Illinois Waste Management
& Research Center
A Division of Illinois
Department of Natural Resources

Illinois Environmental
Protection Agency

Greening Schools
of WMRC

What color is your waste? GREEN!—Returning safe substances to the environment

Greening Schools

**A program with the Illinois Waste Management and Research Center
and
Illinois Environmental Protection Agency**

Green Chemistry

**High School Lessons
Or
Elementary/Middle School Demonstrations
For more information
www.greeningschools.org or
cknepp@wmrc.uiuc.edu**

What color is your waste? GREEN!—Returning safe substances to the environment

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Objectives
1) Examine ways to make packaging more "environmentally friendly."
2) Understand the concept of biodegradation/bioremediation.

Green Chemistry Principles
• Safety first—and last.
• Wastes? Why make them?
• Use renewable resources

IL State Standards (Science)
11.A.3a, 11.A.3b, 11.A.3f, 11.A.4a, 11.A.4b, 11.A.4c, 11.A.4d, 11.A.4f, 11.A.5a, 11.A.5d, 12.B.3a, 12.B.4a, 12.C.5a, 12.E.3c, 13.B.3e, 13.B.3f, 13.B.4c, 13.B.5d, 13.B.5e

Levels
High school (may be used as a demonstration for discussion in middle school classes)

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Materials
• Samples of typical packaging materials used including: shredded or wadded newspaper, polystyrene (such as Styrofoam) packing "peanuts", and starch packing "peanuts"
• A balance or scale
• Scissors
• Six small cups or other containers for samples
• 1 15-20 mL beaker
• Amylase powder (1 gram)
• 24-well plate
• 12 pipets
• Iodine solution
• Glucose test strips
• Paper & writing utensils
• Distilled or deionized water
• Toothpicks
• Samples of packaged products

Time
One class period

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Vocabulary
Biodegradation, bioremediation, degradation, photoremediation, photodegradation, enzymes, decomposers, synthetic, amylase, glucose

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This material is adapted from the ACS text *Introduction to Green Chemistry.* See the "references" section of the introduction to this manual for additional information on this text.

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Overview

Commercial packaging pervades life in the Western world. Our food, clothes, medicine, furniture, computers, cleaning materials, publications, and other items are packaged in one way or another. Packaging has a number of functions, notably, protecting the contents from damage. Often, the final shipping package incorporates several types of packaging materials in various shapes to ensure the transportability of the product. Yet, once the product is put into use the packaging material is designed to be discarded. If it is not possible to redesign the product to eliminate or recycle the packaging, then the next best alternative is to ensure that the packaging material does no harm to the environment when discarded.

Most packaging is not toxic to the environment. However, because many of the more common packaging materials do not degrade easily once they are discarded, they keep adding to the large volume of solid waste that is piling up on the planet. If a packaging material can decompose quickly, it can be recycled naturally. For example, some companies are designing plastics that will break down into harmless products through the action of microbes (biodegradation) or in the presence of light (photodegradation).

In the following activity, students will compare an enzyme action on different packaging materials. The students will observe which biodegradability and other natural processes can break down these materials.

Procedure

1. Weigh two pieces each of samples of paper, polystyrene (Styrofoam) peanuts and starch peanuts. Trim each as necessary to ensure that the mass of each sample is approximately equal.

2. Place a piece of each into each of six small beakers or cups.

3. Label your samples of packaging materials so that you have two identical groups, A and B, as follows:

   Paper—Group A Paper—Group B
   Polystyrene—Group A Polystyrene—Group B
   Starch—Group A Starch—Group B

4. Crush and/or tear each sample into small pieces.

5. Add 10 mL of distilled or de-ionized water to each, and stir thoroughly.

   Note any changes in the samples.

Add a small amount of amylase powder (about 0.05 g) to each sample in Group B and stir. Allow the sample to sit for 10–15 minutes

Starch test

This test is based on the principle that iodine reacts with dissolved starch to produce a blue-black color.

6. Label a sheet of paper under a 24-well plate for each test described below.

7. Using a pipet, transfer approximately 2 mL of the liquid for each of the six samples to separate wells in the well plate. (Be sure to rinse your pipette well after each transfer so that you do not cross-contaminate samples.)

8. Add 4–5 drops of iodine solution to each of the samples in the well plate, and stir each with a separate toothpick.

9. Note any color changes in each, let samples sit for 10 minutes, and make final observations

Test for glucose

10. With a clean well plate, repeat steps 7 and 8 above.

11. Using glucose test strips, determine the glucose concentration of each sample and record.

What observations did you note for each sample after water was added?	*The paper may have flattened and lost its shape because of the water. The Styrofoam is likely unchanged. The starch peanuts should dissolve at least partially.*
Which samples contained starch?	*Only the starch pellets. Some paper samples may change color because of starch coating that may have been added during the paper manufacturing process.*
Did the enzyme make any difference in material degradation?	*The enzyme should break the starch into individual glucose molecules. It is hard to tell by just looking, because the starch is fairly soluble in water and dissolves. The evidence is in the chemical*
Research the chemical structures of glucose, starch, cellulose, and polystyrene molecules. Notice any similarities?	*Except for the glucose, which is a simple sugar, they are all polymers. Starch and cellulose are natural polymers made from glucose subunits. Styrofoam is polystyrene, a synthetic polymer*
Make a hypothesis about the degradation that was noted in these tests using the chemical structures as a basis.	*Microorganisms have developed an enzyme to decompose starch, but not the synthetic polymer polystyrene.*
The principles of green chemistry encourage us to consider the environmental impact of a substance before it is designed and manufactured. Explain why the production and use of starch peanuts rather than polystyrene for packaging could be considered an example of green chemistry.	*This use of starch packing peanuts in place of polystyrene for packaging is a perfect example of the "benign by design" concept. The starch pellets were introduced with their entire product life cycle taken into account. Many products are created without regard to how they will be disposed of or recycled. Green chemistry hopes to change this pattern of behavior.*

Use this for an open-ended discussion: How can packaging be formulated in "greener", more environmentally friendly ways?

The Twelve Principles of Green Chemistry

1. It is better to prevent waste than to treat or clean up waste after it is formed.

2. Synthetic methods should be designed to maximize the incorporation of ALL materials used in the process into the final project.

3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.

4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.

5. The use of auxiliary substances (e.g. solvents, separation agents, etc) should be made unnecessary whenever possible and, innocuous when used.

6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

7. A raw material feedstock should be renewable rather than depleting whenever technically and economically practical.

8. Unnecessary derivatization (blocking group, protection/deprotection, temporary modification of physical/chemical processes) should be avoided whenever possible.

9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.

10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.

11. Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.

12. Substances and the form of a substance used in a chemical process should be chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

Anastas, Paul T., and Warner, John C. *Green Chemistry Theory and Practice*, Oxford University Press, NY, 1998

The Methodology of Green Chemistry

"Green chemistry is an approach dealing with a fundamental environmental problem of the world, the problem of pollution. Pollution is usually defined as chemical pollution. Most often the approach utilized in the laws has been one of controlling the amount of release of a chemical or controlling the final concentration of that chemical in the medium to which it was released. Green chemistry deals with the above situation somewhat differently: preventing the releases." Nelson, William M. *Green Solvents for Chemistry Perspective and Practice*, Oxford University Press, NY, 2003

Background

Why are products packaged in various types of materials? Some seem to require boxes, others only bags, or simply nothing at all. The type of product usually dictates the type and extent of packaging required: Fragile items require more packaging, while durable items require little or none. Not all materials are practical for protecting products, and some packaging materials are better than others.

Why are some consumer products so heavily packaged? A bottle of aspirin is typically sealed with foil and padded with cotton, the cap shrink-wrapped onto the bottle, and placed inside a cardboard box whose flaps are glued shut. The multiple layers of packaging, particularly for products that people will eat or drink, is largely a result of the 1982 Tylenol poisonings in which seven people in the Chicago area died after taking cyanide-laced Tylenol capsules. Because of this case, industry-wide changes in packaging were implemented, making it more difficult to tamper with consumer products.

Allow your students a few minutes to list what they consider ideal properties of packing materials and then discuss them as a group. Some suggested characteristics are compressibility, shear strength (resistance to tearing), density, durability, flexibility, and cost. Extend this by offering a variety of objects to small groups of students and let them design(verbally or on paper) an appropriate packaging and then as a large group discuss the pros and cons of these selections.

Decomposers tend to break down natural substances, but synthetic substances can be more difficult. Microorganisms have not yet developed the metabolic processes required to digest and decompose these materials, although in time they may adapt and evolve to possess this ability. In the meantime, in landfills synthetic substances are problematic.

Packaging materials are not “toxic” per se; however, they are unsafe for the environment because they persist or cannot be recycled naturally. Some critics of modern landfill design say that many natural substances also persist in landfills, not just plastics and polymers. Because the landfills are sealed and dry, the natural processes of decomposition are slowed dramatically.

In this activity, the enzyme amylase is used to break down complex starch molecules into simple glucose molecules. Amylase is a very common enzyme found in both plants and animals, including humans. Amylase in saliva is involved in one of the first steps of digestion, beginning the breakdown of complex carbohydrates as soon as the chewing of food starts.

The expected result is that the starch pellets will test positive for starch and negative for glucose in the control sample. After the enzyme has been allowed to work, the sample will test negative for starch and positive for glucose. Fungal amylase is available as a powder from science supply houses. Glucose test strips are available from science supply houses or from local pharmacies.

Ideas for Further Study

1. **Discuss how the following principles of green chemistry, if widely applied in industry, could substantially reduce the amount of toxic chemicals released into the environment:**
   - **Identify reactions that use nontoxic starting materials to make a desired product.**

     Starting with safer materials means that any leftover starting materials would be much easier to dispose of. Also, these materials present fewer dangers to employees who handle them or to residents of the area surrounding a manufacturing plant if there should be an accidental release of chemicals.

   - **Eliminate the use of toxic solvents to dissolve the reacting materials.**

     Although they do not end up in the final product, the solvents used in industrial products are part of the waste stream, and finding less toxic choices can significantly reduce the total pollution.

   - **Design reactions in which all or most of the atoms that you start with end up in the desired product rather than in waste byproducts.**

     It is much more efficient if all the raw materials end up in the final product of a process. It is not helpful if the amount of byproduct produced is far in excess of the benefits of the product. Clever chemical engineering can make processes more efficient by design.

   - **Produce materials that are benign or rapidly biodegradable at the end of their use.**

     The concept of building for the entire life cycle of a product is a relatively new idea for industry. If careful consideration is given during the design process on how the product will be recycled or reused, this can significantly reduce the amount of pollution.

2. **Discuss the use of bioremediation**

Bioremediation is the process by which living organisms act to degrade or transform hazardous organic contaminants. The rapid expansion and increasing sophistication of the chemical industries in the past century and particularly over the last thirty years has meant that there has been an increasing amount and complexity of toxic waste effluents. At the same time, fortunately, regulatory authorities have been paying more attention to problems of contamination of the environment. Industrial companies are therefore becoming increasingly aware of the political, social, environmental and regulatory pressures to prevent escape of effluents into the environment. The occurrence of major incidents (such as the Exxon Valdez oil spill, the Union-Carbide (Dow) Bhopal disaster, large-scale contamination of the Rhine River, the progressive deterioration of the aquatic habitats and conifer forests in the Northeastern US, Canada, and parts of Europe, or the release of radioactive material in the Chernobyl accident, etc.) and the subsequent massive publicity due to the

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...resulting environmental problems has highlighted the potential for imminent and long-term disasters in the public's conscience.

Bacteria can be altered to produce certain enzymes that metabolize industrial waste components that are toxic to other life, and also new pathways can be designed for the biodegradation of various wastes. Since waste management itself is a well-established industry, genetics and enzymology can be simply "bolted-on" to existing engineering expertise.

Use of microbes for bioremediation is not limited to detoxification of organic compounds. In many cases, selected microbes can also reduce the toxic cations of heavy metals (such as selenium) to the much less toxic and much less soluble elemental form. Thus, bioremediation of surface water with significant contamination by heavy metals can now be attempted.

Scientific Process:

1. Formulate or evaluate question or form a hypotheses: (*There can be a variety of questions including can enzymes increase the biodegradation of waste materials.)*
2. Plan and conduct experiments or test the hypotheses. *Select packaging materials to on which to test enzymatic activity.*
3. Make systematic observations and measurements. *Weigh, label and test your materials*.
4. Interpret and analyze data. *Discuss conclusions in a question and answer format.*
5. Draw conclusions. *Did the enzyme make any difference in material degradation?*
6. Communicate the results either orally or in writing.

Real World Applications:
As a class discuss the use of this practice in reducing pollution. How can this be applied at home and in our communities?

On the Web:

Environmental Inquiry: Authentic Scientific Research for High School Students.
http://ei.cornell.edu/biodeg/ Environmental Inquiry (EI) is a website and curriculum series developed at Cornell University to help students conduct environmental science research and participate in communities of fellow student scientists.This particular site discusses biodegradation, composting, bioremediation and wastewater treatment.

Green Chemistry Institute, http://www.chemistry.org/portal/a/c/s/1/acs display.html?DOC=greenchemistryinstitute\index.html

Make Your Own Biodegradable Packaging Peanuts, from Corn in the Classroom, http://www.kycorn.org/corneducation/cornclass/8peanut.pdf

***Recycling Styrofoam Peanuts,* http://www.ci.concord.ca.us/living/recycle/env-styrofoam-peanuts.htm** Use this as an opportunity to discuss opportunities for reusing peanuts if you must deal with them.

Why Reduce the Waste and Why Pick on Styrofoam!

Suggested activities and resources:

Part One.

Why does society love Styrofoam?

1. Provide teams of four each two uncooked eggs.
2. Provide packaging materials and other items. This can include newspaper, foam sheets, Styrofoam, cardboard, shredded packaging, starch packaging peanuts and Styrofoam packaging peanuts, yarn, plastic bubble wrap and items that could lead to creative thought.
3. Divide the class into small groups of 4 (engineering teams) and encourage them to devise a creative way to package their raw eggs. Explain that each team will drop their eggs from a ladder or high place. They will design one with some form of Styrofoam (sheet, peanuts, blocks, etc) and one without Styrofoam.
4. Record the results of this experiment and their observations on a chart and then discuss the successes and failures.
5. Lead the conversation into a discussion on why Styrofoam packaging is so eagerly used and preferred over other forms of packaging.

Some recommended resources include
http://www.epa.gov/epaoswer/osw/conserve/2003news/10-pack.htm
http://www.epa.nsw.gov.au/waste/packaging.htm

Part Two.

Some Reasons to Pick on Styrofoam

1. Using your favorite search engine, search on Styrofoam, birds, sealife
2. Read some of the articles and have students write news releases about the problems associated with pellets from plastic and from Styrofoam.
3. Discuss the biodegradability of Styrofoam in our landfills.
4. Discuss the benefits of using a packaging material that breaks down in the presence of sunlight (photodegradation).
5. Outline alternatives packaging materials that can be used for shipping.

Some recommended resources include
www.seashepherd.org/essats/ocean_realm_auto01.html
http://sacoast.uwc.ac.za/education/resources/envirofacts/plasticpollution3.htm

On the Web:

Environmental Inquiry: Authentic Scientific Research for High School Students.
http://ei.cornell.edu/biodeg/ Environmental Inquiry (EI) is a website and curriculum series developed at Cornell University to help students conduct environmental science research and participate in communities of fellow student scientists. This particular site discusses biodegradation, composting, bioremediation and wastewater treatment.

Green Chemistry Institute, http://www.chemistry.org/portal/a/c/s/1/acs display.html?
DOC=greenchemistryinstitute\index.html

Make Your Own Biodegradable Packaging Peanuts, from Corn in the Classroom,
http://www.kycorn.org/corneducation/cornclass/8peanut.pdf

Recycling Styrofoam Peanuts, **http://www.ci.concord.ca.us/living/recycle/env-styrofoam-peanuts.htm** Use this as an opportunity to discuss opportunities for reusing peanuts if you must deal with them.

Against the Current, The Plastic Sea by Captain Paul Watson (A Sea Shepherd Essay)
www.seashepherd.org/essats/ocean_realm_auto01.html This is a resources that discusses some of the problems associated with plastic pollutants and trash in the marine environment.

Save our Sea Life: Prevent Plastic Pollution
http://sacoast.uwc.ac.za/education/resources/envirofacts/plasticpollution3.htm Use this as a resource for discussing the pros and cons of plastic uses.

All Wrapped Up, http://www.cancentral.com/canc/nontext/lesson1.htm This activity helps to raise the awareness of packaging as natural or manufactured.

Cornstarch…Kinda Like Plastic, Used as Biodegradable Packaging
http://www.agclassroom.org/ut The Utah Agriculture in the Classroom program has offered a nice activity and information packet on Eco Foam packing peanuts.

Conigliaro Industries Total Recycling Services Product Line Catalog
http://www.conigliaro.com/ This is website is only one of many that offers environmentally friendly products for purchase. In this case, specifically polycorn (starch) packing peanuts.

Greening Schools and GLRPPR web sites at Illinois Waste Management and Research Center provides links to many other resources. www.greeningschools.org and www.glrppr.org