastic in many ordinary household items.

C. Procedure

1) Place a small fragment of each of the plastic samples in a container of water. Observe whether the fragment floats or sinks and record your observation in a data table. (You may need to push the fragment under the water and shake off any trapped air bubbles to get an accurate result.)
2) Observe and record whether the material is transparent or cloudy.
3) Observe and record whether the surface is glossy. Use terms like high, low or none to compare.
4) Try to bend samples of each plastic. Note whether they are rigid or flexible, and again use descriptive terms to record comparisons in the data table. (Use caution when bending. Some materials may break and send pieces flying at high speeds. Hold the materials away from yourself and others to avoid accidents. For greater safety, bend toward a box lined with foam padding.)
5) Using forceps (tweezers), place a pea-sized pellet or 1-inch-square piece in a candle flame for one or two seconds. Withdraw it and observe whether it ignites. Hold the burning plastic over a container of water. Notice the nature of the burning—crackling, dripping, color of smoke, or odor. Note the cautions in the safety section. Record all these observations.
6) Compare results with other groups. Where you differ, repeat tests until there is general agreement.
7) Now use steps 1-5 of the procedure to identify an "unknown" plastic fragment. Record your observations and the name of the unknown plastic in your data table.

Lesson Four
A CHAIN REACTION

It is now obvious that we are constantly surrounded by plastic materials, but how are they made, and of what are they made? It is important to know this if we are going to do something with plastics besides bury them in a landfill.

OUTCOMES

1) Students will be aware that plastics are formed from chemicals found in petroleum.
2) Students will recognize that plastics are based on a nonrenewable resource.
3) Students will understand the basic processes of polymerization by simulating the formation of polyethylene.

PREPARATION

This lesson will require some open space for the polymer dance that forms the chain. It would also be convenient to have an overhead projector in the same room to help guide the activity.

Prepare overhead transparencies from following diagrams.

TEACHING PLAN

Simply stated, plastics are petroleum products. There are a few minor exceptions where research is producing small quantities of polymeric materials from living organisms or their by-products. But of nearly 60 billion pounds of plastic produced this year, essentially all of it is from oil. While this accounts for only about one-tenth of all petroleum used (most is burned for heat or fuel), the data from the overhead show that known oil reserves are being rapidly depleted.

Using the information from the overhead, have students calculate the number of barrels of oil used every year. Then have the students calculate the date that known oil reserves will be exhausted at current rates of consumption (approximately 21.5 billion barrels per year, all gone mid-2019). Consider the following questions:

1) Compare throwing away plastic and burning petroleum. How are they similar? How do they differ?
2) Can plastics be burned as fuel or for heat? (The fuel value of plastic is comparable to that of oil fuels, but the energy used in making the plastic is not recovered if it is burned.)
3) What should be done to change this outcome?

For a second activity, students can learn about polymer formation by performing the simulation described below. By following the instructions and using the overhead transparencies as a guide, students can do the polymer dance. This should be for fun, but it also provides an easy way to see how chain reactions occur. Remember that in real polymers, the number of units in each chain is in the millions, and a regular sandwich bag contains billions times billions of these chains.

Plastics are formed in two ways—addition polymerization and condensation polymerization. Five of the plastics mentioned here are addition polymers; they are formed by a reaction similar to that for polyethylene. The addition polymers differ only by side chains on the main hydrocarbon strands. Only PET is a condensation polymer. Its structure and process of formation are more complicated and will not be shown here.

In the classroom, students can participate in a simulation of addition polymers. The simplest is PE:

1) Have pairs of students lock elbows with each other while back to back.
2) The reaction begins when one "molecule" encounters an initiator. (For this you can "break" one of the bonds by opening one set of elbows of a pair of students leaving the other set of elbows locked. Place an object—an initiator—in the open arm of one of the students in this pair. The other student's arm is now the reactive portion of the molecule.)

3) The "reactive" student can then unlock another molecule and form a new bond with one end (by locking elbows). Now the student with a free arm at the end of this "chain" becomes reactive.

4) The process continues until all of the monomers have combined to form one long chain.

5) To be somewhat more accurate, the last pair to be added will still have a reactive end. The chain may be terminated by allowing this to react with another one of the initiators.

For a final activity, it is possible to form a polymer quite simply as a demonstration of chain formation. A very long strand of nylon can be pulled out of a beaker containing two clear liquids. A complete description of a safe procedure can be found in reference 3 below.

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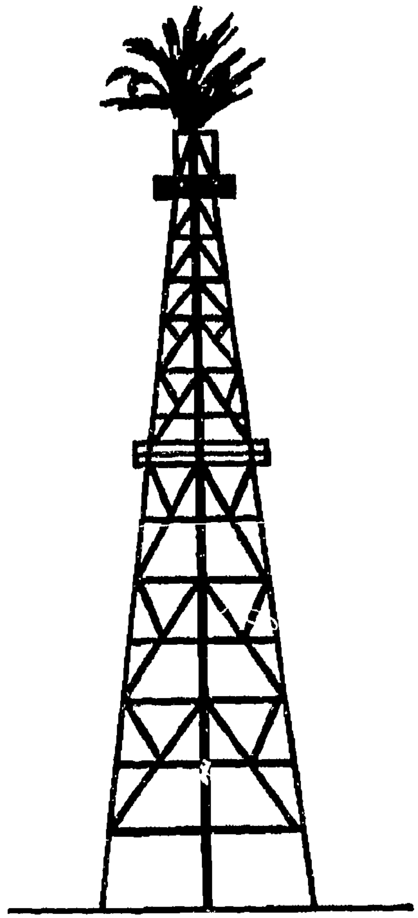
1) Alper, Joseph, *Polymers*, ChemMatters, April 1986, p. 4.

2) Any encyclopedia and most chemistry textbooks will have helpful sections for more specific details on polymers.

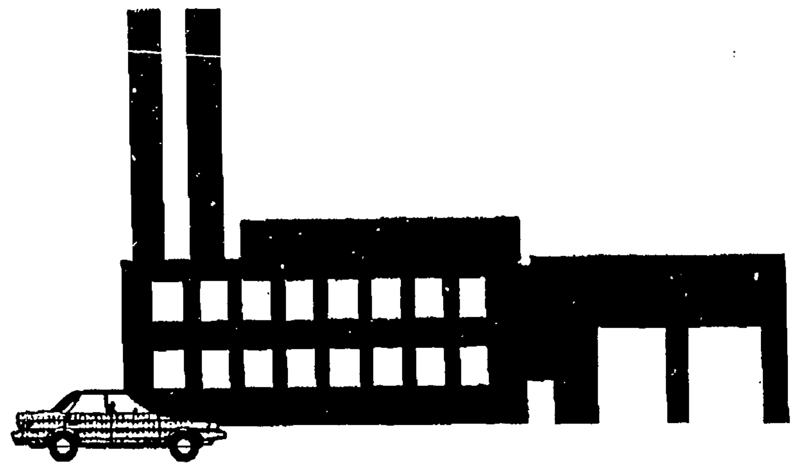
3) There are several excellent sources for chemical demonstrations that contain procedures for polymer demonstrations such as the nylon formation. These include: Shakhashiri, Bassam, *Chemical Demonstrations*, PP. 213-215. Summerlin, Lee, and James Ealy, *Chemical Demonstrations*, pp. 126-127, and the National Science Teachers Association publication called *Polymer Chemistry*. Another excellent source of laboratory investigations on the synthesis and analysis of polymers is: *Polymers*, The Polymer Group of the University of Illinois, 1304 W. Green St., Urbana, IL, 61801. It is available free by writing the above address or calling (217)333-0149.

Can We Keep Making Plastics Forever?



Known Worldwide Oil Reserves (1/1/87)

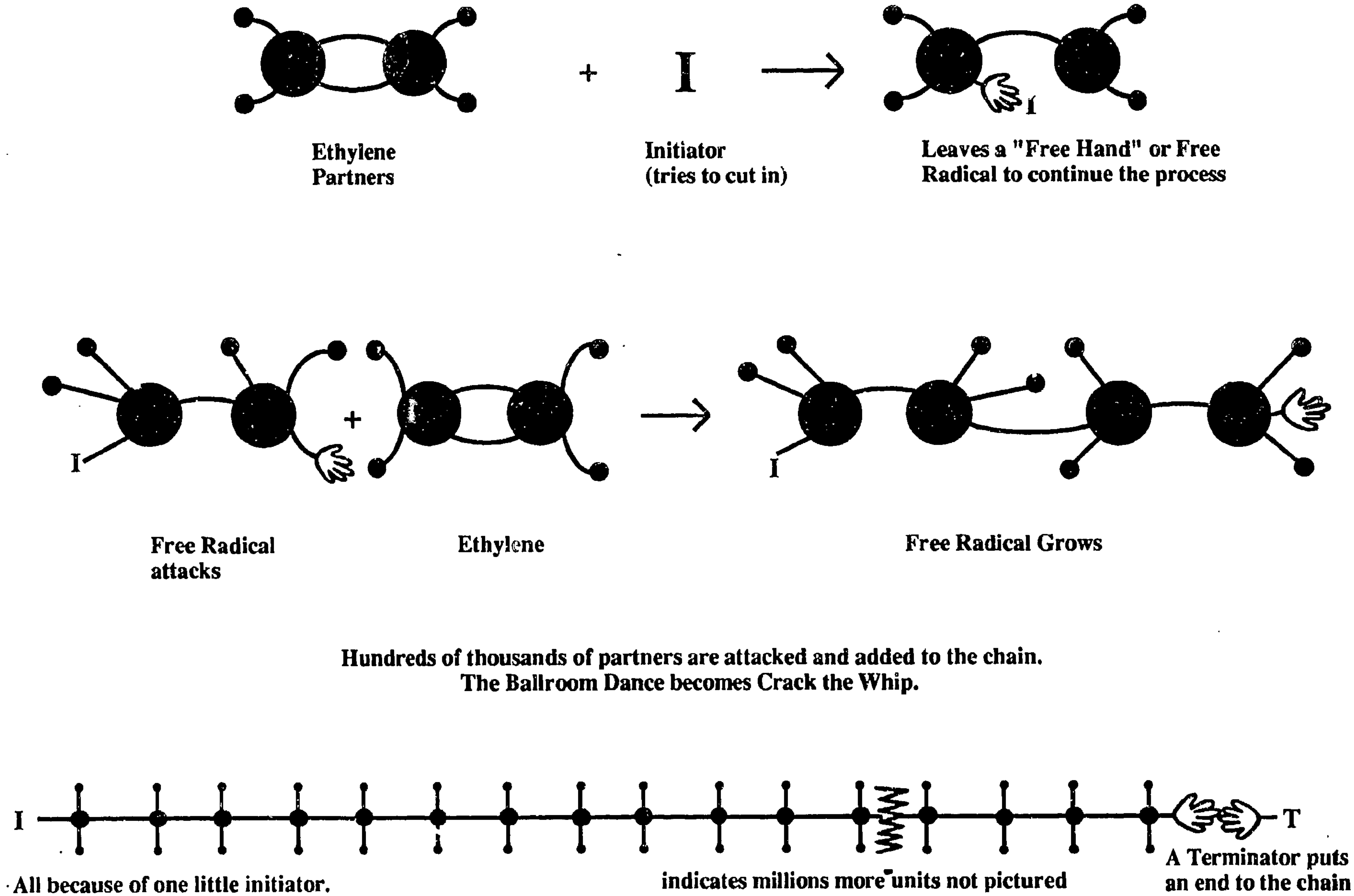
700 Billion Barrels



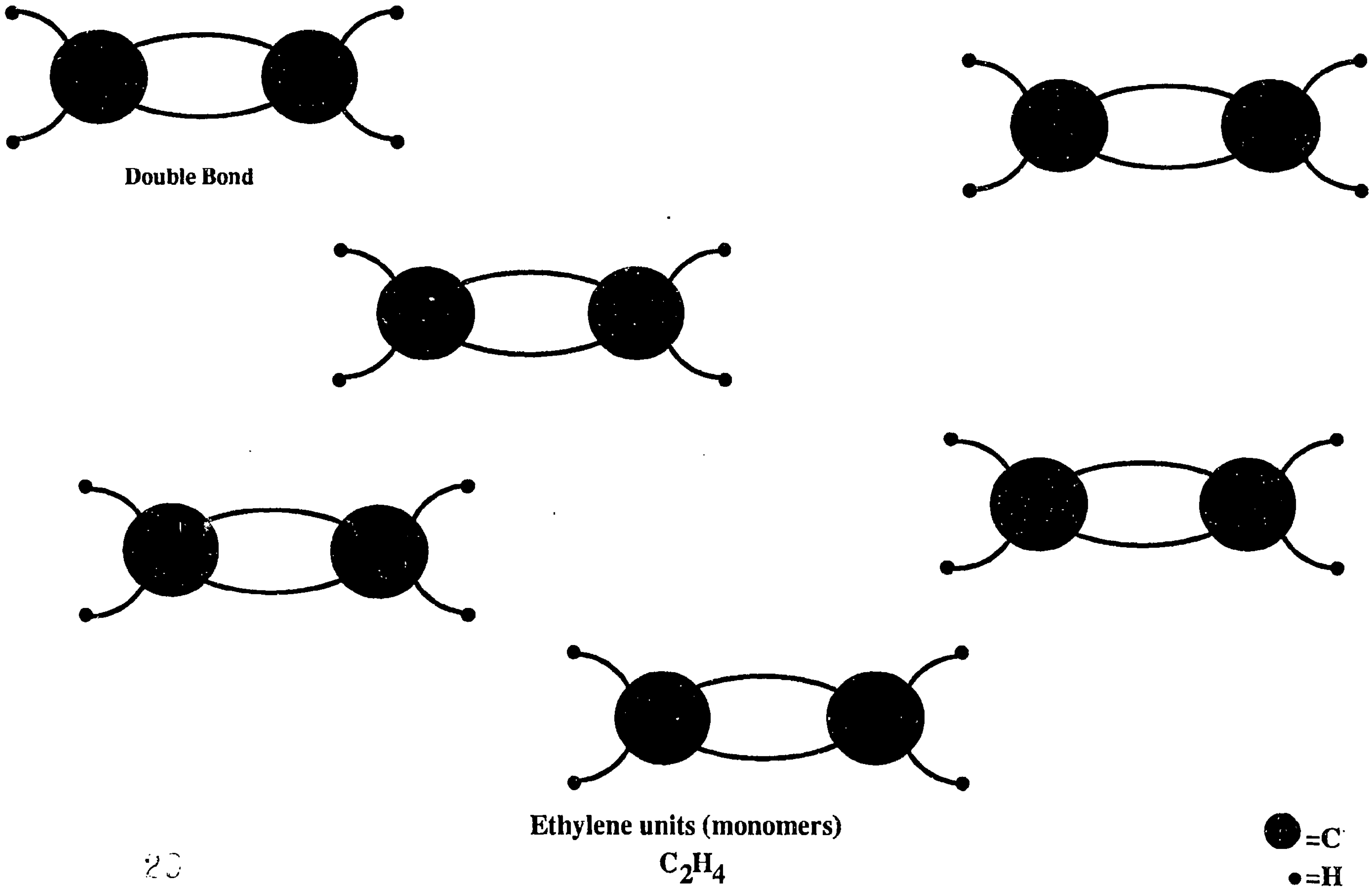
Current Consumption Rate of Oil (1/1/87)

(58.9 Million Barrels per day of Oil)

Information taken from *Energy in America's Future: The Choice Before Us*

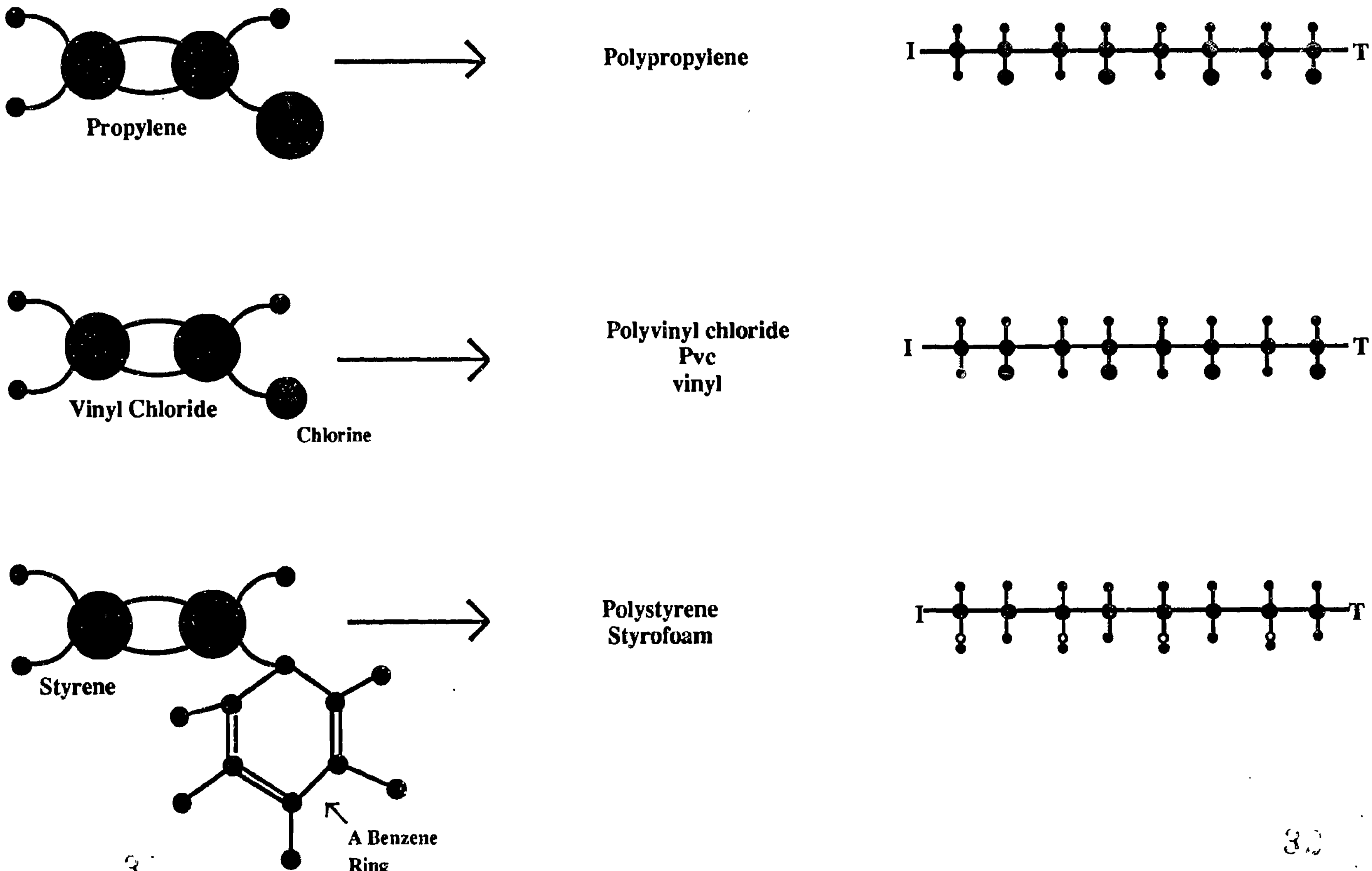

Ethylene
Partners
+
I
Initiator
(tries to cut in)
Leaves a "Free Hand" or Free
Radical to continue the process
I
+
Free Radical
attacks
Ethylene
Free Radical Grows
Hundreds of thousands of partners are attacked and added to the chain.
The Ballroom Dance becomes Crack the Whip.
T
A Terminator puts
an end to the chain
All because of one little initiator.
indicates millions more units not pictured

A Ballroom Dance



Ethylene units (monomers)
C_2H_4

Other monomers like Ethylene are ...



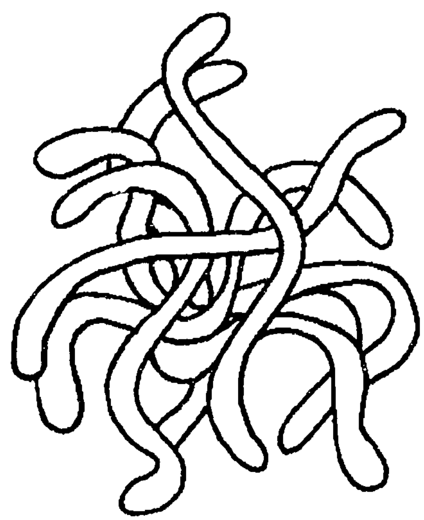
3

3

A terminator ends the chain.

A real polyethylene chain looks like a flexible zig-zag.

Now imagine millions of these atomic chains wrapping around each other like a bed of snakes....



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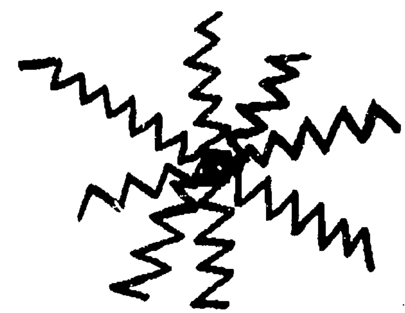

Depending on how the network forms, the material could be a fiber, a flexible or rigid film, or a sheet. This is generally how plastics are formed.

Lesson Five

LONGEVITY OF LITTER

The amount of trash littering our landscape is actually quite small considering that over 300 billion pounds of garbage is generated in the U.S. each year. However, the problem of littering is obvious, especially in the case of plastic. Unlike paper, wood, food, and even some metals, plastic is not broken down naturally in the environment. In fact, plastic left in the open may remain essentially unchanged for several hundred years. To address this aspect of the problem, some new "degradable" plastics have been tested and marketed.

Degradable plastics include photodegradable products that decompose when exposed to sunlight for some period of time. The material seems to disappear. Biodegradable products are made edible to small organisms by including some fraction of starch in the network of molecules in the plastic. The starch is consumed by bacteria or larger organisms (such as insects), and the remaining plastic, after being chewed and swallowed, is reduced to dust in the organism's waste.

In this activity, you will compare the behavior of some degradable plastics to other plastics and other common litter items. This can be accomplished either in an open area or on a compost heap.

OUTCOMES

1) Students will observe the effect of nature on various items in other litter.
2) Students will compare the behavior of degradable vs. other plastics.

PREPARATION

This activity can be performed in two ways. You may prepare a more normal litter setting for students to observe, or you might speed up the process by placing the materials in a compost heap. The purpose here is to get some idea of what happens to plastics in nature and compare it to some other materials as well as degradable plastics.

For a normal litter setting, you might want to prepare several weeks or even months ahead so your students can see the result at this point in the unit, or you can set it up now as part of an ongoing project and continue to monitor it for some time.

Choose an area of the school yard that can remain undisturbed for a long period of time. Select a sample of each of the resins used so far (PE, PET, PVC, PP, PS) and, for comparison, add photodegradable and biodegradable items as available. (You may wish to add some other typical litter for reference—like drink cups, soda cans, glass bottles, etc.) Observe and record (photograph) the condition of each of the items for the next few months.

The same items can be tested more rapidly in a compost heap (except for the photodegradable items which require sunlight) by observing their condition each time you turn the pile. Instructions for creating a mini-composter can be found in reference 1 (see Bibliography).

Back in class, have the students predict what they think will happen to the objects and how much time they think it will take. These predictions can be compared with the actual outcome at the completion of the project.

TEACHING PLAN

The audio tape recording of "Plastic: Here Today, Here Tomorrow" is an excellent introduction to this aspect of plastic waste. It should help generate a great deal of discussion, which can be enhanced by having the students read some of the articles from the bibliography on degradable plastics. There are some very important questions to answer concerning degradability before it is mandated as a solution to the problem of litter.

DISCUSSION

Answers to most of these questions are not known, but they are addressed in the readings. And the opinions of an educated public can affect the outcome on this issue

1) What happens to normal plastic litter left out in the open?
2) How long does plastic take to break down in nature?
3) How does this durable plastic litter affect the environment?
4) How is plastic litter different from/similar to paper, glass, and metal litter?
5) Does degradability really lead to waste reduction?
6) Will these plastics degrade in the real environment?
7) Will these plastics degrade in landfills?
8) What is the effect on a landfill if they do?
9) What is left after the plastic has degraded?
10) How will these new "food sources" affect the life cycles of organisms and their ecosystems?
11) How will degradable plastic be protected during storage?
12) Is it desirable to use degradable plastics for packaging—especially for food items?
13) How will degradable plastics affect plastic recycling?
14) Who benefits from the use of starch-based biodegradable plastics?

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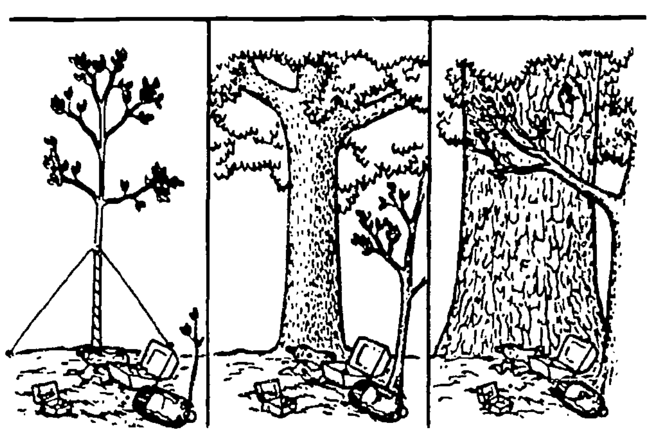

Lesson Six
GETTING INTO TRASH

You have seen that Americans produce an incredible amount of trash. In fact, we could fill two Superdomes every day with our garbage. How much do you produce, and are you really average? These questions can only be answered by getting into your own trash.

OUTCOMES

1) Students will understand their own personal involvement in the solid waste problem.
2) Students will measure mass, and calculate percent for the components of trash.
3) Students will consider ways to reduce their contributions to waste.

PREPARATION

As seen in the data on solid waste, the average American is responsible for about 1,200 lbs. of trash each year. Broken down by percentages, this means that each person discards about 95 pounds of plastics annually. To get some idea of the mass and volume of garbage individuals or families produce, one of these activities could be performed.

1) Have students save their own trash for a day or two - even a week if approved by parents. This must include all food scraps, paper waste, etc., throughout the day. This may present some problems including odor, transportation to school, or inconvenience of taking a bag along to save trash. But it can be most rewarding to actually account for all of the things one throws away over the course of a day or week. For this to be successful, students must carry a bag with them to deposit all trash as it is generated.
2) Volunteers could bring in a family's trash. The contents of a can of trash on trash day might be more representative of average solid waste. To do this, garbage cans or bags must be transported to school. Be sure to obtain parental permission first.
3) The contents of a school trash receptacle could be analyzed. This could be quite interesting, but it will likely be different from household trash.
4) All three of the above could be done and then compared. This would provide an opportunity to discuss the variations between the trash generated in one setting and another.
5) Along with collecting, students could be asked to keep a log of all items they throw away for some period of time. They might address questions such as:
   What kind of item is this?
   What is its approximate size, mass?
   Why is it being thrown away?
   Of what is it made?
   Could the item be reused?

Remember that trash can be very personal and embarrassing - especially those relating to personal hygiene. You may want to remind students to be discrete concerning these things.

TEACHING PLAN

Depending on how this is done, there could be a great deal of trash in a small classroom. Make arrangements beforehand for its removal.

Spread out newspaper or plastic to protect the floor, and empty the garbage onto this covering. Sort the garbage into piles of paper/cardboard, wood, yard waste, glass, metal, food waste, textiles, leather/rubber, and plastics. Try to estimate proportion of each for items containing more than one material. Items clearly not fitting into one of these categories may be called "other."

Once separated, the piles may be weighed by placing them in bags and having a student stand on a bathroom scale, hold each bag, and record the increase in weight. This should be recorded. (Smaller items could be weighed with a spring scale or laboratory balance.)

Now create bar graphs of the percent mass of the various fractions. Compare these with the graphs you made on the first day.

DISCUSSION

After analyzing the trash according to the scheme and recording data, consider the following more general issues:

1) What are some simple ways to reduce the amount of material discarded? (What else could be done with it?)
2) How do reuse, redesign of products, and recycling lead to waste reduction?
3) Describe how one of your "trash" items might be reused.
4) Describe how one of the items might be redesigned for more durability (longer life).
5) Can any of the items in your waste be recycled?
6) Looking at the plastic in your trash, what is the lifetime of each item from the time of purchase to the time of disposal?
7) How does this compare with the expected lifetime of the material from which it is made?
8) Estimate the volume of one person's trash. About how much space would a week's worth of garbage take up? How much space for one week of trash from each person in the class? How much space for one year of trash from each person in the class? How much space would be taken up by a year of trash from each person in the United States (250 million)?

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Lesson Seven
A MOUNTAIN OF TRASH

Do you really know what happens to your trash? For many people, the biggest problem of solid waste is getting it out to the corner in time for the weekly pickup. But where does it go? What is done with this mountain (or Superdome) of trash? What does it cost to dispose of all of this garbage? (Nationwide, about $5 billion is spent annually to remove our trash from our sight.) A visit to your city dump or municipal landfill might be enlightening.

OUTCOMES

1) Students will realize where most of their trash goes.

2) Students will be more aware of the mounting problem of solid waste, in terms of both space and cost.

PREPARATION

Make arrangements with appropriate municipal authorities to visit the landfill. It would be best to have the tour hosted by an official who could not only point out the various processes or stations involved but who could also answer questions about the theory and purpose of the landfill, how it works, problems associated with the technique, cost to the community, etc.

If this is not possible, as a backup, arrange for an individual to come to your class to make a presentation on the local facility (with slides if possible) and answer questions from your students.

Videotapes are available from the Illinois Department of Energy and Natural Resources that look at the state of landfills and their future. These could be shown in lieu of an on-site visit (see "Mailing List" on page 69).

TEACHING PLAN

Take the tour or have the talk as scheduled and encourage the students to get involved with lots of questions. Students can prepare for their questions by reading from some of the articles on landfills in the bibliography.

DISCUSSION

Students should frame their own questions, but you might draw from the areas listed below:

1) How many years has the facility been in operation?
2) Is it licensed by the EPA as a sanitary landfill or otherwise?
3) What is its total volume/mass capacity?
4) Why was it located where it is?
5) Is collection done by the city or by private haulers?
6) How much does it cost to collect, dump, and treat the garbage?
7) How does this compare to other items in the municipal budget?
8) What happens to the materials in the landfill?
9) What happens to biodegradable materials?
10) Is there a problem with leaching, gas production, or pests?
11) What has been done to contain these?
12) Where is the nearest ground or surface water?
13) What alternatives have been considered for the future?

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4) Raloff, J. *Are landfills a major threat to climate?*, Science News, Vol. 131, p. 150.
5) *Available disposal capacity for solid waste in Illinois*, IEPA publication available through ENR.
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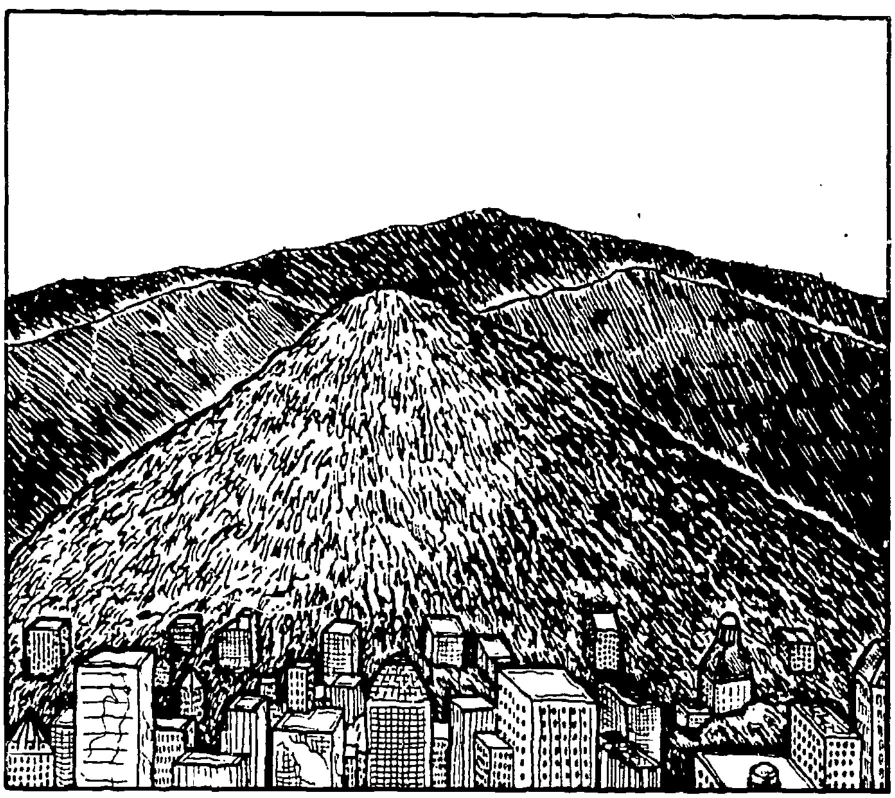

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Lesson Eight

WHERE DO WE GO FROM HERE?

You have examined the incredible amount of trash that is generated by Americans. It has been estimated that our trash could fill two sports stadiums like the Superdome each day. Is it reasonable to think we could safely store that volume of trash? Think of the expense. Is placing the trash into a hole in the ground any better in principle? While cities are running out of usable landfill space, there are areas of the country (or the world) with expanses of unused land. Why not haul garbage to these places, or export it to other countries for a fee? (Remember the KHIAN SEA from Philadelphia and her year-and-a-half voyage?) Couldn't we just dump the trash into the ocean or shoot it into space?

These are alternatives that may have crossed your mind, and some have been attempted. But they may be expensive, unethical, or simply undesirable. One reason more landfill space is not being created is that people don't want a landfill near them. This is sometimes called the "not in my back yard" (NIMBY) syndrome.

Although they will probably always be a part of solid waste management strategies, landfills are certainly not the best choice for resource management. After further research on landfills, you will compare this method of handling trash with some other options.

One of these options is incineration. This is a term that can simply mean burning. However, very strict guidelines govern what kind of gases and how much of them can be released into the atmosphere during the burning of trash. Imagine if all the residents of a large city burned their own trash. Besides the fire hazard, there would be a terrible odor, hazy smoke and dangerous gases in the air. Also, the ash left behind would have to be disposed of. This would still be the case if there were one incinerator for all the solid waste of a large city like Chicago. For this reason, incinerators require careful control and monitoring to keep them from creating problems in the atmosphere. But there would still be a problem with the ash produced.

Reduction of the trash to ash that is one-tenth of the original volume may be a good enough reason for incinerating, but there is one more very important benefit. A great deal of energy created in the burning can be captured for use in heating buildings or supplying power to factories, etc. This is referred to as "waste to energy." After research, you will determine how this method might be incorporated most effectively into a waste management program.

In the last few decades, recycling has become an important factor in dealing with the solid waste problem. What is meant by recycling, and what can be recycled? Typically, recycling refers to taking a product back through the process of forming in a factory. For instance, used aluminum cans can be melted down and reformed into more cans or other products. Glass, paper, and other metals have been handled in this way for many years. The cost of recycling a material for reuse is substantially less than using virgin materials.

Plastic is and has been recycled since the beginning of the industry by reusing in-house scrap and overrun, but only recently has consumer waste been accepted for recycling as well. It appears that plastic may be nearly as valuable a recycled material as aluminum.

Recycling can be accomplished in many ways using incentives, relying on good feelings of individuals, providing convenient drop-off sites, curbside pickup, etc. Communities involved in recycling have found that these methods and others can lead to a successful recycling program. You will continue to explore the reasons behind recycling and determine which methods might be most appropriate for a community like yours.

No waste management program would be complete without considering reduction (sometimes called source reduction). The problem of solid waste is really many-sided. The cost of disposal is rapidly increasing, space is running out for landfills, some landfills leach damaging chemicals into the environment, and people are more aware that we are throwing away valuable material resources.

Reduction of waste can be achieved simply by reusing items before discarding them, by not using items that cannot be reused, by banning some items from the market, or by charging users' fees, or by charging per bag or per pound for waste disposal. Think about how source reduction differs from recycling.

Spending all of this time looking at the refuse of a society could become quite dreary if it were not for the incredible value of all those materials being buried. It is quite true that one person's trash is another's treasure. The trick is finding a good way of getting the treasure out. This may mean mining old dumps eventually, but more profitable methods are on the horizon. For this lesson, students will do some research on alternatives to landfills and create visuals for a class presentation.

OUTCOMES

1) Students will acquire a broader and deeper knowledge of solid waste management alternatives.
2) Students will become aware of the need for an integrated approach to solid waste management.
3) Students will apply this learning specifically to plastic in solid waste.
4) Students will create an integrated approach to address this problem.

PREPARATION

Either as a prior homework assignment or using some extra class time, have groups of students prepare posters, overhead transparencies, etc., to illustrate a short presentation on the alternatives to landfills. These include waste reduction, recycling, and incineration. (You may also want someone to summarize all of the information on landfills from the various readings and the tour of your local facility.) Several readings have been recommended in the bibliography for each topic, but more can be found by searching the *Reader's Guide* or other indexes.

TEACHING PLAN

Since the students will be teaching today, pass these hints on to them. In each case, the method proposed should be clearly defined. All requirements (equipment, costs, licenses, etc.), processes involved, and outcomes should be concisely described and illustrated. Also include a brief comparison of advantages versus disadvantages. When possible, make specific references to how these methods would relate to plastic waste.

DISCUSSION

The three alternatives are quite unique, so there is a set of guiding questions for each.

Source Reduction:

1) Why do we desire disposable products?
2) How does source reduction differ from the other methods of waste management?
3) How is waste reduction related to product design?
4) What are the economic benefits?
5) What are the environmental benefits?
6) What is required to make source reduction work?
7) How could manufacturers be induced to create products that are easier on the environment and more reusable?
8) List several common plastic products and describe how they would have to change to make them more durable or reusable.
9) When considering source reduction of waste by product replacement, how should you account for the energy used in the production of the materials? (See reference 7 under this heading.)
10) Can product bans help reduce waste in America?

Waste to Energy:

1) What are the environmental costs in terms of the Greenhouse Effect?
2) Does this address the problem of dwindling resources?
3) What are the special advantages/disadvantages of burning plastics? (heat output, toxic by-products, etc.)

4) Where should these incinerators be located?

5) Is there a unique place for incineration in a total solid waste management system?

Recycling:

1) Can 100 percent of trash be recycled?

2) What are the barriers to recycling plastics?

3) What are the incentives to recycle plastics?

4) How do you get people to participate?

5) How can manufacturers or stores assist in making consumers aware that some items are recyclable?

6) How is product design related to recycling?

7) Are there uses for recycled plastics?

8) In what way is recycling a "band-aid"—that is, only a temporary solution?

9) What is the role of recycling in a long-term integrated solution?

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Lesson Nine
THE REALITY OF RECYCLING

Historically, Illinois has relied heavily on landfill disposal for the management of solid waste. The number of permitted sanitary landfills, however, has declined dramatically from 147 in 1987 to 126 in 1989 to 117 in 1990 and, as landfill capacity has decreased, collection and disposal costs have continued to rise. Total statewide landfill disposal capacity will be exhausted later in this decade without waste reduction and recycling programs.

Landfill disposal is no longer the preferred method of waste management in Illinois. Many of the materials we now discard can be recycled, converting the value of these resources into other useful products. Recycling reduces pollution, saves energy and natural resources, and can create new industries. Recycling, however, does have its limitations. The number of times some materials may be recycled is finite. Furthermore recycling has economic limitations. In the end the best way to handle solid waste may be to reduce waste through reuse, redesigning products, and product delivery systems. Successful recycling requires a familiarity with community efforts, markets, and technical procedures, and it is important to devote at least a day to study these various aspects. With this background, it will be easier to develop a feasible approach for your community.

Despite these virtues, some individuals consider recycling to be a "band-aid" because it does not reduce the amount of material that is discarded, though it does give it a longer life. Since the number of times that any material can be recycled is finite, even recycled products eventually will end up on the trash heap. Therefore, further reduction of waste through reuse and redesign of products will have to be achieved. It has been suggested that, for a number of technical and economic reasons, much less than 50 percen' of all plastics destined for the landfill can be recycled. Even so, recycling will be useful despite effective steps toward reduction because durable goods still wear out. Recycling, however, should not be used as an excuse for continuing our wasteful habits.

Since a venture in recycling requires a familiarity with community efforts, economics and market research, and technical procedures, it is important to devote at least a day to study these various aspects. With this background, it will be easier to develop a feasible approach for your own community.

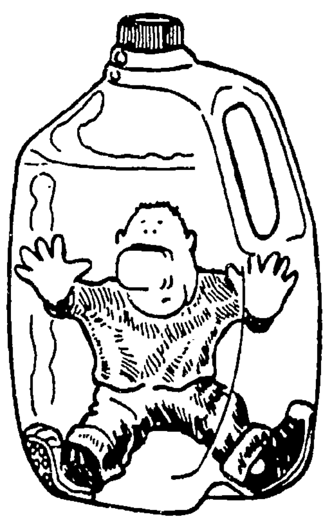
OUTCOMES

1) Students will be introduced to the fundamental ideas and procedures involved in plastics recycling.

2) Students will consider steps for initiating a plastics recycling project in the community.

PREPARATION

This lesson works best with the aid of either a videotape, a slide presentation, or both. These visual aids have been prepared by the Society of the Plastics Industry and portray plastics recycling in a very positive manner. They obviously promote recycling, and they demonstrate what is currently being done and look to the future.



TEACHING PLAN

"Plastics Recycling Today: A Growing Resource" (available from the Society of the Plastics Industry, see page 69) is a videotape that goes from the many roles that plastics play in our lives to the need for recycling. It is a good introduction to the issue. "Plastics Recycling: A Strategic Vision" is another video similar to the article of the same title. It looks at the more technical aspects of collection, processing, and economics. It is based on research supported by the plastics industry.

The slide set is meant to accompany the article, *Plastics Recycling: From Vision to Reality*. Using the text as a script and the slides as illustrations provides a thorough introduction to the fundamentals of plastics recycling.

The materials might be most effective if used together, with the slides and talk first and the tape of recycling in action after. These are the same materials used by professionals from the plastics industry when they make presentations on recycling.

For further discussion, students can be assigned readings from the extensive list in the bibliography. The articles contain more specialized information on collection and sorting, processes, and markets and economics.

DISCUSSION

Armed with all of this information, the students should be ready to do something about the solid waste problem and recycling of plastics in particular. Discussion should focus on whether the students want to initiate a plastics recycling program in the community, if that seems possible, and what steps would be necessary. The following questions may help:

1) More than 1 billion pounds of PET soft drink bottles and more than 1 billion pounds of PE milk jugs will be sold in the U.S. this year. How many pounds of these plastic containers are there for each person in the U.S.? (population is about 250 million)
2) How many pounds of these plastics would be discarded by your community in one year? (Multiply your answer by the total population.)
3) How much money could your community earn by selling plastics to recycling companies at 15 cents per pound? (Assume 100% recovery.)
4) If each person in your community discards a quarter of a pound of plastics per day, how much plastic does your entire city discard in one year?
5) Assuming that 25 percent of this plastic trash could be recycled, how much money could your community earn in one year at 15 cents per pound?
6) Do you think consumers will be willing to purchase goods made from recycled plastics? Why or why not?
7) What other factors affect recycling?
8) What would be required to make recycling work in your community?
9) What are some other benefits of recycling besides money?
10) Would you still be willing to recycle if recycling were not self-supporting?
11) What makes some plastic resins/products easier to recycle than others?
12) What are some technical, economic, and social barriers to recycling?
13) How are recycled plastics currently being used?
14) Are there enough new uses for recycled plastics to create viable markets for consumer plastic waste?
15) Can you imagine some other uses for recycled plastics?

There are many other questions to ponder before you are ready to get involved. Take time to discuss these, and consider inviting municipal officials or recyclers from your area to provide more guidance.

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Lesson Ten
SURVEYING THE SITUATION

Even if you are convinced of the need to recycle plastics, your own personal contribution of a few pounds will be small compared to the billions of pounds discarded annually. You need community support and co-operation, but in order to obtain them, you must know if people are willing and ready to literally "pitch in."

One way to find out is through the use of a survey. The questionnaire provided already has been used in various places in Illinois to determine attitudes toward recycling and to predict levels of participation. This survey will be a crucial step in the development of a recycling program your community.

OUTCOMES

1) Students will administer a survey to community members.
2) Students will assess the results of the survey.
3) Students will draw conclusions concerning attitudes and participation from the results of the survey.
4) Students will devise a plan for initiating plastics recycling in the community based on their conclusions.

PREPARATION

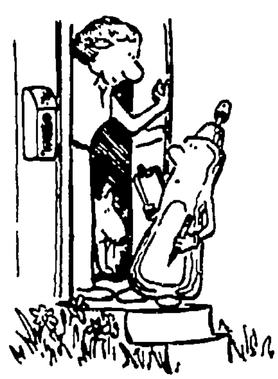
You might consider doing one of several things. To feel for the survey, you could have your students take it first and compile the results. This will allow them to see how they feel as a group, and it will also provide a practice session in both giving and analyzing the survey. This could be carried one step further by giving the survey to the students at some time before the study of plastics begins. They could see how their attitudes had changed over the course of their education and might clarify the need for public education as well.

Remind the students that the purpose of the survey is to find out what people think—not to teach them or have them agree with what you believe. Have them arrange to interview at least two individuals who have not previously discussed the project. This should give you a fair sampling of your community. Also, to ensure that you get a good return, suggest that the students wait while the form is being filled out or schedule a definite time when it can be picked up. The survey has been designed so that a short version (Sections I and II only) can be used, or the entire document may be used to obtain more information.

Once the surveys have been collected, the responses for each item should be tallied and averaged (this could be done beforehand or as a class project).

TEACHING PLAN

With the class, look more closely at the data gathered. Try to see patterns. Are people currently recycling anything? What are the most important factors for/against recycling? Is there an overall disinterest in recycling? What did people indicate the city should do to encourage recycling? Are people generally willing to make an effort and be inconvenienced? Do people have strongly positive attitudes concerning the environment? Are people most concerned with the financial rewards?



Section I is designed to provide some baseline data on how much recycling is currently taking place. Section II looks at people's attitudes concerning recycling. Section III is optional, and the questions are designed to look at general attitudes people hold about the environment and personal responsibility for its care.

For the multiple choice questions, have students record the number of each response, calculate percentages for comparison, and draw histograms (bar graphs) to display these data. Other useful information might be the average response (median) or the most frequently given response (mode).

The results of this survey have indicated that the most important reasons for or against recycling are more closely tied to internal motivating factors like reducing litter or saving energy. Economic factors are the least important. The level of information about recycling and social pressure also plays a key role in determining the level of participation.

It is evident that the beliefs of individuals will affect their behaviors, but weak beliefs may not be acted upon in the absence of some external motivation. This could be as simple as a newspaper article, pamphlet, or other information; convenient dropoff sites or pickup service; or rewards, fines, and mandatory involvement.

Some research indicates that the longest-lasting participation will result from strengthening the beliefs and personal commitment of the individual. Further, some communities have found that this can be accomplished by creating a grass roots public education effort and providing inexpensive but convenient dropoff locations.

DISCUSSION*

In a more elaborate study done in the Champaign-Urbana area, results indicate that individuals recycle for a number of different reasons. Though it is true that a strong concern for the environment can be an incentive to recycle, it alone may not be enough. The matter of convenience seems to be extremely important. When colored buckets were provided for curbside pickup, participation soared. (Social pressure also becomes a factor in that it is obvious to neighbors if someone does not have the bucket out in front on collection day.) But other studies have shown that individuals will make the effort to drop off goods for recycling if the site is conveniently placed, for example, at a local grocery store.

While some are motivated by economic incentives, many people will participate at a loss, considering their time and transportation costs. Some sort of reward system early in a new recycling effort can be effective in helping to establish participation, but as the behavior becomes habitual, the reward can be removed.

A successful recycling program seems to boil down to attitudes and convenience. Strong attitudes can lead to positive behavior if recycling is made convenient. And weak attitudes can be improved through public education. The factor of social pressure can also help to instill the habit when the attitude is weak. It has also been indicated that the act of recycling can be a valuable reinforcement, helping to strengthen environmental attitudes.

Try to look for indications of environmental, convenience, social, and economic factors in your surveys, and discuss them in light of information presented here.

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The survey questions included here were taken from a survey prepared by the staff of the University of Illinois Institute for Environmental Studies.

The analysis of the survey was reported in IES Staff Paper No. 48 entitled, *Changes in Recycling Attitudes, Behavior, and Motivation as a Result of Community Recycling Information and Education Program*, by Joanne Vining, et.al.

*For classroom discussion, spend time with the survey questions. Let students air their views and comment on what they believe is conveyed by the questions. Also discuss the use of a survey as a tool for gathering information. How will you select a population for the survey? Is there a particular way to administer the survey—by interview, by phone, written response by individual, etc.? How will you interpret the responses?

Questionnaire #________

SECTION I:

We begin with a few questions about how much you are involved with recycling.

1. Have you ever recycled any materials with any program? (Circle one)

Yes.....1 No......2

2. Have you recycled any materials with any program during the past year?

Yes.....1 No.....2

(If you answered YES to Question 2):

3. Do you plan to continue recycling? (Circle one.)

Yes.....1 No.....2

4. Indicate how much of each of these materials from your household you recycled during the past year. (Circle one.)

1. Almost All 2. Some 3. None

a. Glass containers	1	2	3
b. Newspapers	1	2	3
c. Cardboard & grocery sacks	1	2	3
d. Magazines	1	2	3
e. Office and computer paper	1	2	3
f. Soda and beer cans	1	2	3
g. Tin cans (soup, vegetables, etc.)	1	2	3
h. Plastic jugs & bottles	1	2	3
i. Yard waste (leaves, grass, brush)	1	2	3
j. Used motor oil	1	2	3

5. Overall, how satisfied were you with your experiences recycling during the past year? (Circle one.)

a. Very satisfied....1

b. Somewhat satisfied....2

c. Not very satisfied....3

d. Not at all satisfied....4

6. What do you think the city could do to encourage residents to recycle?

Section II.

We would like you to tell us what, in your opinion, are the reasons for and against recycling.

7. How important is each of the following possible reasons in favor of recycling? (Circle one.)

1. Extremely important 2. Very important 3. Moderately important
4. Somewhat important 5. Not at all important

a. To receive payment for materials	1	2	3	4	5
b. To reduce the cost of my household's garbage collection	1	2	3	4	5
c. To conserve natural resources	1	2	3	4	5
d. To reduce litter	1	2	3	4	5
e. To save energy	1	2	3	4	5
f. To reduce the use of land	1	2	3	4	5
g. To create more jobs	1	2	3	4	5
h. To help charity or club	1	2	3	4	5
i. Because neighbors and friends recycle	1	2	3	4	5
j. Because other members of the family recycle	1	2	3	4	5
k. Use of free collection container	1	2	3	4	5
l. Other________________________					

8. How important is each of the following possible reasons against recycling? (Circle one.)

a. Household does not produce enough recyclable materials	1	2	3	4	5
b. Not enough storage space at home	1	2	3	4	5
c. Storage in home attracts pests and insects	1	2	3	4	5
d. No one to pick up the materials	1	2	3	4	5
e. Too busy; not enough time to prepare materials	1	2	3	4	5
f. Too difficult to prepare materials for recycling	1	2	3	4	5
g. Don't receive enough money from recycling to make it worthwhile	1	2	3	4	5
h. Don't know how or where to recycle; not enough information	1	2	3	4	5
i. Lack of container for convenient drop off	1	2	3	4	5
j. No curbside pickup	1	2	3	4	5
k. Don't like public display of my recyclables at curbside	1	2	3	4	5
l. No one else in my neighborhood recycles.	1	2	3	4	5
m. Other________________________					

SECTION III: (Optional)

The views of people like you are very important in designing workable community recycling programs. The next few questions ask for your reactions to some possible new programs as well as some old ones. (Circle one.)

1. Strongly agree 2. Agree 3. Disagree 4. Strongly Disagree

9. Local governments should:

a. require that recyclables are separated from garbage going to the landfill	1	2	3	4
b. require a deposit on all glass beverage containers	1	2	3	4
c. require a deposit on all beverage cans	1	2	3	4
d. ban any nonrecyclable plastic containers for which there are no recyclable alternatives	1	2	3	4
e. give priority to purchasing products made of recycled material	1	2	3	4
f. incinerate (burn) all combustible waste material that is not recycled	1	2	3	4
g. require residents to separate recyclables from other garbage going to the landfill	1	2	3	4

10. Your opinions please. Circle the number most closely representing your opinion.

a. Household recycling is a major way to conserve vital natural resources	1	2	3	4
b. The balance of nature is very delicate and easily upset	1	2	3	4
c. Almost no one I know recycles any household materials	1	2	3	4
d. Plants and animals exist primarily to be used by humans	1	2	3	4
e. Household recycling is a major way to reduce litter	1	2	3	4
f. There are limits to growth beyond which our industrialized society cannot expand	1	2	3	4
g. I feel a strong personal obligation to recycle a large portion of my household's recyclables	1	2	3	4
h. When humans interfere with nature it often produces disastrous results	1	2	3	4
i. Households like mine produce very little of the material that is disposed of in local landfills	1	2	3	4
j. We are approaching the limit to the number of people the earth can support	1	2	3	4
k. I am willing to go blocks out of my way to recycle household materials on a regular basis	1	2	3	4
l. Mankind was created to rule over the rest of nature	1	2	3	4
m. For me, recycling is just a matter of money—I wouldn't recycle materials I didn't get paid for doing it	1	2	3	4
n. Humans must live in harmony with nature in order to survive	1	2	3	4
o. Household recycling is a major way to conserve energy	1	2	3	4
p. The earth is like a spaceship with limited room and resources	1	2	3	4

q. Households like mine are responsible for a large part of the material disposed of in landfills here	1	2	3	4
r. My neighbors and friends expect me to recycle household materials	1	2	3	4
s. Humans have the right to modify the natural environment to suit their needs	1	2	3	4
t. I would recycle household materials whether or not I received any payment	1	2	3	4
u. Mankind is severely abusing the environment	1	2	3	4
v. Household recycling is a major way to reduce the wasteful use of land for dumps	1	2	3	4
w. To maintain a healthy economy we will have to develop a "steady state" economy where industrial growth is controlled	1	2	3	4
x. I would feel guilty if I didn't recycle a large portion of my household's recyclables	1	2	3	4
y. Humans need not adapt to the natural environment because they can remake it to suit their needs	1	2	3	4
z. Feeling like I am part of the community is important to me	1	2	3	4
aa. My participation in the city's recycling efforts is important	1	2	3	4

Lesson Eleven

WRAPPING IT UP

You now know a fair amount about plastics, solid waste issues, and recycling. It is time to put it all together into an integrated package that will suit your local community. The purpose is to draw up a reasonable and workable plan for action in your area.

OUTCOMES

1) Students will create an integrated plan for action based on the information gathered in this unit.
2) Students will test the feasibility of the plan by submitting it for consideration to the municipal governingboard. (optional)

PREPARATION

Recycling

The best way to create a plan of this nature is to do lots of research on the area and then look at how others have done it. References in previous lessons have provided details on successful programs in a number of locations around the world. The *Plastics Recycling Action Plan For Massachusetts* is a comprehensive document that carefully treats all issues involved. And there is a mailing list of industries involved in recycling that can be contacted for more information. However, utilizing all of the resources available could be extremely difficult to manage as well as time consuming. Consider the following simpler alternative.

Start with your own survey. This will tell you how hard you will have to work to make something happen, but remember that by strengthening beliefs already held, people will be more willing to become active and even face some inconvenience in "doing the right thing." For this reason, public education may be your best tool (after all, it is what you do for a living). To be most effective, you will need to decide at what level to promote this education, i.e., newspaper articles, radio/TV advertisements, distributing pamphlets, signs in store windows, public forums, etc.

To make this education possible, you will need both monetary and moral support. This could be solicited from local businesses and/or political officials in the form of donated materials for building dropoff facilities, free paper and printing for a newsletter or pamphlet (use recycled paper if possible), listing of all businesses that contribute to and participate in recycling efforts (social pressure), free space in the newspaper or on the radio/TV, printing on grocery sacks, etc.

To keep costs and chances for failure low, join together with other communities in your area - especially if one already has a recycling program in action. A recent newspaper article indicates that small towns in Champaign County have surpassed predicted levels of participation in a dropoff only program by joining together with the existing Champaign/Urbana program. By becoming a part of an existing recycling program, you can reduce some of the economic headaches related to dealing directly with the industrial buyers.

Finally, explore the possibility of small grants for this purpose available from state or federal agencies. Consider extra incentives like a drawing or coupons (supported by donors) or other unique motivational factors to help initiate the program. And try to be innovative. It is important to draw from the successes of others, but you know your community best, and you need a program that will keep people involved.

Reduction

Waste reduction is the second component of this unit. Though perhaps not as technological as recycling, reduction is also related to strongly held beliefs and values. But to be successful, waste reduction requires a double commitment. Consumers must be willing to modify their wasteful patterns and demands for convenient disposable items, and manufacturers must be willing to produce goods that are more durable and less harmful to the environment.

The action plan should contain a second section that focuses on waste reduction.

TEACHING PLAN

Recycling

Let the students imaginations be their guide. Allow a brainstorming session to consider all of the above issues. Let students decide:

1) how best to educate their parents and other adults,
2) who to contact and how to go about it,
3) what donations and support to request,
4) how to design dropoff facilities and where to place them,
5) what to call the campaign (very important), a mascot, a logo, and a slogan
6) what types of motivation to employ,
7) who to contact in other cities,
8) what time line to follow.

Then draw up a document that summarizes the need for such a plan (what you just studied) and spells out details for all the steps mentioned above. Include any pertinent data in charts or graphs (try to show the money to be earned by recycling and the saving in trash disposal costs avoided), and draw a map showing location of dropoff facilities.

Thus far the plan only addresses recycling. Now have a second brainstorming session on what can be done to reduce waste at the source.

Waste Reduction

This component of solid waste management will also require some public education, but the outcome will be much different than that of recycling. The students should concentrate on two areas: 1) How do we encourage people to change their wasteful habits over time? 2) How can we influence the plastics industry to create more durable, environmentally safe, and more recyclable products?

Actions in this area could include how to educate the public on solid waste issues and the growth of plastics in solid waste, how to look for products that have been recycled or can be recycled, and how to communicate with manufacturers and make consumer demands heard.

This part of the plan may be less structured than for recycling, but students can begin to put it into action immediately by modifying their own patterns of wasteful behavior.

The finished plan could be a blueprint for a waste management program in your community. Going beyond class, you could share this plan with municipal officials and encourage your students to become involved in the community to help initiate the program.

Also, remember that plastics are only one component of solid waste. Total solid waste could be reduced significantly by recycling paper, glass, and metals and composting. Keep what you have learned about plastics in mind as you explore these other areas.

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4) Glenn, Jim. *Enforcing mandatory recycling ordinances*, Biocycle, March 1989, p. 31.
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6) A number of ENR publications also provide a great deal of useful information (see page 69 to request publications list).

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Illinois Department of Energy and Natural Resources Information Clearinghouse
325 W. Adams St., Rm. 300
Springfield, IL 62704-1892
1 (800) 252-8955

Ask for their solid waste publications order form.

Dow Chemical USA
(517) 636-5847

Ask for a laminated copy of IDENTIFYING RIGID PLASTIC CONTAINERS.

University of Illinois Film/Video Center
1325 S. Oak St.
Champaign, IL 61820
1 (800) 367-3456

Ask for the catalog of solid waste management video resources.

Keep America Beautiful
Mill River Plaza
9 W. Broad St.
Stamford, CT 06902

Ask for OVERVIEW: SOLID WASTE DISPOSAL ALTERNATIVES. They also have a catalog of other resources related to recycling and litter. (The overview also contains a useful glossary of terms related to solid waste issues and alternatives.)

National Soft Drink Association
1101 Sixteenth St. NW
Washington, D.C. 20036
(202) 463-6732

Ask for PROMOTING RECYCLING TO THE PUBLIC. This guide has an extensive list of recycling programs throughout the nation. (The guide also contains a useful glossary of recycling terms.)

Plastics Recycling Foundation
1275 K St. NW
Suite 400
Washington, D.C. 20005
(202) 371-5200

Ask for a catalog of their free publications and videos. Many of the resources in the bibliography are available through this office. Also ask for the PLASTICS RECYCLING DIRECTORY, which contains information and contacts for the plastics recycling industry.

The Society of the Plastics Industry
1275 K St. NW, #400
Washington, D.C. 20005
(202) 371-5212

Ask for a catalog of their free publications. Many of the resources in the bibliography are available through this office.

The Polymer Group of the University of Illinois
1304 W. Green St.
Urbana, IL 61801
(217) 333-0149

Fabri-Kal Corporation
Plastics Place
Kalamazoo, MI 49001
(616) 385-5050

Degradable Plastics and the Environment

Part of the Solution

or

Just More Pollution?

D. Andrew Holm, Ph.D.

Parkland College

Champaign, IL

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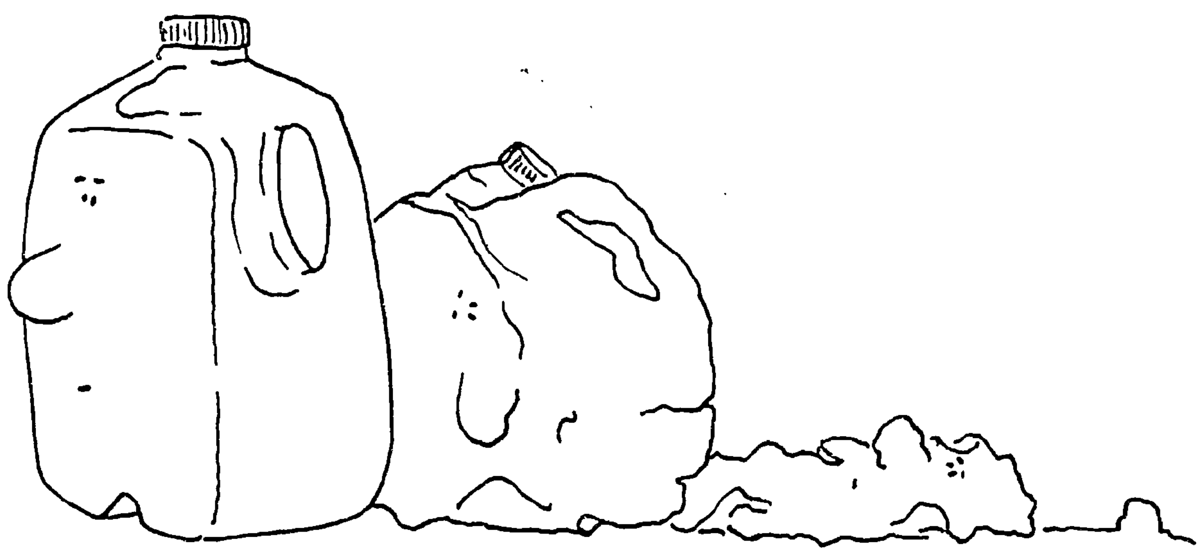
Introduction
Degradable Plastics and the Environment

In this unit, you will have an opportunity to explore the factors that cause degradable plastics to break down in the environment. You will begin by learning how degradable plastics are being suggested as a solution to the plastics solid waste problem. You will then learn about the two main types of degradable plastics: biodegradable and photodegradable. Next you will design an independent research project and select one of several degradation tests to monitor the rate of degradation. Several suggested projects as well as specific degradation tests are described in this unit.



The Problem

As we consider the enormous challenge of solid waste management, one of the biggest problems we face is how to deal with plastics. About six million *tons* of plastics are disposed of in the United States each year (Wool, 1989). Where does this all end up? According to an article in the *Smithsonian* (Smithsonian, 1988), the following plastic materials were gathered in a three-hour cleanup of 157 miles of Texas shoreline in September 1987:

31,773	plastic bags
30,295	plastic bottles
28,540	plastic lids
15,631	plastic six-pack rings
7,460	plastic milk jugs
1,914	disposable diapers
1,040	plastic tampon applicators

This accumulation of these nondegradable plastic products not only poses an eyesore that impacts on the economics of tourism but also kills wildlife and creates a major solid waste disposal problem, with our cities paying the enormous costs of pickup and disposal. (Sudol and Zach, 1988).

What exactly are the problems that result from the dumping of plastics?
There are three major ones:

A. Litter in the environment

Plastic materials were designed at great cost by engineers to last a long time. Now, after years of being dumped, this plastic debris is showing up on beaches, in parks, in waterways, and on streets. At a meeting of the Society of the Plastics Industry, Inc., in 1987, the following percentages of debris on coastal beaches were found to be plastic materials (SPII, 1987):

Year	Location	Percentage Plastics *(by weight)*
1986	Oregon	over 70%
1982	Alaska	over 75%
1986	Maine	over 60%
1986	Massachusetts	over 55%
1986	New Jersey	50%
1986	Texas	over 45%

B. Destruction of Wildlife in the Waterways

A 1984 study by Dahlberg (SPII, 1987) reported that plastic materials comprised over 80% of the floating debris sighted at sea.

It is estimated that plastic junk kills two million sea birds and 100,000 marine mammals each year. Part of the problem is the attraction of the animals to the plastics because they look like food. (Blunck, 1989)

Other studies give more details. The 1986 Sievert study showed that plastic debris was found in the stomachs of 100 percent of the chicks of the Laysan Albatross, and 80 percent of the species of birds at the Midway Island sampling location showed evidence of plastics consumption. Sea turtles are being found suffocated and starved to death by plastics caught in their lungs and digestive tracks; sea gulls and sea lions are being choked by plastic carriers for six-packs of beverage cans. (Sudol and Zach, 1988)

The situation has caused David Laist of the Marine Mammal Commission in Washington, D.C. to state, "Plastics may be as great a source of mortality among marine mammals as oil spills, heavy metals, or other toxic materials." (Sudol and Zach, 1988)

C. Major Contribution to Volume of Garbage in Landfill

Most sources report municipal solid waste on a percentage *by weight* basis. One of the more commonly cited sources is the Franklin Associates, which did a study for the EPA in March 1988:

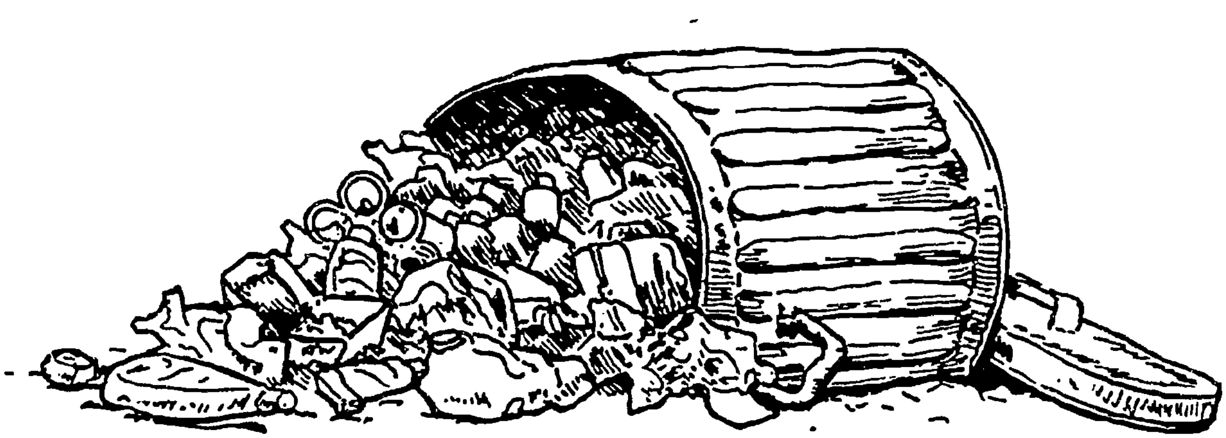
Material	*Percentage, by weight (rounded)*
Paper and paperboard	36%
Yard Wastes	20%
Food Wastes	9%
Metals	9%
Glass	8%
Plastic	7%
Other	11%

Most other studies also report about 7 percent of our municipal solid waste is composed of plastics. But this is based on *weight*, not volume. On a *volume* basis, we can again cite a study by Franklin Associates, Ltd., concluded in February 1990:

Material	*Percentage, by volume*
paper	38%
plastics	18%
metal	14%
yard waste	11%
food waste	4%
glass	2%
other	13%

Notice that only 7 percent of the MSW is plastics *by weight*, although 18 percent is plastics *by volume*.

In other words, about *one-fifth* of the space occupied by our solid waste is taken up by plastics, even though less than *one-tenth* of the total weight is due to plastics. Since most of us are more concerned about space occupied by landfills rather than weight of landfilled materials, this figure seems to be a better one with which to work.



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A Potential Solution

One common method for disposal of plastics has been "open dumping," i.e., discarding plastics into the environment. This has led to the problems discussed in Part I. What is a better way to manage these tons of discarded plastics? The most obvious solution is to use less plastic. This is certainly the best solution but, with most people ignoring the pleas to change their lifestyles, it seems that other options must be considered.

Many citizens and legislators are looking at "degradable" plastics as one way to help solve the nation's solid waste problem. Federal, state, and local legislators are proposing legislation that would require plastics packaging to be degradable. Apparently the thinking is that if plastics were degradable, they would simply disappear, thereby minimizing both the litter and the landfill problems.

There are several possible benefits if plastics can be made degradable:

A. Landfills

According to Professor Richard Wool, head of the degradable plastics laboratory at the University of Illinois in Urbana, one benefit to landfills would be the use of degradable plastic covers to replace the 6 inches to 12 inches of dirt that are deposited daily on landfills as a cover. This could save approximately 18 percent of the space in landfills. This earth covering is needed to prevent the escape of odors and to stop the accumulation of flies and animals. (Wool, 1989)

B. Litter

If it were not for major problems with litter both on land and in our waterways, recycling would be the optimal solution to the solid waste problem rather than degradability. But a significant portion of litter is plastic (see Part I). If plastics can be made degradable, this litter would eventually degrade when exposed to sun, wind, rain, insects, waterways, the soil, and microorganisms. At least the visible litter would disappear as the plastic breaks into pieces and eventually into dust.

This technique has been used since the late '70s in Hi-Cone plastic six-pack carriers for canned beverages, which have been made photodegradable to meet the mandates of states that require degradable carriers (Harlan & Nichols, 1987). Environmer is now manufacturing degradable bait container lids that often end up in waterways after disposal by fishermen (Redpath, 1990). There are obvious additional benefits to wildlife in the waterways if plastic that commonly ends up as litter is made degradable.

C. Yard Wastes

About 20 percent of the wastes in landfills (see EPA figures listed in Part I) is due to yard wastes such as grass clippings, weeds and leaves. Under the right composting conditions, these materials are naturally degradable. The resultant compost can be used on lawns, gardens, or as soil cover in landfills. The main problem with large-scale composting is the time and labor needed to pick up bags, open them, empty them, and then dispose of the bags. If, however, the bags *themselves* are degradable, a single worker can quickly dispose of the bag with its grass or leaves *together* without emptying the bags. Elevated temperatures (as high as 160 degrees Fahrenheit) found in compost heaps will enhance the degradation process (Wool, 1989).

An experimental large-scale composting program is currently underway in Urbana, Illinois. The Yard Waste Reclamation Project uses biodegradable U-Bags containing 6 percent cornstarch, which are collected curbside and composted (Fletcher, 1990).

Types of Degradation

There are essentially four mechanisms by which plastics can degrade (Wool, 1989):

A. Microbial Degradation

Bacterial and fungi attack the plastic either in the presence of air (aerobic) or in the absence of air (anaerobic). There are several factors that will affect how quickly the plastic degrades (rate of degradation):

1. temperature
2. oxygen
3. moisture
4. number of microbes present

B. Macro-Organism Degradation

Larger organisms such as insects and invertebrates consume the plastic as food. Examples include crickets, worms, snails, slugs, and other organisms in the soil.

C. Photodegradation

The plastic absorbs ultraviolet (UV) radiation from the sun, which causes a breakdown of the large molecules in plastics.

D. Chemical Degradation

Certain chemicals added into the structures of plastics during the manufacture promote reactions that cause the breakdown of the plastics molecules.

NOTE:

It is important to note that a number of other environmental factors will further contribute to any of the above mechanisms of degradation: wind, rain, ice, heat, abrasion, etc., could speed up the process.

Biodegradation

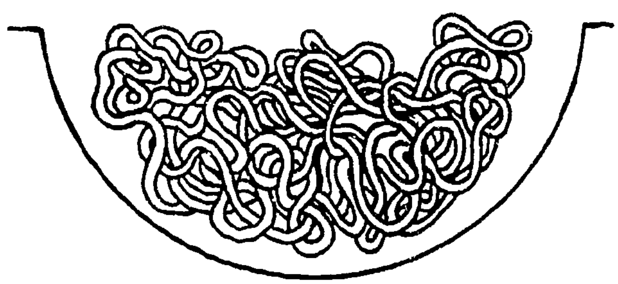
The first two mechanisms described on page 81 can be grouped together as "biodegradation." Ordinary plastics have been developed to be resistant to break down by microorganisms; this stability is primarily due to two factors (Guillet, Haskins, Spencer; year unknown):

1. The low surface area and the difficulty of other substances penetrating and passing through ("impermeability") of plastic films and molded objects.
2. The extremely large size of the molecules (high "molecular weight") in the plastic materials.

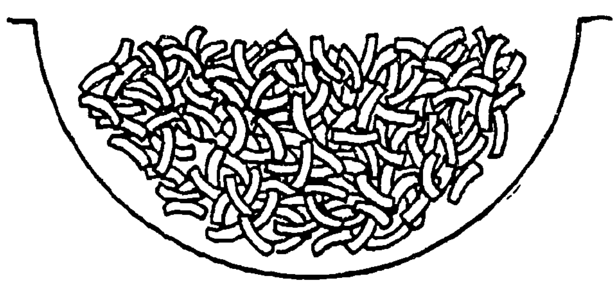
It seems that when the microorganisms attack a substance, they tend to attack the *ends* of the molecules. If a substance is made up of small molecules, a greater number of molecules are present in a given amount of the substance than there would be in the same amount of a substance made up of large molecules. Therefore, in a substances with small molecules, there are more *ends* to be attacked than in a substance made up of large molecules. Plastics are made up of extremely large molecules, and therefore, there are *very few ends* that can be attacked. This makes it difficult for the microorganisms to break down the plastics.

If plastics are to be made degradable, somehow more ends of molecules need to be made available to the microorganisms. This can be done by breaking the plastics down into very small particles with a much larger surface area. It can also be done by making the *molecules within the particles* much smaller (reducing their "molecular weight").

The process is much like eating spaghetti. Assume that you can only devour it by finding the end of a piece and slurping it up. If you have a large bowl of spaghetti with very long pieces, it will be difficult to eat:



But if you cut the long pieces into shorter chunks, then there are more ends exposed and it will be easier to eat—more like eating macaroni.



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Remember, in *biodegradation*, the plastics are broken down when living organisms—either very small ones (like bacteria or fungi) or larger ones (like crickets, bugs, snails)—consume the plastics as food; but the molecules are long, and not easily broken down. However, microrganisms can easily break down a substance such as cornstarch and use it as a food source. Cornstarch can be incorporated into the long plastics molecules. When this is done, the organisms can devour the starch and thus break down the plastic molecules into many smaller molecules. These can then be degraded, since more "ends" are exposed.

Consumption by insects can be a much faster way of eliminating litter than by other methods (on the order of *days* rather than months or years). In order for this to happen in plastic films (polyethylene), the films must contain about 20 percent starch; they are then considered to be "food" by many insects and will be completely ingested (Wool, 1989). Wool also claims that insects will not only consume these plastics as open litter but will also cause breakdown of these plastics at solid waste sites.

For polyethylene film that has been buried, the time for degradation depends on the percentage of starch in the molecules (Sudol and Zach, 1988):

% Starch	Time for Degradation
15%	six months
6%	three to five years

There are several potential advantages and disadvantages to the use of cornstarch as an additive in polyethylene:

A. Advantages

In addition to the advantage of improving the biodegradability of plastics, the use of cornstarch could reduce corn surpluses, raise farm income, and reduce government subsidies ($12 billion a year for corn). It would also lower oil import bills since plastics come from petroleum.

B. Disadvantages

Researchers at Rutgers University argue that there are several potential problems with degradable plastics. Are the conditions in a landfill, where much will be dumped, going to cause rapid degradation? Are there studies that have been done under landfill conditions? Do we know what the products of degradation are? If these products are just shorter pieces of plastic, will these cause an even greater threat to the environment (that is, more mobile and leachable) (Renfree and Forster, 1989; Warren, 1989)?

Keep America Beautiful, Inc., also raises concerns about degradation in landfills (Keep America Beautiful, no date). It claims that "research shows that a 65% moisture level is necessary for a significant rate of biodegradation to occur." However, apparently there is only 25 percent to 30 percent moisture in the solid waste that typically enters landfills. And landfills are purposely kept dry to prevent surface water from leaking through and contaminating the aquifer.

Other concerns relate to possible opposing directions for the use of degradable plastics and recyclable plastics. Recyclers want a rigid container product to be recycled into durable construction products. Cornstarch impregnation may just be an impurity that weakens the recycled product (Renfree, Forster, 1989; Warner, 1989). Wool however argues that up to a ratio of 30 percent degradable plastics mixed with 20 percent normal plastics will still make a product without a significant change in durability (Wool, 1989).

Some argue that the plastic bags and films containing cornstarch are less durable, not as strong, and are considerably more expensive than the traditional plastic bag (Keep America Beautiful, no date).

Photodegradation

All plastics are polymers and will break down when exposed to ultraviolet (UV) light from the sun. By adding one of several chemical additives when the plastics are produced, these chemicals are inserted into the polymeric chain and enhance the degradation by sunlight.

One of the more common methods for enhancing this photodegradation process is to insert carbon monoxide, CO, into the plastic, polyethylene (fig. 1):

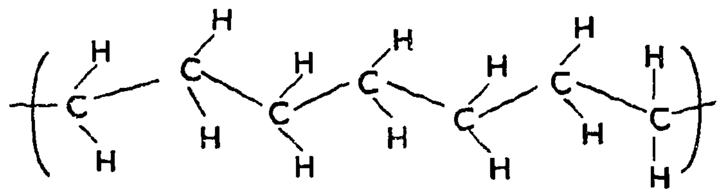


Figure 1 Polyethylene

The resultant product, called ethylene carbon monoxide (E/CO), is manufactured by several companies such as Dow Chemical, Dupont, and Union Carbide (fig. 2):

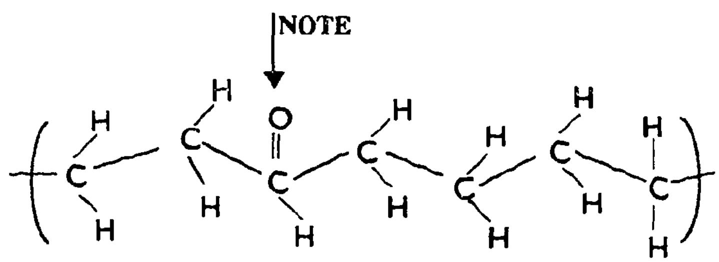


Figure 2 Ethylene carbon monoxide

As these plastics are exposed to UV light (especially with wavelengths around 290 nm, the higher-energy UV light), the plastic loses its ability to stretch and eventually becomes "brittle" (essentially, no more stretch). This change in properties is due to a breakdown in the polymer chains whenever the UV light hits the CO in the chain. This degradation process is enhanced as the plastic product is exposed to wind and rain and breaks into smaller and smaller pieces. The time needed for degradation varies from season to season and from state to state, but generally a minimum of several months should be expected if the plastic is exposed to regular sunlight (Sudol and Zach, 1988; Harlan and Nicholas, 1987).

E/CO-type products have been identified since 1950 but have been of significant commercial interest only since the early 1970s. One of the earliest applications was in the production of Hi-Cone carriers, the six-pack plastic loops for carrying beverage cans. A number of states in the 1970s mandated that those carriers be "degradable"; since then millions of pounds of Hi-Cone carriers have been produced to try to aid the degradation of carrier litter and help the protection of marine wildlife (Harlan and Nicholas, 1987).

On-the-ground winter exposures were monitored in New Jersey, comparing the E/CO plastic (2.7 percent CO) to regular low-density polyethylene plastics. The E/CO became "embrittled" (when the stretch to the break point is less than 5 percent of the total original length of the stretch) within two months, while the standard carrier stayed intact over the five-month test period (Harlan and Nicholas, 1987).

Immediate products of the breakdown will be shorter chains of the plastic, polyethylene. However, according to Union Carbide, "as with standard low density polyethylene, ultimate decomposition products for E/CO would be essentially water and carbon dioxide" (Harlan and Nicholas, 1987). Research to support that is apparently not yet available.

Eagle grocery stores, in June 1989, began labelling their plastic grocery bags with the phrase, "Degrades in Sunlight." A representative of the Mobil Chemical Company (the manufacturer) said that experiments done in Arizona took 10 weeks to 12 weeks to degrade the bags (apparently to this 5 percent stretch point, or until "brittle") (Mobil, 1989).

Examples of Independent Research Projects

COMPARISON OF GROCERY BAGS: PHOTODEGRADABLE VS. NORMAL

Several grocery store chains are now using photodegradable polyethylene grocery bags. For example, In the summer of 1989, Eagle stores started using bags that made the claim, "Degrades in Sunlight."

Students can design a project to test that claim by placing several photodegradable grocery bags (PGBs) and several normal grocery bags (NGBs) in the sunlight for a period of months and periodically doing several degradation tests on each type of bag. (These tests are described on pages 93-96.)

There are a few *general guidelines* to keep in mind for any of these experiments. Make every effort to be sure that *every part of the bag* is *equally exposed to the conditions*. For example, if the bag exposed to the sun, rotate it at regular intervals to allow both sides to have equal exposure to the sun. Cut the bag so that it is only *one sheet thick*; this allows both sides to be exposed to weather, soil, or water. Do not use the whole bag since the interior surfaces are then unexposed. If possible, leave one sample *completely undisturbed* throughout the process; then do one final test at the end. This is true especially for *buried* samples; digging up for testing alters the conditions in the soil.

1. Exposure to Sunlight

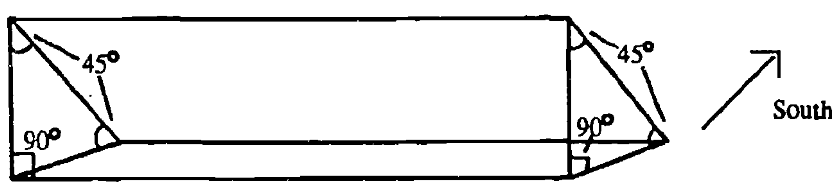
Several techniques have been used to expose the bags to sunlight. First choose an area with as much sun exposure as possible.

a. Hanging on clothesline

Use several clothespins to fasten the bags to the line. Good exposure to sunlight is assured and nice agitation from the wind will hasten the degradation process. In order to minimize the amount of winding around the line, it is good to weight the bag down somehow (rocks or bolts in the bag work well). Strong winds will still wind the bag around the line, so regular (at least daily) unraveling is necessary in order to maximize the exposure to the sunlight.

b. At a Rigid 45-Degree Angle

Researchers in the field of plastics degradation place the plastic bags at a 45-degree angle to the sun, facing south. This is in accordance with the ASTM (American Society for Testing and Materials) Standard Practice for Outdoor Weathering of Plastics. Students can design a simple wooden frame from any one of a variety of thin wooden sticks.



The grocery bag is attached with metal tacks or staples to keep it in place. This design is of course not very close to the type of exposure real grocery bags would get if discarded into the environment, but it does allow for a nice comparison of PGBs with NGBs under the same conditions to see which ones really do degrade more rapidly.

Sample strips must be taken from evenly spaced locations in order to prevent a big hole being cut in the bag and thereby loosening the bag from its frame. (NOTE: Florida State Legislature simply suggests mounting on a plywood board.)

c. Free-Moving, Caged Container

CAUTION: This test seems to give the most erratic data because of the random motion.

In order to more closely approximate the random motion of litter, a wooden cage with wire mesh can be used to contain the bags. They will blow around or lie in a pile, so the motion is random and therefore adds an additional variable into the experiment. But this procedure does approximate much more closely the condition of the real world of the littered bag.

Periodic pictures of the arrangement of the bags in the cage will make this experiment more informative.

d. Natural Conditions of Bag Reuse

Environmentally concerned people are making an effort to reuse materials as much as possible. Are there some natural ways of reusing photodegradable grocery bags that would enhance their exposure to sunlight? Have students devise their own conditions and test them out.

Some suggestions:

1. Use the bags as "beach bags" for a period of months and monitor the degradation.
2. Store them in the back seat of your car (in the heat and sunlight) and reuse them to buy groceries; then monitor the degradation.
3. Normal kitchen fluorescent lights emit some UV radiation. Leave several bags exposed to kitchen lights for several months and monitor the degradation.

2. Other Conditions for Degradation

In addition to considering the effect of exposure to sunlight, students need to think about other places where the bags will be discarded. Two of the more likely places are in waterways or buried in a landfill. Students might also design experiments using both PGBs and NGBs that try to approximate these conditions.

a. In Waterways

Students might place bags in a river, stream, lake or pond and make regular tests on the exposed bags. Or students might simply use pans of water and immerse both bags in this water exposed to sunlight. This alters the conditions from those in air in several ways; less exposed O_2, some filtering of the sunlight, less agitation from the wind, and exposure to additional components in the waterways.

b. In Landfills

Realistically, this is where most of these bags will be disposed. Students can bury several bags (single sheets, not whole bags) in their lawns or gardens, making sure to use the same soil depth and same soil type. Ideally, students should *bury one sheet for each sampling of the bags for degradation tests*; digging up and reburying will probably disturb the growth of microorganisms on the buried bags and cause greater deviation from "reality."

3. Frequency of Degradation Tests

Students can select one of the degradation tests, described on pages 93-96, to use on their bags. The stretch test is probably the best test; it is most easily administered, allows for multiple trials, and gives reasonable reproducibility.

Students should make initial tests on both types of bags (8-10 trials) and then sample every 10 days to 14 days for at least two months. (Three months is even better.)

NOTE: Florida State Legislative: "Plastic bags must degrade within 120 days, effective January 1, 1990."

Students can average their eight trials each time or somehow try to indicate *range* or *uncertainty*. One simple way to indicate this variation in the stretch is to record the average deviation from the calculated mean. For example: using the sample data from Part IX:

Trial	Length of Stretch	Deviation From the Mean
1.	30 cm	2 cm
2.	25 cm	3 cm
3.	18 cm	10 cm
4.	23 cm	5 cm
5.	44 cm	16 cm
6.	29 cm	1 cm

Mean: 28 cm Ave. Dev.: 6 cm

RESULT: 28 cm • 6 cm

NOTE: It may be wise, based on the wide range of variation that occurs, to eliminate the highest and lowest values before averaging.

4. Degradation vs. Disintegration

There are no clearly stated definitions for what is meant by "degradable." Most researchers are using the "Brittle Point" standard: When the polyethylene stretches to no more than 5 percent beyond its original length, it is considered "degraded." This can occur in as little as two months of Illinois summer sun, with optimal exposure.

Most students, however, look at the finished product and respond, "That bag's not degraded; I can still see it!" In other words, they're equating degradation to *disintegration* (the point where the bag is torn up into such little pieces that it is no longer visible).

If students want to carry their experimentation through to that extent of disintegration, additional tests will have to be devised. One method would simply be a visual record of the size of the pieces remaining using photographs.

AN ANALYSIS OF THE EFFECT OF VARYING OUTDOOR CONDITIONS ON THE DEGRADATION OF PHOTODEGRADABLE GROCERY BAGS

This project is just a variation of Project A (page 15). Instead of comparing two types of bags under one or two different conditions, students would instead take one type of photodegradable plastic bag and choose three or four of the conditions described in Part A. For example:

1. Sunlight - Free Movement in Wind (handing on clothesline)
2. Sunlight - Rigidly Fastened (on wooden frame)
3. In Waterway
4. In Landfill
5. Free-Moving (in cage)

COMPARISON OF PHOTODEGRADABLE FISHBAIT LIDS TO NORMAL BAIT LIDS

Environmer Enterprises is now manufacturing a vented lid for plastic bait packages used by dealers of fishing baits. The lids, to be marketed by Fabri-Kal Corporation of Michigan, are made with ECOLYTE degradable polystyrene, which is "a polymer with special molecules sensitive to ultraviolet light." You can obtain current information concerning this material by writing to: Fabri-Kal Corporation (see mailing list on page 69).

Degradation will occur "only in direct sunlight, not in artificial indoor light." Sunlight causes the plastic "to eventually disintegrate into an inert material resembling sand." The lids are particularly designed to help alleviate this unique litter problem.

"The degradable bait lid will help ease litter problems when the lids are blown out of a boat, carelessly discarded or accidentally left on a lake shore," says Robert Kettridge, president of Fabri-Kal.

Alan Coxhead, sales development manager, emphasized that the ECOLYTE products are both degradable and recyclable. For student testing, if outdoor sunlight is used, he suggested it be combined with the effects of wind and rain. Additional samples for testing are available from him.

1. Conditions for Testing

Students would probably want to test Photodegradable Bait Lids (PBLs) compared to Normal Bait Lids (NBLs). Samples of each could be placed in the sunlight immersed in water, and/or placed on a lake shore where they would be exposed to water. Bait lids could be rigidly fastened down, placed in a cage to allow more agitation by wind in rain, or left dangling on a string or wire attached to the ground. Suggested degradation tests would be the Maria Bend Test or the Todd Poke Test.

Another monitoring technique to either supplement or replace the two degradation tests would be weekly photographs of the bait lids until complete disintegration occurred.

2. Frequency of Sampling; Length of Exposure

A minimum of three months' exposure (four months are better) is required. Sampling should occur every two weeks or so; that frequency requires a minimum of four bait lids of each type exposed to the elements since whole lids are needed for the degradation tests. Duplicate trials would require eight lids of each type.

NOTE: Florida State Legislature: "Polystyrene foam must degrade within one year."

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COMPARISON OF PHOTODEGRADABLE SIX-PACK RINGS TO NORMAL SIX-PACK RINGS

Illinois Tool Works (ITW) manufactures a photodegradable "Hi-Cone ECO" plastic six-pack ring that is used to hold a variety of six-pack canned beverages. ITW also manufactures a non-photodegradable ring, using a diamond symbol to identify the photodegradable rings.

Between August 1985 and March 1986, the state of Oregon did a series of tests at nine different outdoor locations to see if these photodegradable six-pack rings (PSPRs) decompose within the 120-day (four-month) deadline of the Oregon State Legislature.

When the PSPRs reach "maximum brittleness," they tend to crack and break into small pieces when "subjected to sufficient environmental action" such as the blowing wind. The Oregon study concluded that "the Hi-Cone ECO material generally attains maximum brittleness in about 40 days in Oregon during the middle of the summer," but takes as long as 200 days (6-7 months) during periods of weakest sunlight in the fall and winter.

1. Their Design

Eight PSPRs were placed in sunny locations at each of the nine stations. The rings were contained on the top and sides by wire cages that were about one foot high and three feet square. This allowed the rings to blow around and simulate the wind action of the natural environment.

At the end of each month, experimenters removed two rings from the cages, photographed them, and tested for brittleness by three methods:

a. The Stretch Test
b. The Crumple Test
c. The Bend Test

(All are described in Part IX.)

2. Our Design

Students could attempt to replicate the Oregon study under the conditions of Illinois weather. One modification would be to test samples every two weeks rather than every month.

Other Projects Dealing With Degradation Variables

Comparison of ecolyte photodegradable styrofoam food containers to normal styrofoam containers - 0 percent, 5 percent, 10 percent: sunlight and landfill.

Comparison of photodegradable garbage bags to normal garbage bags: brief sunlight exposure plus landfill vs. just landfill.

Comparison of biodegradable lawn waste bags (U-Bags) to normal lawn waste bags: compost pile vs. landfill.

Comparison of biodegradable book bags to normal book bags: landfill

Comparison of insect degradation to either microbiol or environmental degradation: sunlight, waterways, or landfill.

Accelerated degradation techniques for photodegradable plastics: normal "black light" vs. water spray

Possible Degradation Tests

STRETCH TEST (For plastic bags and films such as Low Density Polyethylene - LDPE)

As polyethylene degrades, it becomes less and less elastic. Normal polyethylene will stretch to 400 percent to 500 percent of its original length before breaking. As defined earlier, "brittle" plastic bags are ones that stretch to 5 percent or less of their original length.

To do the test, cut a rectangular strip of plastic about 2 cm by 8 cm.

Be sure the cuts are *smooth* with no tears or cuts on the edges.

Grasp the plastic with your thumb and forefinger at both ends. Using a yardstick or meter stick, very slowly stretch the plastic strip, watching for the length at which it breaks.

To calculate the percentage elongation, use the following equation:

$$\% \text{ Elongation} = \frac{\text{Length at Break - Original Length}}{\text{Original Length}} \times 100$$

Percentage elongation would decrease steadily as the polyethylene is exposed to various degradation conditions.

TIPS:

1. Do multiple tests each time (at least 8 to 10), then eliminate the highest and lowest values and take the average of the remaining trials. There can be considerable variation. (See Sample Data below)
2. It may be helpful to cut a card 8 cm x 12 cm. Trace this on your plastic bag. Cut out the section. Then cut eight equal 8 cm x 2 cm pieces for your eight tests.
3. It may be good to have students begin with one bag. Have them break into groups of three or four. Then have them cut eight or nine strips per group and do the stretch test on each one. Tabulate the data; compute a class average; notice the variation.
4. "Andy Grain Observation." Andy observed that plastic bags may have a different stretch when stretched "across the grain" of the plastic than when stretched "with the grain." Watch for that. Try to take samples uniformly from the bag.
5. It doesn't matter whether your thumb and forefinger extend over the ends by a half an inch or so— the plastic will stretch *underneath* your fingers as well, so the total length can be used for your calculation.
6. Do all stretch tests under the *same temperature* conditions. We suggest taking the bags indoors, allow them to come to room temperature, and then do the stretch tests.
7. A *slow* stretch is crucial. If you stretch the sample too quickly, it will break too soon. We recommend *timing the stretch*; it should take *at least 30 seconds* from start to break. If the sample breaks before 30 seconds, do the test again more slowly.
8. Record *visual observations* in a separate column each time the stretch test is done. Look for changes in color, texture, and flexibility, and also try to observe any evidence of breakdown such as holes or tears.
9. Some feel greater consistency is achieved by keeping one end of the sample *rigid* and stretching the other end.

Sample Data (from original photodegradable Eagle grocery bag)

Original Length: 8 cm

Length of Stretch (6 trials): 30 cm, 25 cm, 18 cm, 44 cm, 29 cm

Average: 28 cm

$$\% \text{ Elongation } \frac{28-8}{8} \times 100 = 250\% \text{ (ave.)}$$

(this kind of variation in six trials is typical student data)

STRENGTH TEST (a less refined modification of the stretch test)

Spread the plastic film over the opening of a large jar. Affix it with several rubber bands. While one person holds the plastic firmly (reinforcing the rubber bands), the other person slowly pours lead shot into the center of the plastic film until the film breaks. The container of lead shot is weighed before and after to determine how much lead the plastic holds at the point of breakage.

Again three to five trials are suggested. Other massive objects can be substituted for the lead shot, such as coins, stones, nuts (as in nuts and bolts), etc. Some experimentation will be necessary to find a jar large enough to allow for enough metal to break the plastic films. Remember, plastic bags are designed to be strong; one strength test for a certain brand of grocery bag is to fill it with several *six-pack containers of pop.*

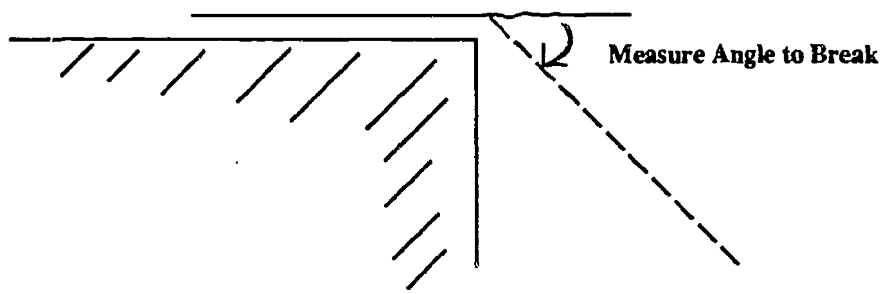
This test is not as tried and true as the stretch test. It is good for the more creative and pioneering student who wants to perfect the method or add his/her own special twist to the design.

CRUMPLE TEST (for polystyrene, any rigid or semi-rigid plastic, or heavy LDPE)

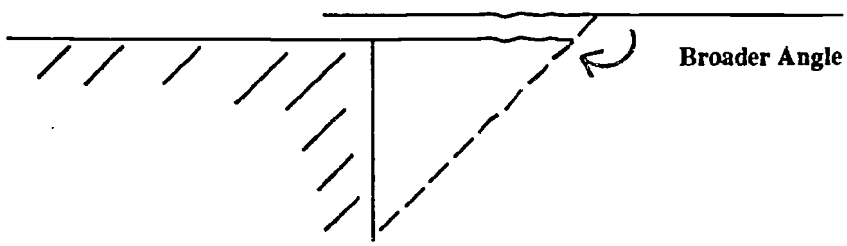
This is a fairly qualitative test that needs refinement. The object is simply crumpled in the hand, held for five seconds, and then released. The object is then timed to see how long it takes to return to its original form. Observations are also made on breaks, or crumbling into pieces; record number of breaks or number of pieces.

MARIA BEND TEST (for styrofoam or other rigid or semi-rigid plastics)

Simply place the piece of plastic on the edge of a bench or table, half on, half off. Using a protractor to measure the angle, slowly bend the plastic down until it breaks. (Caution: Safety glasses should be worn for this procedure.)



This test needs modification for some plastics. They will not break at a 90-degree angle. Using a thin, flat overhang, one can allow for a 180-degree bend.

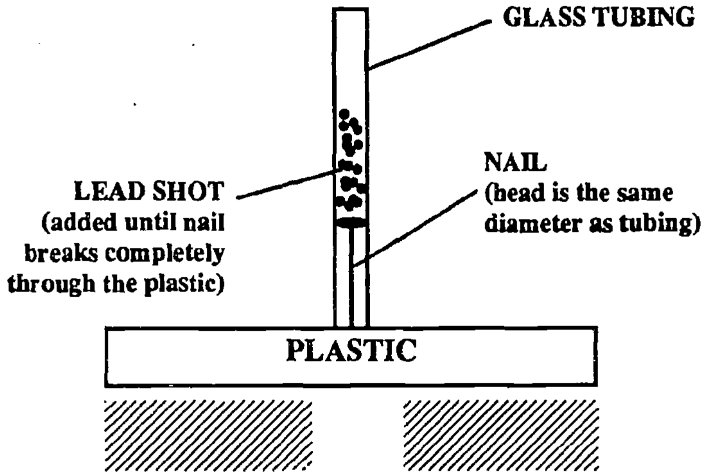


A third modification that has been used by some students is to repeat the 180-degree bend over and over until breakage occurs. They then count the number of repetitions needed for breakage.

Dr. Violet Jonas, who directed an Oregon study on plastic six-pack rings, has defined brittleness in terms of angle of bend as follows:

1. Maximum Brittleness: a six-pack ring that breaks upon being bent through an angle of less than 90 degrees.
2. Near-maximum Brittleness: Breaks between 90 degrees and 135 degrees
3. Substantial Brittleness: Breaks between 135 degrees and 180 degrees

TODD POKE TEST (for styrofoam or heavier films)



The diagram shows the procedure. Again the lead shot is weighed before and after to determine the weight of lead supported at the point of breakage.

ERIC TRANSPARENCE TEST (for films and bags)

This test needs some refining but has potential. Simply take a bright, concentrated source of light such as a lamp, place the film or bag near it, and note the degree of transparency. Only qualitative data are available from this test unless you use a light meter.

TUMBLE TEST (being investigated)

STANDARDIZED TESTS AND FACILITIES

Tests on various physical properties are done by researchers and industry to monitor plastic degradation. Such tests include elongation, tensile strength, molecular weight, impact strength, tear resistance, friability (tumble test) and flex test. Three companies that will do standardized "outdoor weathering" for comparison to your own tests are the following:

Suggested Testing Facilities

South Florida Test Services
9200 Northwest 58th Street
Miami, F'orida 33178
Mr. Steve Lane
(305) 592-3170

Eco Plastics
518 Gordon Baker Road
Willowdale, Ontario M2H 3B4
Canada
(416) 499-3060

Subtropical Testing
8290 Southwest 120 Street
Miami, Florida 33156
Mr. M. Mollman
(305) 233-5341

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