

**April/May 2017 Teacher's Guide**

**for**

***Recycling Plastic Bags***

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# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at <http://tinyurl.com/o37s9x2>.

# Student Questions

**Genetically Modified Foods: Are They Safe to Eat?**

* + 1. Why are plastic bags referred to as “urban tumbleweeds”?
    2. Why is it estimated that most of the plastic that has ever been made still exists somewhere?
    3. Give two reasons why plastic bag litter is harmful to wild animals.
    4. What is a gyre and what can it trap?
    5. Describe the type of substance that makes up plastics.
    6. What are the raw materials used to produce plastics? Where are they located?
    7. What type of plastic is used for most plastic bags? How is it formed?
    8. When an ethane molecule is subjected to a high temperature and a catalyst, which bonds are broken to form a molecule of ethylene?
    9. Why is HDPE called high density polyethylene?
    10. Why is it costly to recycle plastic bags?
    11. Why are small plastic pellets an important material in the recycling process?
    12. How is composite lumber manufactured?

# Answers to Student Questions

**(taken from the article)**

**Recycling Plastic Bags**

1. **Why are plastic bags referred to as “urban tumbleweeds”?**

*Plastic bags are referred to as “urban tumbleweeds” because they are so light that they become airborne and can be blown everywhere.*

1. **Why is it estimated that most of the plastic that has ever been made still exists somewhere?**

*Most of the plastic that has ever been made still exists somewhere because it will not break down for 500 to 1000 years.*

1. **Give two reasons why plastic bag litter is harmful to wild animals.**
2. *Wild animals can become tangled in plastic bags.*
3. *Wild animals can confuse plastic with food and eat it. The plastic can then block their digestive tracts.*
4. **What is a gyre and what can it trap?**

*A gyre is a circular ocean current that can trap debris into its center (creating an enormous floating island of trash).*

1. **Describe the type of substance that makes up plastics.**

*The type of substance that makes up plastics is a polymer that consists of single monomer units that link together in long chains.*

1. **What are the raw materials used to produce plastics? Where are they located?**

*The raw materials used to produce plastics are fossil fuels (crude oil, coal and natural gas). They are located deep under the earth’s surface.*

1. **What type of plastic is used for most plastic bags? How is it formed?**

*Most plastic bags are made of high-density polyethylene (HDPE). It is formed by linking together thousands of ethylene molecules.*

1. **When an ethane molecule is subjected to a high temperature and a catalyst, which bonds are broken to form a molecule of ethylene?**

*When an ethane molecule is subjected to a high temperature and a catalyst, its carbon-carbon bond and two carbon-hydrogen bonds are broken to form a molecule of ethylene.*

1. **Why is HDPE called high density polyethylene?**

*HDPE is called high density polyethylene because it is formed from ethylene molecules linked together in long straight chains that line up parallel to one another and pack closely together forming a polymer of high density. (Some students might note that this polymer is composed of many ethylene monomers, thus the name polyethylene.)*

1. **Why is it costly to recycle plastic bags?**

*It is costly to recycle plastic bags because they tend to get caught in the sorting machinery and must be collected and recycled separately.*

1. **Why are small plastic pellets an important material in the recycling process?**

*Small plastic pellets are an important material in the recycling process because they can be made into new plastic bags.*

1. **How is composite lumber manufactured?**

*Composite lumber is manufactured from a mixture of sawdust and recycled plastic that is heated and shaped into boards.*

# Anticipation Guide

Anticipation guides help to engage students by activating prior knowledge and stimulating students’ interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

**Directions: *Before reading***, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Scientists estimate that plastic will break down in about 100 years. |
|  |  | 1. The Great Pacific Garbage Patch is found in the southern Pacific Ocean. |
|  |  | 1. Plastics are made from fossil fuels. |
|  |  | 1. Ethane, containing only single bonds, can be converted to ethylene, which contains a C=C double bond, at high heat. |
|  |  | 1. High-density polyethylene (HDPE) is a sturdy plastic used for plastic bags. |
|  |  | 1. Plastic bags can be mixed in with other plastics for recycling. |
|  |  | 1. Bread bags and food storage bags can be recycled with plastic bags. |
|  |  | 1. Plastic bags can be made into new plastic bags and composite lumber. |
|  |  | 1. Recycled plastic bags are pelletized to create new materials. |
|  |  | 1. The amount of recycled plastic bags decreased between 2005 and 2015. |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Students’ understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

***Teaching Strategies:***

* Links to **Common Core Standards for Reading**:
  + ELA-Literacy.RST.9-10.1:Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  + ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
  + ELA-Literacy.RST.11-12.1:Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  + ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
  + ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  + ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.
* **Vocabulary** and **concepts** that are reinforced in this issue:
  + Chemical reactions
  + Macro- and micronutrients
  + Personal and community health
  + Proteins
  + Structural formulas
  + Biochemistry
  + Consumer choices
  + Recycling
* Some of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them in their personal lives.
* Consider asking students to read “Open for Discussion” on page 4 to extend the information in “Growing Green on the Red Planet” on pages 5-7.
* The infographic on page 19 provides more information to support the article “Espresso, Café Latte, Cappuccino…A Complex Brew” on pages 10-12.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles.
* You might also ask them how information in the articles might affect their health and/or consumer choices. Also ask them if they have questions about some of the issues discussed in the articles.
* The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

**Directions**: As you read the article, complete the graphic organizer below to describe plastic bag recycling.

|  |  |  |
| --- | --- | --- |
| 3 | **New things you learned about plastic bags** |  |
| 2 | **Ways a knowledge of chemistry can help you do a better job of recycling plastic bags** |  |
| 1 | **Question you have about recycling plastic bags** |  |
| Contact! | **What would you like to tell others about recycling plastic bags** |  |

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Intermolecular** **forces (IMFs)**—During the study of IMFs, HDPE polymers in the article provide the opportunity to discuss how structure and properties can be explained by the strong IMFs that occur when the long straight chains pack closely together.
2. **Covalent bonding**—Information in this article can be used to show the strength of covalent bonds. The experimental conditions (high temperature and a catalyst) can be used to emphasize the energy required to break the carbon-carbon and two carbon-hydrogen covalent bonds in ethane.
3. **Density**—The density of HDPE can be compared to that of LDPE, along with a discussion to discover/explain the reason for the density difference.
4. **Polymerization**—Polymerization can be introduced during the study of covalent bonding. The polymerization of HDPE discussed in the DeAntonis article is an example of C=C bonds in monomers breaking to form reactive C–C bonds that allow those monomers to link, forming polymers.
5. **Unsaturated compounds**—In the study of polymers, multiple bonds in unsaturated compounds must be broken for monomer additions (polymerization). Typically, only unsaturated monomers can form polymers through addition polymerization.
6. **Recycling**—During environmental studies, include the rationale for recycling (beyond litter) to protect our planet by reducing global warming, the use of fossil fuels and harm to wildlife.
7. **Catalysis**—When studying catalysis, note that a catalyst is required to break the strong covalent bonds shown in the ethane to ethylene conversion in the article.

# Possible Student Misconceptions

**(to aid teacher in addressing misconceptions)**

1. **“I tell my parents to always buy plastic containers with numbers in triangles on them, that way I know that they will be recycled into new containers.”** *The numbers only identify the general type of resin used to make the plastic, they do not indicate whether the plastic can be recycled into new plastic containers. Numbers in the triangles are Resin Identification Coding System (RIC) that manufacturers use to show the type of resin used in making a product. They are not meant to tell the customer whether or not the plastic can be recycled. Yet since the RIC identifies the resin, the number can be used by recyclers to determine if their facility is capable of processing the item.*
2. **“When we separate our trash, we always put plastics in the “blue” bin so they will never go to a landfill.”** *Most recyclable plastics eventually end up in a landfill. Many plastics that are recyclable are used to make new secondary items such as composite lumber, parking lot bumpers and plastic park benches. These items are not recyclable, so eventually this plastic ends up in a landfill.*
3. **“We do our own recycling by using grocery bags to reline our kitchen trash can and to pick up after our dogs.”** *While this helps by saving bags, these bags of garbage go straight to the landfill. This is called “reusing” your grocery bags, a process that does conserve fossil fuels. But once the bag contains garbage, it will have to go straight to the land fill anyway, so you’ve only prolonged its eventual disposal. Only clean, dry grocery bags can be recycled.*
4. **“I’ve heard that brown colored grocery bags are not as strong as white ones.”** *When a bag is brown, it usually means that it was made from partially recycled polyethylene. These bags must pass the same quality (including strength) tests as bags made from entirely new (virgin) polyethylene.*
5. **“Recycling at my home is pretty easy. We just dump everything into the big blue bin, the truck collects it and takes to a place where they pull out the paper and melt down the rest into plastic again.”** *Recycling is not quite that simple. Aside from paper, the blue bins contain other recycled products such as glass and metal objects that must be removed before recycling plastics. Also, different plastic resins require resin-specific recycling procedures, so this requires additional sorting. Thin HDPE films are best collected separately in special drop-off bins at supermarkets. Once materials have been sorted, plastic pellets of different resins are produced. New (recycled) products are made from these pellets.*
6. **“I’ve seen the Bag-to-Bag bins at our local supermarket. I assume that this is the best place to put *all* plastic bags.”** *All plastic bags should not be placed in these recycling bins. The Bag-2-Bag program is specialized to process only empty, clean, dry single-use PE grocery bags and certain PE thin films (resin numbers two and four), like those covering rolls of paper towels and newspapers. While some frozen food and salad mix bags may be composed primarily of PE, they often contain additional polymers or layers of materials to extend the shelf life of the products. These additives can act as contaminants that ruin an entire batch of resin. So, unless this type of bag is marked with a “how2recycle” label as shown in the De Antonis article, they should not be placed in the store Bag-2-Bag Novolex bin.*
7. **“My family usually goes on at least one Pacific cruise each year. Will our ship have problems if it runs into the Great Pacific Garbage Patch of floating plastic?”** *Encountering the Garbage Patch will not be a problem even for a small sail boat. This marine current-driven collection of plastic is composed of tiny bits of plastic mixed with water, heavy materials quickly sink to the bottom of the ocean.*
8. **“Doesn’t most of the resin used for grocery bags come from refinery waste?”** *Except for some recycled resin, most of the grocery bag resin comes from the same natural gas that we use to heat our homes and cook our food.*

# Anticipating Student Questions

**(answers to questions students might ask in class)**

1. **“If I put my used water bottle in the recycler, will it eventually become a new bottle?”** *Probably not. This is almost never the case, because much of the recycled plastic is used in the manufacture of composites such as parking lot bumpers, license plate holders and lumber. These products have longer lives than water bottles, but, as mixtures of various plastics, they are not recyclable.*
2. **“What do the big and little “n”s mean in the chemical equation that forms polyethylene: *n C*2H4 🡪 (C2H4)n?**

*The “n”s are chemistry (and mathematical) shortcuts that represent any number. The first “n” represents the number of ethene molecules (monomers) that link together to form one polyethylene molecule (polymer) that is composed of the subscript “n” monomer units.*

*For example: Since n is any number between 50,000 and 100,000 monomer units, we could say that if the first “n” = 70,000 C2H4 ethene monomers; then subscript “n” shows that the one product polyethylene molecule is one long chain of 70,000 ethene monomers covalently bonded together.*

1. **“If the Great Pacific Garbage Patch of plastic is made up of very tiny beads of plastic, why are marine scientists worried?”** *Sea birds and fish are attracted to these tiny pieces of plastic and mistake them for food. When an animal’s stomach is**full of plastic, it loses its appetite and eventually starves to death. Actually, it’s been shown that marine animals prefer plastic to their normal food sources (bad for them).*
2. **“I read that fossil fuels are ‘Buried Sunshine’. What does this mean?”** *Fossil fuels are sometimes considered buried sunshine because long ago their energy was captured from the sun during photosynthesis by prehistoric plants and the animals that ate them. These plants and animals died and were buried long ago. Over millions of years, heat and pressure converted the fossilized material into fossil fuels.*
3. **“Where does old plastic made from petroleum go long after it is discarded?”** *Actually most of the petroleum plastic ever made is still in our environment. After it is discarded, about 6.5% of the plastic is recycled; 7.7% is burned in waste management facilities to produce energy; and the rest ends up in landfills, waterways and oceans where most of it very slowly breaks down into microscopic pieces that are still plastic.*
4. **“Is it more expensive to make a plastic bag from recycled plastic than to make one from virgin plastic?”** *No, it costs about the same or slightly less to make a plastic shopping bag from recycled content. The savings is actually in the reduction of fossil fuel use.*
5. **“Why are new plastic food storage containers always white?”** *The virgin plastics industry is opposed to adding recycled materials (that color resin pellets) to their container resins. So, by U.S. law, these containers are made entirely from white virgin resins.*
6. **“Why do fish think that plastic is food?”** *This is an excellent question, one that scientists are currently studying. Researchers think that plastic must emit a chemical or physical cue that triggers a feeding response in fish. Once identified, perhaps it can be eliminated by reformulating plastic resins.*

# Activities

**Labs and demos**

1. **Polymer Demonstrations:** The Elmhurst College Web site provides instructions and safety precautions for making several polymers as labs or short demonstrations: Superball, nylon rope, polyurethane foil, slime, Gaviscon snakes, ghost busters and siphon polymer. (<http://chemistry.elmhurst.edu/demos/index.html>)
2. **Recycling Lab:** In this laboratory activity, students investigate ways to separate and identify a mixture of plastics by their physical characteristics, such as density. Instructions, list of materials and suggested data tables are included. (<http://www.juliantrubin.com/encyclopedia/environment/plasticseparation.html>)
3. **Physical Properties of polymers lab:** This is a suggested 40-minute laboratory exercise for students to identify polymer resins by comparing the flexibility and density of various polymer samples. The density is estimated by whether samples “sink or float” in various concentrations of calcium chloride solution and ethanol. The materials include complete teacher directions plus student questions with suggested answers. (<http://matse1.matse.illinois.edu/polymers/h.html>)
4. **Short introductory activity using grocery bags:** Cut grocery bags into small squares. Avoid anything that will indicate the original bag orientation by cutting off lettering, handles, etc. Give each student one piece, tell them to pull the plastic each way. Which direction was the top of the bag? Why? Students will find that there is noticeably more stretching in one direction. Maximum stretching must be the horizontal direction to ensure proper packing of grocery items so that heavy items do not quickly fall through the bottom of the bag.
5. **Two student labs from the Polymer Ambassador’s Program investigate the properties of HDPE and LDPE bags:**
6. Students test and compare properties of food packaging bags by stretching and inserting a pencil into an inflated PE bag. This activity is designed for middle school students, but is can easily be adapted for use in the high school classroom. (<http://polymerambassadors.org/pdf/polybags.pdf>)
7. An initial discussion of polyethylene production precedes three lab activities similar to those above, but the relative density of several polymer types is also investigated. These activities, designed for middle through high school are presented in a more formal format that those in a., above. (<http://polymerambassadors.org/pdf/polyethylene.pdf>)
8. **Styrofoam™ and acetone demonstration (2:00–4:00):** Styrene molecules polymerize to form polystyrene. Expansion of the polymer by steam and butane or propane gas produces the Styrofoam**™** used for drinking cups, supermarket meat trays and packing pellets. Acetone quickly softens and deflates Styrofoam**™** and shrinks it into a small ball of the original polymer. This demonstration never fails to catch student attention. Although the activity described at this URL suggests that it can be done at home, due to the flammability of acetone, it would be safer done as a classroom demonstration. (<http://mindtrekkers.mtu.edu/lessons/96.pdf>) Note: See a video demonstration in the “Media” section of this Teacher’s Guide.

**Media**

**Videos**

1. **production of polyethylene bags—Two YouTube videos**

a. “Polythene Production” (4:08) was produced for the Royal Society of Chemistry by British Petroleum (BP). Illustrations show how ethene is used to produce polyethylene. Then, the viewer is taken through the step-by-step process of polyethylene production at a working factory. (<https://www.youtube.com/watch?v=U6d_F1jcKzI>)

b. “How it’s made: Plastic Bags” (4:29) begins with polyethylene beads being melted, then pressed into sheets. Finally it shows rolls of polyethylene film being dyed and cut into plastic bags. (<https://www.youtube.com/watch?v=aQ4O8MMDuH8>)

1. **“Single-stream Recycling System” at work:** This YouTube video (6:16) shows how 65 tons/hour of mixed recyclables are separated. The process is very similar to the one described in the “Single-stream recycler” section of this Teacher’s Guide. (<https://www.youtube.com/watch?v=X02CVm08s5A>)
2. **Lesson, “Crash Course in Chemistry—Polymers”:** Instead of the usual blackboard style Khan video, this Khan AcademyYouTube video (9:13) is more interesting. The moderator asks, “Did you know that polymers saved the lives of elephants?” Beginning with a bit of polymer history, the film proceeds with ball and stick models to show basic polymers and how they are formed by addition and condensation reactions. If students are familiar with basic organic functional groups, this presentation could serve as an end of the section review on organic and biochemistry. (<https://www.khanacademy.org/partner-content/crash-course1/crash-course-chemistry/v/chem45-polymers>)
3. **Lesson, “Polymerization of Alkenes with Acid”:** This is a basic blackboard-drawing Khan video (YouTube, 12:03) showing how the pi electrons transfer when the C=C double bonds break and addition polymerization occurs. (<https://www.khanacademy.org/science/organic-chemistry/alkenes-alkynes/alkene-reactions/v/polymerization-of-alkenes-with-acid>)
4. **“Materials Recovery Facility”:** This short video (1:48) leads the viewer through an animation of the single-stream recycling process at a materials recovery facility. (<https://vimeo.com/51939288>)
5. **“Plasticbaglaws.org—Part 1”:** In this video (3:21), Jennie Romer, an attorney who formed plasticbaglaws.org, speaks of the concerns expressed in the De Antonis article. To promote zero waste goals, she has produced several videos on the subject. The right margin of this link lists other videos. (<http://plasticbaglaws.org/short-youtube-videos-by-jennie-romer-explaining-the-intricacies-of-plastic-bag-laws/>)
6. **YouTube video (2:49), Styrofoam™ and acetone demonstration:** This video shows the reaction between Styrofoam**™** (polystyrene) and acetone. Complete demonstration details are given in the “Labs and Demos” section of this Teacher’s Guide. (<https://www.youtube.com/watch?v=Pt-c6beDoPU>)

**Lessons and lesson plans**

1. **Three-day plastics analysis lesson plan:** Complete instructions for this lesson include: prior week long student collection of plastic samples by resin code number, Day 1-Exploration, Day 2-Chemical and Physical Properties wet lab, and Day 3-Application. Instructions are clear and comprehensive for both students and the teacher. Day 2 is one of the few lab activities that include testing the chemical as well as the physical properties of resins. (<http://www2.monroecounty.gov/files/DES/education/plastics_analysis_lab_lesson.pdf>)
2. **“The Plastics Test”, a Teach Engineering activity:** This lesson, from the Polytechnic Institute of New York University, is designed for Grade 4 students. However the engineering aspects can be used in planning high school lessons that meet engineering standards. The goal is for students to act like engineers conducting tests and comparing different plastics. A cost-benefit analysis helps students consider which plastic is best for a particular application based on both cost and physical properties. (<https://www.teachengineering.org/activities/view/nyu_plastic_activity1>)
3. **“Simple Tensile Testing of Polymeric Films and Sheeting” lab (3+ hours):** This is a *Terrific Science* activity on common industrial testing. There are three hour-long sessions plus analysis time. Tensile and elongation tests are done on plastic film samples. Detailed teacher instructions contain sample results.(<http://www.terrificscience.org/lessonpdfs/PolymerLab06.pdf>)
4. **“Start Recycling Today”, a lesson for grades 6-12:** Although designed as a 45 minute lesson, there are many suggestions for longer projects. (<http://www.recommunity.com/wp-content/themes/recommunity/pdf/ReLessonPlan_6-12.pdf>)
5. **5E Instructional Model Lesson, “The Right Polymer for the Job” includes computer simulations and Process Oriented Guided Inquiry Learning (POGIL) activity:** This high school lesson is from the 2016 American Association of Chemistry Teachers (AACT)-Ford Content Writing Team. The focus is on IMFs as they pertain to polymers used in automobiles. (<https://teach-chemistry.s3.amazonaws.com/2016/10/28/17/01/51/e1e748f0-a3dd-40da-b103-f0cee9606ee9/lesson-rightpolymerforjob.pdf>)

**Projects and extension activities**

1. **A debate—Plastic versus paper bags:** Supermarket clerks ask customers, “Plastic or Paper?” How do you decide? There are many pros and cons regarding energy and environmental costs to be considered. This will provide rich material for a classroom debate. These two articles contain some basic information. “Paper Bags or Plastic Bags? Everything You Need to Know” (<http://www.treehugger.com/culture/paper-bags-or-plastic-bags-everything-you-need-to-know.html>) “About Plastic Grocery Bags─ Recycling and Environmental issues” (<https://www.plastech.biz/forum-plastech/About-Plastic-Grocery-Bags-7546>) If you live in a state that prohibits the use of single-use HDPE grocery bags, consider including reusable bags in the debate. (<https://www.theatlantic.com/technology/archive/2016/09/to-tote-or-note-to-tote/498557/>)
2. **Experimental design/research project to compare single- and multi-stream recycling processes:** This is an experimental design project where students are given the charge to compare two major forms of recycling (single and multi-stream). First questions will be crafted to focus data gathering; next the Internet will be used to answer their questions; and finally results will be discussed and published. One example: To prepare for a published study, “A Comparison of Single and Multi-Stream Recycling Systems in Ontario, Canada” the following questions were crafted:

(a) Are material management costs for municipalities who implement single-stream collection less than those that implement multi stream collection?

(b) Are recycling rates for single-stream municipalities higher than municipalities with multi stream collection?

(c) Do municipalities with multi-stream collection realize higher revenues from the sale of recyclable material?

Once testable (via local systems or Internet data) questions have been identified, the research will have a definite path and data can be collected and analyzed. A presentation of the data comparing common recycling systems can be designed.

(<http://www.mdpi.com/2079-9276/4/2/384>)

# References

**(non-Web-based information sources)**

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles   
published from the magazine’s inception in October 1983 through April 2013; all available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen).**

**Selected articles and the complete set of   
Teacher’s Guides for all issues from the past three   
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**



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This article shows how biodegradable bags made of polyethylene (non-biodegradable) with inserted starch molecules (biodegradable), can be broken down into small molecules by bacteria that digest the starch. Degrading experiments that can be done in or outside class are included. (Downey, C. Biodegradable Bags. *ChemMatters*, 1991, *9* (3), pp 4–6)

The Classroom Guide for the October 1991 *ChemMatters* article above, “Biodegradable bags”, compares the volumes and weight of paper and plastic grocery bags. While the information about the difficulty of sorting and recycling different plastics is dated, details about the characteristic properties of various resins is relevant today.

Addition and condensation polymerization are discussed with structural diagrams showing two monosaccharides forming a disaccharide by condensation polymerization. The production of food wrappers includes PE sandwich bags and edible food wraps. (Mahoney, M. Edible Wraps. *ChemMatters*, 2003, *21* (2), pp 14–16)

This article discusses environmental concerns involved in the production of petroleum plastics, including the release of carbon dioxide and its contribution to global warming. Information about the production of bioplastics and their composting is accompanied by a student activity with instructions on how to produce a bioplastic from cornstarch. (Washam, C. Plastics Go Green. *ChemMatters*, 2010, *28* (2), pp 10–12)

The focus of this article is the recycling of petroleum plastics by physical and chemical processes. A detail of the chemistry involved includes relevant chemical equations. The industrial process of recycling and inherent problems of handling mixed resins, plus the importance of the recycling industry in India are discussed. (Husband, T. Recycling to Survive. *ChemMatters*, 2011, *29* (1), pp 5–7)

The Teacher’s Guide for the February 2011 *ChemMatters* article, “Recycling to Survive”, provides information on recycling of various plastic resins and distinguishes between thermoplastics and thermosets. A table comparing the properties of these two basic types of plastics is included.

This article presents natural (biological) polymerization, while discussing diabetes and the development of an artificial kidney. Structural formulas for DNA show the repeating units. Since many students know or are related to a diabetic, this article will introduce the biochemistry of polymers involved in both the illness and possible treatments. (Karabin, S. Changing the Course of Diabetes. *ChemMatters*, 2011, *29* (4), pp 12–13)

The Teacher’s Guide for the December 2011 *ChemMatters* article, “Changing the course of Diabetes”, presents a wealth of information about the polymerization process. Structural diagrams for monomers and for polymerization reactions are accompanied by explanations. Material includes natural organic polymers as well as synthetic polymers.

# Web Sites for Additional Information

**(Web-based information sources)**

**History of plastic grocery bags**

This paper, “Polyethylene: Discovery and Growth”, details the laboratory work that led to the discovery of polyethylene and eventually to low and high density polyethylenes. (<https://www.researchgate.net/publication/228813221_Polyethylene_discovery_and_growth>)

In contrast to the scientific paper above, the British Royal Society of Chemistry (RSC) has published “Plastic Fantastic”, the story of the discovery of polyethylene plus the later efforts to repeat the experiment. This true tale includes interesting experimental details. RSC gives permission to copy and share with your students. (<http://www.rsc.org/images/InfoChem_Jan2005_Plastic_fantastic_tcm18-217681.pdf>)

**History of polymer discovery**

Leo Hendrick Baekeland (1863–1944) developed the first durable plastic (Bakelite) from phenol and formaldehyde. His invention is said to have begun the “Age of Polymers” for the world. His biography and work on the first synthetic thermoset plastic is well described in this article. (Note: Once molded, thermoset plastics keep their shape during heating or exposure to many solvents.) (<https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/bakelite.html>)

Section 1.1: “Historical Overview on the Origin of Polymer Science and Synthesis of Polyamidesand Polyesters” of the book *Biodegradable Polyesters: Synthesis, Properties, Applications* by Chi Zhang describes the opposition to crediting Staudinger with the discovery of high molecular weight compounds. The book details Zhang’s research and the scientific evidence that he used to verify the existence of polymers. (<https://application.wiley-vch.de/books/sample/3527330860_c01.pdf>)

**Chemistry of polyethylene**

This site contains a fairly complete table of the physical and chemical properties of LDPE and HDPE. The values and descriptions are in two side-by-side columns for easy comparison. (<http://www.ausetute.com.au/polythen.html>)

In this article, the various polyethylenes are listed, with a discussion about the difference between them. The material is easy to read and use as a quick guide.

(<http://www.usplastic.com/knowledgebase/article.aspx?contentkey=508>)

**Chemistry of polyethylene production**

Braskem, a major Brazilian ethanol producer, is becoming a leader in the production of bio-based ethene from sugar cane, for use in the production of polyethylene. The ethanol is dehydrated and heated with either concentrated sulfuric acid or a catalyst to crack the material and yield ethene molecules. This article in *Ethanol Producer* magazine discusses other Brazilian projects and provides their own market analysis of the Braskem project. (<http://www.ethanolproducer.com/articles/8617/feeding-the-chemical-market>)

Karl Ziegler was determined to make HDPE at atmospheric pressure. He succeeded, but questions still remain about the mechanism of his catalytic conversion, such as: “Where is the active site located?” This article contains clear diagrams along with suggested explanations. (<http://wwwcourses.sens.buffalo.edu/ce435/Polyethylene/CE435Kevin.htm>)

New metallocene/methylaluminoxane (MAO) catalysts must be very specific in structure to produce polymers with the correct stereo characteristics to work well with co-polymers in the production of long-lasting materials. This paper, “The Influence of Ziegler-Natta and Metallocene Catalysts on Polyolefin Structure, Properties, and Processing Ability” published in the journal *Materials* discusses the history of catalysis in the polymer industry, proposed catalytic mechanisms, and world use. There is open-access to the entire paper. (<http://repository.um.edu.my/93175/1/materials-07-05069.pdf>)

**Polymer chemistry, by resin numbers**

The American Chemistry Council (ACC) has prepared an excellent, comprehensive table by resin numbers, “Plastic Packaging Resins”. This table includes the following information for each number: Descriptions, Properties, Product Applications and Products made with Recycled Content. This might provide an excellent reference for student projects. (<https://plastics.americanchemistry.com/Plastic-Resin-Codes-PDF/>)

In addition to some technical information about polymerization, this site has a nice table of some “Common Addition Polymers” that includes structural formulas for the monomers, properties and uses. This chart contains many polymers not listed on the RIC 1-6 codes. (<https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/polymers.htm>)

**Collection and recycling PE bags**

This *Smithsonian* magazine article discusses the problems that occur when PE films and garbage bags enter single-stream recycling processes. They clog recycling machinery, contaminate bales of recyclables and are wind driven from landfills to waterways. (<http://www.smithsonianmag.com/science-nature/recycling-you-may-be-doing-it-wrong-180951192/>)

In January 2016 the “2014 National Postconsumer Plastic Bag & Film Recycling Report” was prepared for the ACC. Postconsumer refers to materials that have undergone their intended use and have been discarded or sent for recycling. The report includes nice graphs of the amount and types of thin film recovered and recommendations for increasing the recovery of recyclable thin PE film. **(**<https://plastics.americanchemistry.com/Education-Resources/Publications/2014-National-Postconsumer-Plastic-Bag-Film-Recycling-Report.pdf>)

The single-stream collection process for Boulder County, Colorado is discussed on this Web site. To encourage people to recycle, they stress the ease of collection when following the county procedures. This includes a description of the items that are recyclable by the process used. They also have a list of frequently asked questions (FAQs) about the process. (<http://www.ecocycle.org/recycle-compost-reuse>)

A detailed presentation of the U.S. collaborations and goals of the WRAP (Waste and Resources Action Programme) is presented here. This site includes descriptions of thin film materials that can be placed in store drop-off bins. The benefits of this sustainable program include: decrease in disposal rates, reduction of environmental impacts and methods to increase stakeholder capacity. (<https://www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/US-EPA-and-ACC-Partner-to-Promote-Sustainable-Materials-Management.html>)

This site describes the WRAP program for recycling thin film. A map of U.S. WRAP sites is shown. (<http://www.plasticfilmrecycling.org/wrap/wrap-1.html>)

The “Sustainable Businesses” site discusses the benefits and drawbacks of dual-stream recycling. In addition, the article provides a comparison of the single and dual-stream processes. (<https://www.thebalance.com/dual-stream-recycling-2877730>)

The Novolex Web site discusses how they maintain quality and make a profit by collecting at grocery stores and selling recycled bags. They also work on educating the public about the importance of the specialized collection/recycle program. (<http://novolex.com/news-updates/thats-a-wrap>)

**Environmental concerns**

This site discusses concerns about toxic chemicals that can be absorbed by plastic ocean debris, and their effect on human health. At the end of the article, seven references for more information are given, with easy access by a “click” on the name of the topic. (<http://serc.carleton.edu/NAGTWorkshops/health/case_studies/plastics.html>)

An article published in the journal *Science* describes studies on baby perch that demonstrate a preference for a diet of plastic over natural plankton. Airborne microplastic fibers may also contribute to air pollution and respiratory diseases in humans. This site contains details of the study: (<http://www.independent.co.uk/news/science/fish-microplastic-microbeads-perch-pike-food-marine-pollution-a7063161.html>)

**Possible solutions**

**Biodegradable bags**

As reported in *Smithsonian* Magazine, Blair, Nebraska’s Nature Works is the largest lactic acid production plant in the world. In 2008 Wal-Mart decided to counter criticism about the company’s environmental irresponsibility. They began “moving toward zero waste” by using PLA containers. (<http://www.smithsonianmag.com/science-nature/corn-plastic-to-the-rescue-126404720/>)

**Photodegradable/oxodegradable bags**

The city of Portland, Oregon requested a study by the Pacific Northwest Pollution Prevention Resource Center of the benefits and drawbacks of oxo-degradable bags. They provided thorough answers to questions from the city. This, for example, led to correction of manufacturers’ promotions that advertise an 18- to 24-month decomposition time for the bags. The estimation of a very short decomposition time period relied on a microbe-rich, hot and arid environment. These conditions are not present in rainy Portland. (<http://pprc.org/index.php/2012/p2-rapid/oxo-degradable-bags/>)

A paper published in the July 2016 issue of *Materials Research* discusses work and cites research data on the “Effect of Metal Acetylacetonates on the Photooxidative Destruction of High Density Polyethylene” used as photodestructing additives to HDPE resins. Scientists used the pro-oxidants cobalt(III) acetylacetonate and manganese(II) acetylacetonate. The acetonate anion, CH3COCHCOCH− contains the oxygen required for aerobic biodegradation following exposure to UV radiation. (<http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-14392016000400901>)

**Reusable bags**

There have been several news reports of human poisoning from bacteria, mold and viruses growing in reusable grocery bags. This news article describes a Noro virus outbreak among middle school soccer players in the state of Washington that was linked to a dirty reusable grocery bag. (<http://www.theblaze.com/news/2012/05/09/scientists-link-stomach-flu-outbreak-to-reusable-shopping-bag/>)

**Bag bans**

This site provides a complete list of worldwide bans of HDPE single-use grocery bags. The list can be accessed by country or state. For example if you “click” on U.S. a list will show the legislation for each municipality or territory with the effective date and details of implementation. The list also includes all foreign countries that have issued bans. (<https://en.wikipedia.org/wiki/Phase-out_of_lightweight_plastic_bags#United_States>)

This site contains a U.S. map which allows you to just plug in your state or zip code and grocery bag regulations will be shown. (<http://novolex.com/bag-legislation>)

# General Web References

**(Web information not solely related to article topic)**

The “Polymer Properties Data Base” is a fairly extensive information trove about polymers and their properties. If you want to know the basics about polymers, this should give it to you. The site is arranged according to polymer chemistry and polymer physics. The data is alphabetized by polymer topics and key words. For example, a click on “A” reaches a list of choices that include adhesion forces, apparent viscosity and the Arrhenius Equation. The database was composed as an introduction (less detailed than textbooks) to the physical structure and properties of polymers. It is easy to use and provides an excellent source of reference for polymer topics. ([http://polymerdatabase.com/polymer%20physics/pp%20index.html](https://urldefense.proofpoint.com/v2/url?u=http-3A__polymerdatabase.com_polymer-2520physics_pp-2520index.html&d=DwMFaQ&c=clK7kQUTWtAVEOVIgvi0NU5BOUHhpN0H8p7CSfnc_gI&r=J66GWfxfhh2EUCH5xnkQjA&m=x1_JoHokj0kica-kL_lbprUJYEBBeQFpOSLWeuXi04U&s=PG9-hoYnw8RiEzOcBUdRCSemgY6nM8ad501FhdAvHko&e=))