NATIONAL PEER REVIEWED

GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation

NSF Center for Sustainable Polymers

FRONT MATTER

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4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

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Front Matter

CURRICULUM TARGET AUDIENCE

Youth in grades 9 to 12 (14- to 18-year-old)

DEVELOPED BY

A partnership between the NSF Center for Sustainable Polymers, University of Minnesota Extension, University of California Agriculture and Natural Resources, Cornell University Cooperative Extension. This work is supported by the National Science Foundation (NSF) under the NSF Center for Sustainable Polymers CHE-1901635.

PROJECT CO-DIRECTORS

- Dr. Jennifer McCambridge, Director of Education, Outreach, and Diversity, NSF Center for Sustainable Polymers
- Anne Stevenson, Extension Educator and Extension Professor, Extension Center for Youth Development – University of Minnesota

AUTHORS

NSF Center for Sustainable Polymers:

- Dr. Jennifer McCambridge

University of California, Division of Agriculture and Natural Resources:

- Emily K. Manroe, Dr. Cheryl Meehan, Dr. Martin Smith, and Dr. Steven Worker

CONTRIBUTORS

University of Minnesota, Extension Center for Youth Development:

- Amie Mondl and Anne Stevenson

Cornell University:

- Alexa Maille, Charles Malone

Layout, Graphics, and Design:

- John Beumer, Senior Graphic Designer, NSF Center for Sustainable Polymers

REVIEWERS

- University of California Cooperative Extension: Nicole Marshall-Wheeler, Jacki Zediker
- University of Minnesota Extension: Michael Compton, Margo Bowerman
- Cornell University Cooperative Extension: Sabrina DeRue, Jessica Reid, Evan Lowenstein, Susan Coyle, Kristina Gabalski
- Pius XI High School (Milwaukee, WI): Patty Hupfer Riedel

INDIVIDUAL MODULE CITATIONS

- Worker, S., & McCambridge, J. (2022). Front Matter. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/
- Manroe, E., Meehan, C., & Smith, M. (2022). Trends in Production and Disposal of Aluminum, Glass, Paper, and Plastic Across Time. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/
- Manroe, E., Meehan, C., & Smith, M. (2022). Comparing the Properties of Aluminum, Glass, Paper, and Plastic. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/
- Manroe, E., Meehan, C., & Smith, M. (2022). Life Cycles of Products We Use and Their Environmental Impacts. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/
- McCambridge, J. (2022). All About Polymers. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/
- Worker, S. (2022). The Plastic Life Cycle. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/

- McCambridge, J. (2022). The Plastics Future: Bioplastics. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/
- Worker, S. (2022). Emerging Solutions to the Plastic Crisis. *Sustainable polymers: Confronting the Plastic Crisis. A 4-H STEM curriculum for Grades 9-12*. NSF Center for Sustainable Polymers. University of Minnesota. https://www.4hpolymers.org/

LEARNING OBJECTIVES SUMMARY

Modules are based around a 'driving question', promoting inquiry into an issue related to plastics. By experiencing all seven modules, youth will explore historical trends and why plastic has become so prevalent, learn about the life cycle of materials and plastics, and start to think about how to mitigate negative environmental impacts of plastic waste. The modules are intended to help improve young people's knowledge, skills, and awareness such that they can facilitate lessons to younger youth (using the K-2, 3-5, or 6-8 curricula) or undertake their own service project.

MODULE SUMMARIES

1. **Module 1: Trends in Production and Disposal of Aluminum, Glass, Paper, and Plastic Across Time.** *What are the historical trends for the production and disposal of plastics, glass, aluminum and paper products?* Youth will analyze historical (1960s to 2018 U.S.) production and disposal data tables for plastic, glass, aluminum, and paper. By graphing the data, youth raise their awareness of trends in production and disposal of the four materials comparatively. Youth will communicate evidence about an issue informed and inspired by the data to a larger public audience.

2. **Module 2: Comparing the Properties of Aluminum, Glass, Paper, and Plastic.** *Why are specific materials selected for specific use cases? Why have plastics become one of the most utilized materials in the world?* Youth make comparisons and draw inferences about the physical characteristics of plastic, glass, aluminum, and paper through observation of household items. Youth create an inventory and reflect upon the materials present in the items they interact with daily in school and personal contexts. Youth begin to understand that the applications of different materials depend on the advantages and limitations of each material's properties, characteristics, and abilities.

3. **Module 3: Life Cycles of Products We Use and their Environmental Impacts.** *What are the environmental impacts of common packaging materials – aluminum, glass, and plastic – throughout their life cycle, from extraction of natural resources and product production through consumer use and disposal?* Youth will conduct web-based research on the life cycles of glass, aluminum, and plastic and learn about the environmental impacts associated with each life cycle stage. Specifically, youth will investigate the environmental effects relative to the production of aluminum, glass, and plastic beverage containers from the time natural resources are extracted through to product production, consumer use, and disposal (landfill waste, recycled material, or repurposed product). Youth will then have opportunities to engage in real-world applications of their new knowledge to help address environmental issues associated with material waste in their communities.

4. **Module 4: All About Polymers!** *What is it about plastic that makes it so versatile?* Youth use model polymer chains to explore how structure influences material properties. Youth will also observe biodegradation using a variety of material samples. With these two

activities, youth will understand the same reasons that make plastics a strong material also contribute to their detrimental environmental effects.

The second activity in this module is done over two sessions that require a two week wait in between. Educators can begin another module during the waiting period.

5. **Module 5: The Plastic Life Cycle.** *What happens to all the plastic we continue to consume? What impacts does plastics have on the environment?* Youth simulate becoming a particle of "plastic" and follow it from one learning station to another throughout its material life cycle, being extracted, manufactured, consumed, and disposed. The resin code the plastic is manufactured in to, and chance encounters (dice rolling) determine end-of-life: refuse/landfill (or ocean), recycle, recovery/energy, or reuse.
6. **Module 6: The Plastics Future: Bioplastics.** *How can we develop materials that have the advantages of plastic but fewer of the negative impacts? What are the advantages and disadvantages to transitioning to renewable plastics?* In activity A, Youth will explore the properties of different plastic types to understand the advantages and disadvantages based on application. If the group has access to a microwave, youth will create their own bioplastic sample from cornstarch. If no microwave is available, store bought samples of different plastic cups will be tested to explore how the properties of materials affect its function. In activity B, youth are challenged to create a sustainable polymer container that can hold a liquid and explore future uses for this type of polymer as they identify and test variables. In Part 1, youth will make the pods following a lab procedure designed by scientists at the NSF Center for Sustainable Polymers. In Part 2, youth will make a change to a variable, make a prediction, and test what happens.
7. **Module 7: Emerging Solutions to the Plastic Crisis.** *What are the advantages and disadvantages in emerging methods to deal with the detrimental impacts of petroleum-based plastic?* Youth prepare and deliver a pitch to a "Shark Tank" panel of investors who listen to pitches for products and decide whether to invest. Youth will prepare a pitch for an emerging technology or other solution to deal with detrimental impacts of plastic. Youth use scientific information, may gather additional information, and include? a life cycle assessment. Youth will reflect as a large group on the advantages and disadvantages of each proposal.

CONTENT SUMMARY

The theme of these modules focuses on the prevalence, life cycle, and impact of plastics in everyday life. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties (most commonly referred to by their resin code).

Plastics may be strong and rigid (such as safety helmets and the exterior of automobiles) or soft and flexible (such as those used in shoe cushioning or plastics bags). It is easy to find examples of plastics in everyday life and we all encounter plastic items at multiple points each day. Few other materials, such as paper, aluminum, or glass, are as versatile as plastics. This versatility is perhaps why plastics have surged in production and usage in the last century, making their way into almost every facet of modern life.

Unfortunately, the chemical properties (long polymer chains) that make plastics so strong, durable, and flexible, also make them resist degradation. Plastics that end up littered in the environment can take hundreds or thousands of years to degrade. It is estimated that 4.8 million metric tons of plastics end up in our oceans each year. Plastics may break into smaller and smaller pieces (called microplastics). Microplastics are particularly harmful in aquatic environments because they are easily ingested by animals and can end up in drinking water.

The most effective method to reduce plastic waste is not to create it. Once created, reusing, repurposing, or upcycling a plastic product helps increase its lifespan. Another option in some places is to recycle plastics. Plastics that are recycled can be reprocessed into the same item or converted into a different item. However, not all plastic makes its way to the recycling bin. Only about 8% of all plastic is recycled - the rest is either incinerated, put into a landfill, or ends up as pollution in the environment.

Scientists and engineers are working on new ways to create, use, and recycle plastics made from renewable resources (like corn or potatoes) so we can use plastics for their many advantages and lessen their effects on our environment. Some plastics are now designed to biodegrade without polluting the environment and others are created using renewable resources to lessen the dependence on traditional, oil-based plastics. Sustainable polymers must address the needs of consumers without damaging our environment, health, or economy.

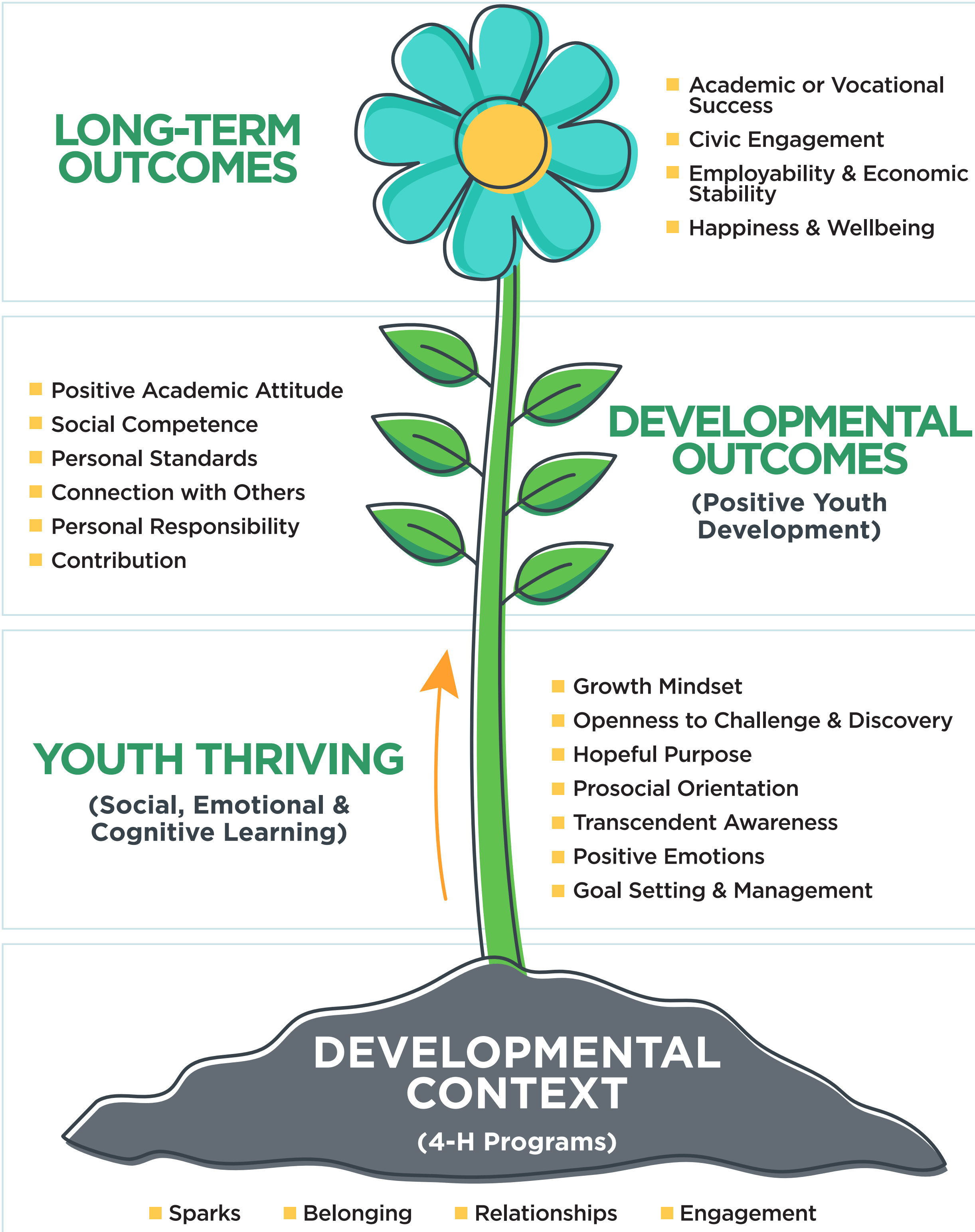
LIFE SKILLS AND POSITIVE YOUTH DEVELOPMENT

Positive youth development builds on young people's strengths and assets. Youth development involves an intentional process that promotes positive outcomes for young people by providing opportunities, choices, caring relationships, and the support necessary for youth to fully participate in families and communities. High-quality programming provides valuable benefits in knowledge, skills, and interests, and also in the form of leadership development, life skills development, and civic development. Through participation in science and engineering education, youth should have opportunities to strengthen their competence, confidence, connection, character, caring/empathy, and contribute to their community.

Practices to support positive youth development:

- Establish a safe environment and build relationships. All youth need a caring, supportive relationship in their lives. Educators provide this by showing interest in, actively listening to, and fostering the assets of youth.
- Provide youth leadership opportunities. Creating opportunities for youth to develop skills and confidence for leadership and self-discipline is important for youth development.
- Provide community involvement experiences. Service forges bonds between youth and the community and doing something valued by others raises feelings of self-worth and competence.

Learn more about the 4-H Thriving model at https://helping-youth-thrive.extension.org/

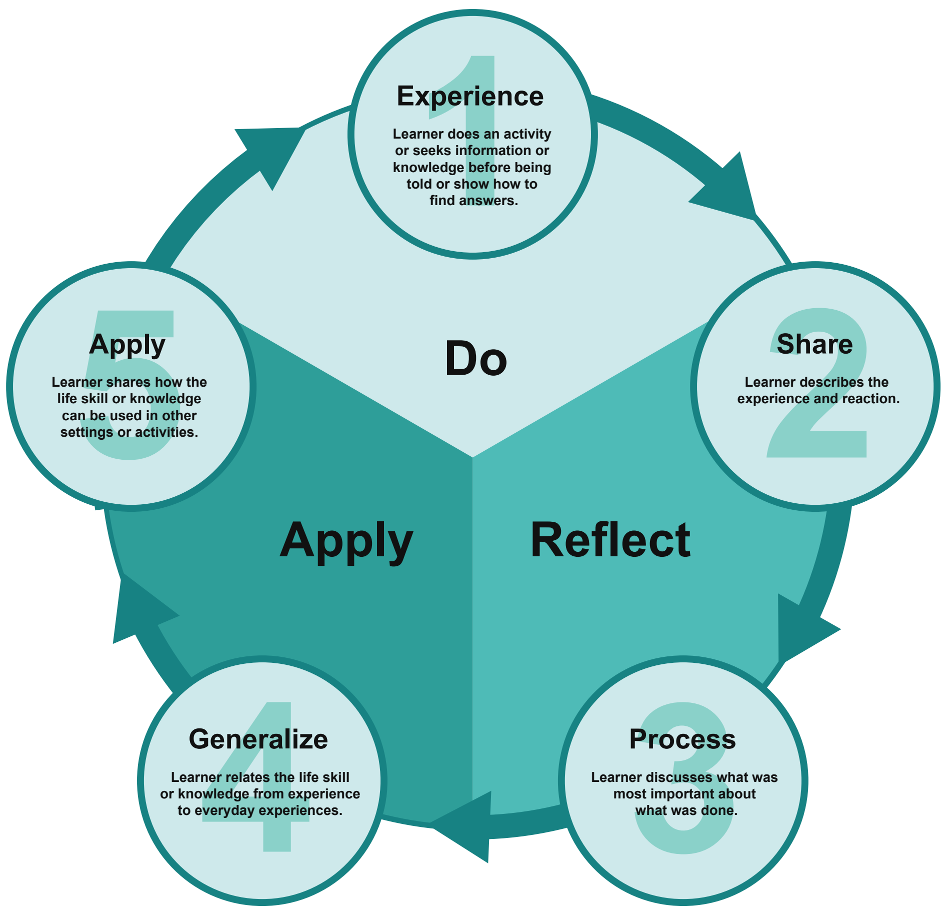


* **Credit: Arnold, M. E., & Gagnon, R. J. (2020)**. Positive youth development theory in practice: An update on the 4-H Thriving Model. *Journal of Youth Development*, *15*(6), 1-23.

EXPERIENTIAL LEARNING CYCLE AND PROMOTING INQUIRY

The curriculum is designed around the teaching methods of inquiry and experiential learning. Experiential learning is a cyclical process where youths have opportunities to construct meaning through engaging experiences. The cycle includes multiple phases including a concrete hands-on experience; a reflection phase where youth share, process, and generalize from the experience; and application of learning in new and authentic situations to deepen their understanding.

In a learning environment that promotes guided inquiry-based learning, youth build understanding through active exploration and questioning. The key to inquiry is that youth seek answers to questions rather than being given answers. This requires those who lead activities to facilitate the learning process and not simply disseminate knowledge. When activities are being led in an inquiry manner, youth actively question, observe, and manipulate objects in the environment.



** Cooperative State Research, Education, and Extension Service (1996). Curriculum Development for Issues Programming - A Handbook for Extension Youth Development Professionals. Based on the work of Kolb, D. (1984). Experiential learning: Experience as the source of learning and development. New Jersey: Prentice-Hall.*

EXPERIENTIAL LEARNING IN THE CURRICULUM

The curriculum outlines each activity around the experiential learning cycle:

- **Opening questions and prompts**: Before providing the materials for the experience, facilitate a group discussion to get youth thinking about what they know about the main learning objectives of the module.
- **Experiencing**: Procedures and instructions for a hands-on activity.
- **Sharing, Processing, Generalizing**: Help guide youth as they question, share, and compare their observations. Sample broad and open questions are included. Often, some of the sharing and processing takes place during "experiencing", however, it is vitally important to schedule time for group reflection after the activity. If necessary, use more targeted questions as prompts to get to particular learning points.
- **Concept and Term Discovery**: During this phase, it is important you ensure the primary learning objectives and concepts have been introduced or discovered by the youth. Important factors to include in term discovery are: (a) concepts must be stated in the young people's own words; (b) you may then introduce the terminology used by scientists to refer to the concepts; and (c) you should lead a brief conversation on the importance of the concepts.
- **Application**: The true test of youths' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth-specific opportunities where they will use what they learned. Suggested application activities are included within each of the polymer science content modules. We have also developed resources to help engage teens as teachers or to assist youth in exploring research projects as an avenue for application.

RECOMMENDED EDUCATOR PRACTICES

The educator is a facilitator of learning, responsible for helping youth make meaning of their experiences. Educators are not expected to be the "sage on the stage" but rather the "guide on the side." Facilitating an open discussion is crucial in helping youths make meaning of their experience. Questions allow us to access information, analyze data, and draw sound conclusions. Good questions help stimulate thinking and creativity. To this end, broad and open questions are ideal in promoting discussion and interaction. They do not have a single right answer. In contrast, focused, narrow, and close-ended questions tend to be fact-based or solicit yes or no answers and do not promote discussion. Encouraging science talk has four purposes (elicitation, consolidation, data, and explanation) and may involve full group, small group, or partner discussions. For more about encouraging productive science talk, see Sarah Michael and Cathy O'Connor's Talk Science, *Primer*, at: https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

The curriculum emphasizes the use of embedded evaluation and formative strategies to assess learning which may occur in multiple places during the implementation of an activity. First, educators may assess youth understanding of the main concepts and their engagement with Next Generation Science Standards (NGSS) practices and concepts through the types of questions youth ask, moments of wonder or puzzlement, and being able to successfully complete the task. Second, when youth share their ideas and experiences, the educators can assess how well youth understood the primary learning objective through the activity. Additionally, during the sharing, processing, and generalizing phase, educators can ask more focused questions to assess youth understanding, particularly in the concept and term discovery. Finally, the application phase provides another opportunity to assess youth learning. Educators may have youth share their application activity at subsequent sessions.

CONNECTIONS TO NEXT GENERATION SCIENCE STANDARDS (NGSS)

This collection of activity modules incorporate many of the science and engineering practices identified in the Next Generation Science Standards. Youth in grades 9-12 will work on their skills in these practices.

Science and Engineering Practices:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematical and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Youth explore many different disciplinary core ideas defined by NGSS through these modules. These core ideas span the physical sciences (PS), life sciences (LS), earth and space sciences (ESS), and engineering, technology, and the applications of science (ETS).

Performance Expectations

HS-PS2-6	Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
HS-ESS3-2	Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
HS-ETS1-1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS1-3	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

TIPS AND CALLOUTS

Facilitator Tips

These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices

The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Facilitator Tools

Tips for Facilitating Group Discussions

Facilitators play an important role in guiding youth through the process of discussion and setting goals collaboratively. Begin creating a safe and supportive environment by using these group facilitation strategies:

1. Welcome youth.
2. Begin with an opening activity/energizer/icebreaker that helps create connection, a sense of belonging, and teamwork with youth in preparation for group discussion
3. Create shared agreements with youth to collaboratively build an environment that supports open discussions and shared decision making. Here are some potential agreements that support a positive discussion.
    a. Respect
    b. Open communication - active listening, open sharing
    c. Everyone has the opportunity to contribute ideas and take a leadership role with responsibilities
    d. Adults and youth share decisions making
    e. Shared Investment - each member plays an important role in planning and working toward the desired outcomes. This leads to a sense of shared ownership and belonging
4. Cultivate Youth Voice
    a. Encourage youth to come up with ideas and share their perspective
    b. Encourage other points of view - no idea is a bad idea, ask for clarification
    c. Intentionally include quieter voices to offer opinions and participate
5. Lead discussion using a variety of active discussion methods to engage youth (examples are included in the Examples of Active Discussion Methods section)
6. Support Collaboration (group mission; individual accountability)
    a. Each participant is an important contributor to the project
    b. Help youth understand partnership and shared responsibility
    c. As a result, each participant should be sure to fulfill their commitment to the project and the group

7. Manage Conflict

    a. Lively debate may turn into disagreements. Help youth understand different points of view. Suggest phrases that youth can use to acknowledge the other point of view, even if they disagree with the statement. Phrases can include: "It's okay that we have different opinions on this", "let's give each person a chance to share their opinion", or "let's listen to understand what they are saying, not just to respond".

    b. With younger youth, an objective method of decision making can be the best choice, such as the toss of a coin or "rock, paper, scissors"

8. Provide positive and concrete feedback

    a. Acknowledge the assets, contributions, and commitment that youth dedicate to the project as well as their unique leadership skills

    b. Offer specific feedback unique to the young person that encourages a growth mindset. For example, "I have seen how hard you have worked and how your persistence has made an impact on the project."

DISCUSSION WARM-UP EXAMPLES

The following warm-ups can be used to help get youth moving and connected around plastic related issues:

- **Matter of Opinion** - Create a series of statements regarding plastics and ask youth to line up based on their opinion regarding the statement using strongly agree at one end and strongly disagree at the other end. For example, use the statement "I believe plastics can be both useful and good for the environment." After youth have moved to the spot on the line that best presents their opinion, ask a few youth to volunteer to share their opinion with the larger group. This can also be expanded to four corners of the room with each corner discussing the statement. Pictures of plastics can also be used to begin the conversation.
- **Photo of Mine** - This activity is geared to start exploring the issue, especially if youth are shy and hesitant to talk. Offer a range of photos related to plastics. Ask youth to choose a photo that strikes them. Once they have a photo, ask them to find a partner with a different photo. The pair then discuss the image and image meaning. Provide time for group sharing.
- **Knee to Knee** - Create two lines, each with equal numbers of youth facing each other. Provide a question or statement related to plastics. For example, "Can all plastics be recycled?" Give one minute for the pair to discuss the topic. After one minute, call for the group to switch with one line moving one person over to right. Then pose a second plastic related question. Continue for as many rounds as best works for the group. Ask youth to share important elements or thoughts from the conversations.
- **Ball Toss** - Ask youth to make a large circle. Use a ball (larger than a tennis ball) and ask students to toss the ball and share one question or belief related to plastics. Make sure all participants get a chance to toss the ball and share.
- **I Wonder** - Provide youth with a half sheet of paper or an index card. Ask students to write one thing they wonder about plastics (our use, the impact on the environment, or sustainability). Ask the students to place their paper or index card in a central pile once they are finished recording the thing they wonder. Next, ask students to take a different paper or index card and read out loud to the group.
- **Rose and a Thorn** - Ask youth to find a partner and ask them to share one "rose" or positive thing about plastics and one "thorn" or negative thing about plastics. After one minute of sharing, ask a few students to volunteer to share some examples of a rose and thorn. Facilitators can also play music as youth move, then when the music stops, youth can find a different partner to share.

Facilitator Tip
Identify creative ways to pair youth together to help alleviate any anxiety in finding a partner. Some ideas include: find someone who is directly behind you, find someone of the same height, find someone with the same number of letters

ACTIVE DISCUSSION EXAMPLES

The following examples of discussion methods can be used to ensure all voice are heard, youth are working as a team to generate ideas, and creating innovative solutions together:

- **Rapid Post-It Brainstorm** - Provide a range of small color Post-It pads to students. Give students two minutes to write any plastic issue they can think of or may want to solve. Ask that they don't write solutions yet, but to focus on quickly listing the issues. After two minutes, ask students to post their notes on a board in front of the group. After the notes are posted, ask one youth to read notes and help identify themes. Choose the top 2-3 themes and lead a second round of two-minute rapid brainstorming focusing on potential solutions. Ask youth to post potential solutions. Ask one youth to read all the solution Post-Its and help identify themes. Discuss as a large group the most common plastic related issue and most common plastic related solution.
- **Rotation Brainstorm** - Around a room, post a designated number of poster papers each with a different topic heading, a statement, or a question related to a plastic issue (our use, the impact on the environment, or sustainability). Ask youth to visit one poster paper to add at least one thought or suggestion. After a designated amount of time (2-3 minutes), the facilitator calls "switch" for the youth to rotate to a different poster. Be sure everyone has an opportunity to contribute to each poster. Youth can switch as a group or move to the next poster in a different group. After youth have finished, a youth or facilitator reads from the posters. Discuss themes and suggestions as a large group.
- **Think-Pair-Share** - Provide youth with an article, a video, or interesting plastic items to review or consider. Group youth in pairs and discuss the article, video, or interesting plastic items. After three minutes, ask for volunteers to share important points from the discussion.
- **Small-Group Rotation** - Create a set of 3-4 different questions or statements related to plastics (our use, the impact on the environment, or sustainability) and list each question on a different poster paper. Station one poster paper at each table. Divide youth into 3-4 groups. Each group will have five minutes at a table to discuss a specific question. Ask one youth to record discussions. After five minutes, ask the youth to visit a different table to discuss. Have enough rotations so participants can visit each question or statement. After all the rotations are complete, ask someone from each table to share insights from the poster recordings.
- **Know and Want to Know** - Create two posters 1) What do we know about plastics and 2) What do we want to know about plastics. Post the paper and ask youth to visit each poster and record thoughts. After brainstorming, ask for a volunteer to read from the posters. As a group, identify themes.
- **Twenty Questions** - Ask youth to work with a partner to brainstorm 20 questions they have related to plastics (our use, the impact on the environment, or sustainability). Ask youth to share their list of questions. Identify the top five common questions to explore. As a large group, select the question the group is most interested in finding the answers.

MODULE

1

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Module 1

Trends in Production and Disposal of Aluminum, Glass, Paper, and Plastic Across Time

Driving Questions:

- **What are the historical trends for the production and disposal of plastics, glass, aluminum and paper products?**

Introduction

MODULE SUMMARY

Youth will analyze historical production and disposal data tables (1960s to 2018 U.S.) for plastic, glass, aluminum, and paper. By graphing the data, youth raise their awareness of trends in production and disposal of the four materials comparatively. Youth will communicate evidence about an issue informed and inspired by the data to a larger public audience.

Time Required:

- Set-up for activity: 15 minutes
- Activity: 60 minutes

TIPS AND CALLOUTS

Facilitator Tips

These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices

The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Understand data tables that display data on a longitudinal (over time) scale. • Convert table data to graphs by correctly plotting data points on the x and y axes. • Interpret graphical data and compare graphs that use different scales. • Make inferences about changes over time including cause and effect. • Integrate graphs into the development of an argument, case study or proposal.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Analyzing and Interpreting Data • Obtaining, Evaluating, and Communicating Information
CONCEPTS & VOCABULARY	• **Data Table**: a way of displaying multiple categories of information (often numeric). Data are represented in rows and columns. • **Line Graph**: graph that uses a line to connect individual data points that are organized over a specific time interval. • **Longitudinal Data**: collection of repeated observations, or data points, presented over time.

Module Focus (Continued)

CONCEPTS & VOCABULARY

- **Microplastics:** plastic fragments (less than 5mm in diameter - the size of pencil eraser) that are produced for certain products or result from larger plastic products degrading. Microplastics comprise approximately 90% of plastic pollution in the open oceans and are detrimental to marine life.
- **Plastics**: a type of material made from polymers that can be molded into solid objects.
- **Single-use Plastics**: any plastic product that is designed to be used once and then thrown away or recycled. This includes plastic storage bags, grocery bags, food wrappers, disposable drink bottles, plastic food wrap, straws, takeout containers, and disposable partyware.
- **Trend**: relationship between two sets of data. If the values of one set of data increases and the values of other set also increases, then the two sets of related data show a **positive trend**. If the values of one set of data increases and the values of other set decreases, then the two sets of related data show a **negative trend**.
- **X-axis**: horizontal axis of a two-dimensional plot.
- **Y-axis**: vertical axis of a two-dimensional plot.

Facilitator Preparation

SUGGESTED GROUPINGS

- ☐ Pairs or small groups of 3-4

MATERIALS NEEDED

- ☐ Copies of Appendices A-D: Data Tables (one per group; cut along lines)
- ☐ Copies of Appendices E-H: Blank Graphs (one set per group)*
- ☐ Copies of Appendix I: Interpretation Template (one per youth)
- ☐ Ruler or other straight-edge
- ☐ Writing materials: (one set per youth)
    - ☐ Pencils
    - ☐ Coloring utensils*: Red, Blue, and Black markers, crayons, or colored pencils
- ☐ Optional Technology-Supported Procedure: Computers with Microsoft Excel (or Google Sheets). *Coloring utensils not needed for this option.

GETTING READY

- ☐ Divide your youth into pairs or small groups.
- ☐ Decide if you will be using the “Pencil and Paper Procedure” or the “Technology Supported Procedure.”
- ☐ Gather supplies and make copies of the Appendices as outlined in “Materials Needed.”

Background Information for the Facilitator

Materials, such as aluminum, glass, paper, and plastic are selected for use in commercial goods, household items, and packaging based on their cost and physical properties. Throughout time, these materials have competed in multiple domains for the cheapest and easiest production. Aluminum began to phase out heavier metals in aviation and space travel and made its widespread public debut in 1959 with the beer can. Soon, aluminum beverage cans outperformed and outnumbered glass bottles. Looking at other materials, by 1925, paper bags had phased out the more-expensive cloth bags. Cardboards and cartons also began to take over aluminum and tin packing of crackers, oatmeal, and bandages towards the end of the 1900s. Glass and cardboard cartons have long battled as premier packages for milk and other dairy products; today, you are more likely to find cardboard cartons of milk and cream on the dairy box shelves. High demand for **plastics** began during WWII when the need for cheap, lightweight, and durable equipment for soldiers abroad caused plastics production in the US to quadruple (Science History Institute, n.d.). Since that time, our demands for plastic products have grown rapidly. In fact, plastic production increased by 19,000% between 1950 and 2015 to meet those demands! Overall, even though plastic dominates our modern packaging, products like cardboard and aluminum have begun to phase out other heavier and more costly materials.

Today, plastics are present everywhere in our daily lives. Many of the plastic items we are most familiar with are **single-use plastics**, like food containers, water bottles, wrappers, and grocery bags that are typically discarded after being used only one time. Plastics are also commonly used in durable products such as automobiles, furniture, pipes, insulation, cell phones, televisions, computers, and many other products. In 2015, about 380 million tons of plastic products were produced globally, with about 146 million tons produced only as packaging.

Plastics do not break down quickly or naturally in the environment, and with approximately one-half of all plastic products marketed as single-use items or packaging, effective disposal is an issue. Between 1960 and 1980, plastics' negative effects on wildlife, increased plastic litter, as well as concerns over disposal and a lack of degradability contributed to plastics' declining reputation among the public. To help regain public support, the plastics industry began promoting recycling programs in the 1980s. The classic recycling symbol debuted in 1988, more than ten years after single-use drink bottles and plastic grocery bags hit the market. However, recycling has not been the solution it was advertised to be. In 2018, an average of only 8% of all plastic waste was recycled. It is estimated that 75% of plastic waste is disposed of in landfills, and approximately 10% of plastic refuse ends up in the world's oceans.

In addition to recognizable plastic objects (water bottles, bags, etc.) plastic pollution also includes microplastics. **Microplastics** are tiny plastic particles that are purposely designed for commercial use (such as cosmetics) or are shed from plastic textiles such as fishing nets. Microplastics can also be derived from the breakdown of larger plastic items as they degrade over time. In fact, washing a laundry load of shirts made of plastic-based fabric like polyester can release between 600,000 and 1,000,000 microplastics into the water system! Microplastics are particularly harmful in aquatic environments because they are easily ingested by animals and can end up in drinking water.

Plastic pollution, whether obvious or microscopic, has worsened over time due to the increased demand for, and use of, plastic products coupled with ineffective processes for recycling or safe disposal. In this activity, we will compare trends in consumption and recycling of plastics with other materials such as glass and aluminum and youth will make inferences about the similarities and differences between the use and disposal of these materials.

Activity

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Describe different types of packaging materials used for various goods and possessions we purchase and use in our everyday lives (e.g., food, clothing, bath and laundry products, school supplies).
- Describe your understanding of some of the advantages and/or disadvantages of using these different packaging materials.
- Describe what, if anything, you know about how the production and disposal of packaging materials has changed over the last 50 years.

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. Have the groups of youth separate into different areas with a working space such as a desk or table.
2. Provide each group with a set of Data Tables (Appendices A-D; cut to separate). If there are 4 youth per group, each youth should have one of the tables (i.e., glass, plastic, etc.). If there are fewer than 4 youth per group, then some members may receive more than one table. If more than 4 members per group, then youth can partner up within the group.
3. Have the youth review the data tables provided and discuss the data tables within their groups.

Facilitator Tip
If youth need help conceptualizing the magnitude of the weights, remind them that a medium-sized car weighs about 2 tons. Therefore, 20,000 tons would equal the weight of 10,000 cars. Also, the data tables are given in thousands of tons, so remind the youth that "1,000" in the table is actually "1,000 thousand", which is equal to 1 million.

4. Choose one of the following procedures to continue.

Pencil and Paper Procedure:

1. Provide each group with a set of Graph Templates (Appendices E-I), pencils and colored writing utensils. Each colored utensil will represent a data category:
   a. Weight of Total Waste = Red
   b. Weight of Recycled Waste = Blue
   c. Weight of Buried Waste = Black
2. Instruct the youth to create line graphs by transferring the data provided in their table onto the graph template. Each category of data should be plotted and graphed in the corresponding color and a legend should be included on the graph. If the youth are unsure how to do this, provide them with the following hints.
   a. Time (decade) is represented on the X-axis (horizontal)
   b. Weight of Product Waste, Weight of Products Recycled, and Weight of Products Buried are represented on the Y-axis (vertical).
   c. Step 1: Plot all points for one category (Waste, Recycled, Buried)
   d. Step 2: Connect the points with a line.
   e. Repeat this process for all three categories.

Technology-Supported Procedure:

1. Using Excel or Sheets, have the youth create a data table based on the printed table provided. The table should be formatted as presented in the printed version with the same column and row labels.
2. Use "Insert" to select "Line or Area Chart" to generate a graph of the data.
   a. Make sure that the x and y axes are labeled and that there is a legend corresponding to each data category.
3. Format line colors as follows:
   a. Weight of Total Waste = Red
   b. Weight of Recycled Waste = Blue
   c. Weight of Buried Waste = Black
4. If possible, print graphs for ease of comparison and discussion.

Both Options:

1. After all the graphs are completed, hand out the **first page** of the Data Interpretation Template. Have youth complete Part 1 and share their responses within their groups.
2. Ask the youth to compare and contrast their graphs with those of their groupmates and complete the Part 2 of the Data Interpretation Template.
3. Hand out the **second page** of the Data Interpretation Template.
4. Ask the youth to complete Part 3 of the Data Interpretation Template and share their responses within their groups.

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

Bring the pairs/small groups together to share their responses on the Data Interpretation Template. Initiate a discussion whereby pairs/small groups share their observations and reactions to their experiences of analyzing and comparing the data. Ask the youth to describe how they went about the process of making sense of the data, and to discuss their interpretations of the outcomes.

Facilitator Tip
Look for evidence of understanding relative to graphing, data interpretation using different scales, and cause and effect inferences based on the data. For example, the graph templates have different scales for weight (Y-axis) and this difference is important when comparing across graphs.

If needed, some prompt questions may include:

1. Based on the data, describe trends in disposal of plastics, aluminum, glass, and paper over time.
2. Discuss some potential implications relative to these trends.
3. Explain how creating data tables, understanding data, and interpreting graphs could be relevant to your learning and/or careers.

Science and Engineering Practices
Analyzing and interpreting data

Facilitator Tip
To increase engagement, encourage a discussion about the relevant environmental implications of these disposal trends. Guide the conversation towards their understanding relative to the environmental impacts of waste.

Facilitator Tip
Encourage these links between data comprehension and scholastic pursuits, as well as the relevance they see to being critical media consumers.

CONCEPT AND TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of youth' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

Using their computers, tablets, smartphones, or poster paper/writing materials, ask youth to develop one or two infographics:

Option 1: Design an infographic that helps others understand an issue pertaining to material production and disposal that you think is important.

- Audience: Younger Youth
- Example (For Facilitator Only): See Appendix K and/or Facilitator Tip below

Option 2: Design an infographic that takes a stance on an issue you see in the material production and disposal data.

- Audience: City council or other local government bodies
- Purpose: Suggest policies or ways to educate the community about waste production (and/or decreasing waste production) in an effort to decrease their overall impact on the environment.

Science and Engineering Practices
Analyzing and interpreting data

Facilitator Tip
See the following links for infographic tips and examples.

Centers for Disease Control:
https://www.cdc.gov/socialmedia/tools/InfoGraphics.html

Easelly:
https://www.easel.ly/blog/10-great-examples-of-using-infographics-for-education/

St. Cloud State Univ.:
https://stcloud.lib.minnstate.edu/subjects/guide.php?subject=visualinfo

The University of Queensland:
https://www.clips.edu.au/infographics/

University of Pennsylvania:
https://guides.library.upenn.edu/infographics/creating

REFERENCES

A brief history of plastic. (2020). Lafayette. https://magazine.lafayette.edu/spring2020/2020/03/22/a-brief-history-of-plastic/

Britannica, T. Editors of Encyclopaedia (2019, November 15). *Polyethylene. Encyclopedia Britannica*. https://www.britannica.com/science/polyethylene

Carnegie Mellon University. (2021). *Natural vs synthetic polymers.* https://www.cmu.edu/gelfand/lgc-educational-media/polymers/natural-synthetic-polymers/index.html

Colman, S. (2020, September 10). *A brief history of plastic* [Video]. TED-Ed. https://ed.ted.com/lessons/a-brief-history-of-plastic

De Falco, F., Di Pace, E., Cocca, M., & Avella, M. (2019). The contribution of washing processes of synthetic clothes to microplastic pollution. *Sci Rep*, *9*, 6633. https://doi.org/10.1038/s41598-019-43023-x

Environmental Protection Agency. (2021, July 2). *Aluminum: Material-specific data*. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/aluminum-material-specific-data
Environmental Protection Agency. (2020, November 12). *Glass: Material-specific data*. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/glass-material-specific-data
Environmental Protection Agency. (2020, December 15). *Paper and paperboard: Material-specific data.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/paper-and-paperboard-material-specific-data
Environmental Protection Agency. (2021, September 30). *Plastics: Material-specific data.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data
Geyer, R., Jambeck, J., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7). 10.1126/sciadv.1700782
Moore, C. (2021, November 17). Plastic pollution. *Encyclopedia Britannica.* https://www.britannica.com/science/plastic-pollution
Plastic life. (n.d.)Plastic Garbage Project. https://www.plasticgarbageproject.org/en/plastic-life
Science matters: The case of plastics. (2021).Science History Institute. https://www.sciencehistory.org/the-history-and-future-of-plastics
Taddonia, P. (2020, March 31). Plastics industry insiders reveal the truth about recycling. *PBS Frontline.* https://www.pbs.org/wgbh/frontline/article/plastics-industry-insiders-reveal-the-truth-about-recycling/
Timeline. (n.d.). The Plastics Collection. https://plastics.syr.edu/page-timeline.php
Trossraelli, L., & Brunella, V. (2003). Polyethylene: discovery and growth. https://www.researchgate.net/publication/228813221_Polyethylene_discovery_and_growth

Appendices A-D

Appendices A-D: Print **one page** per group. Cut between tables to separate and provide one table to each member of each group.

Table 1: US Plastic Waste Production and Disposal from 1960-2018 (weight in thousands of US tons)									
	1960	1970	1980	1990	200	2005	2010	2015	2018
Total Plastic Waste	390	2,900	6,830	17,130	25,550	29,380	31,400	34,480	35,680
Plastic Recycled	0	0	20	370	1,480	1,780	2,500	3,120	3,020
Plastic Buried in Landfills	390	2,900	6,670	13,780	19,950	23,270	24,370	26,030	27,030

Table 2: US Glass Waste Production and Disposal from 1960-2018 (weight in thousands of US tons)									
	1960	1970	1980	1990	2000	2005	2010	2015	2018
Total Glass Waste	6,720	12,740	15,130	13,100	12,770	12,540	11,520	11,470	12,250
Glass Recycled	100	160	750	2,630	2,880	2,590	3,130	3,190	3,060
Glass Buried in Landfills	6,620	12,520	14,080	8,660	8,100	8,290	7,030	6,840	7,550

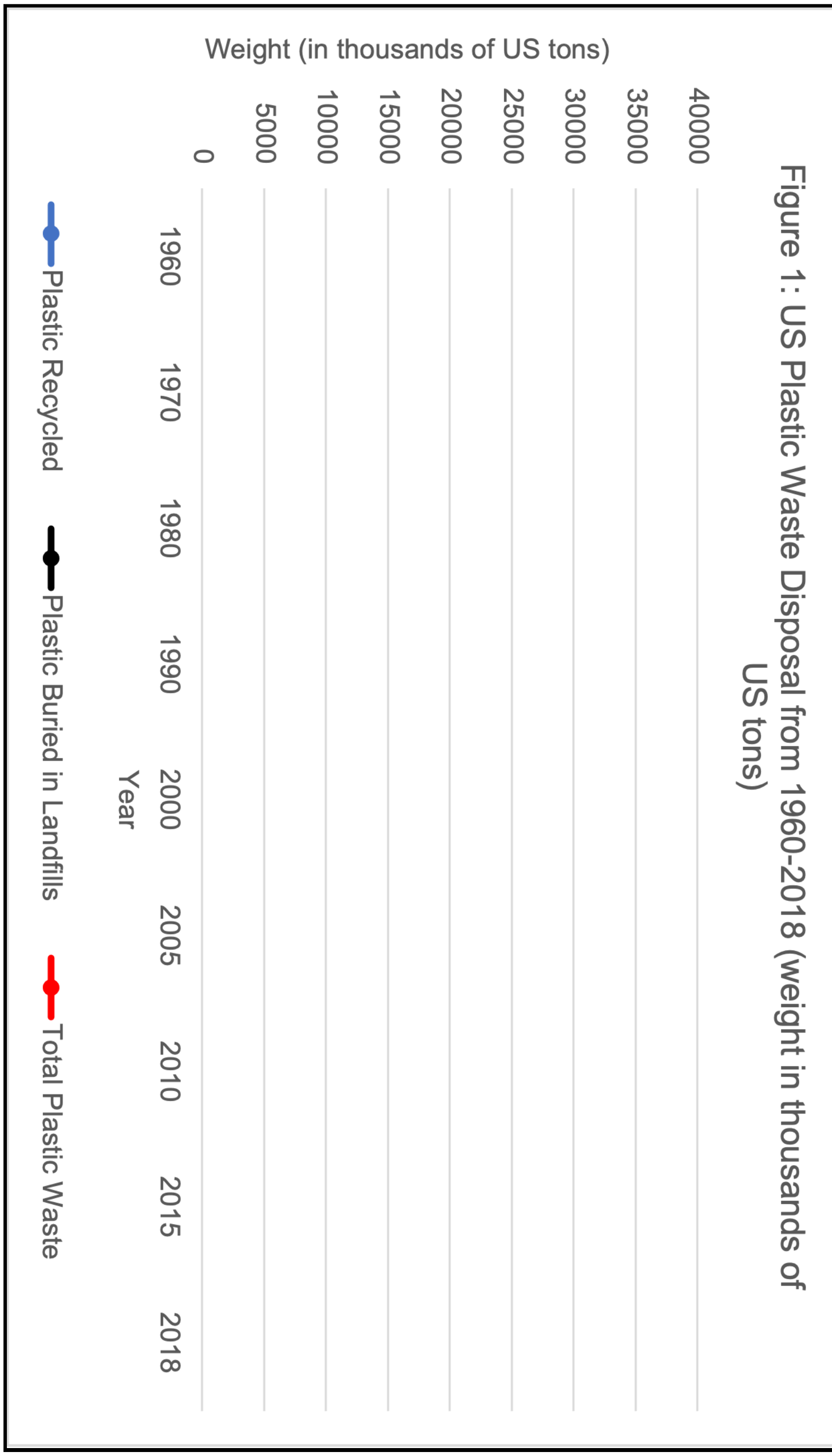
Table 3: US Aluminum Waste Production and Disposal from 1960-2018 (weight in thousands of US tons)									
	1960	1970	1980	1990	2000	2005	2010	2015	2018
Total Aluminum Waste	340	800	1,730	2,810	3,190	3,330	3,510	3,670	3,890
Aluminum Recycled	0	10	310	1,010	860	690	680	670	670
Aluminum Buried in Landfills	340	790	1,390	1,500	1,940	2,230	2,390	2,490	2,660

Table 4: US Fibrous Paper Waste Production and Disposal from 1960-2018 (weight in thousands of US tons)									
	1960	1970	1980	1990	2000	2005	2010	2015	2018
Total Paper Product Waste	29,990	44,310	55,160	72,730	87,740	84,840	71,310	68,050	67,390
Paper Products Recycled	5,080	6,770	11,470	20,230	37,560	41,960	44,570	45,320	45,970
Paper Products Buried in Landfills	24,910	37,390	42,560	43,570	40,450	35,080	22,000	18,280	17,220

Appendices E-H

Print **one set per group** (Appendices E-H). Each member of a group receives the graph template corresponding to their data table (Plastic, Glass, Aluminum or Paper)

Appendix E



Appendix F

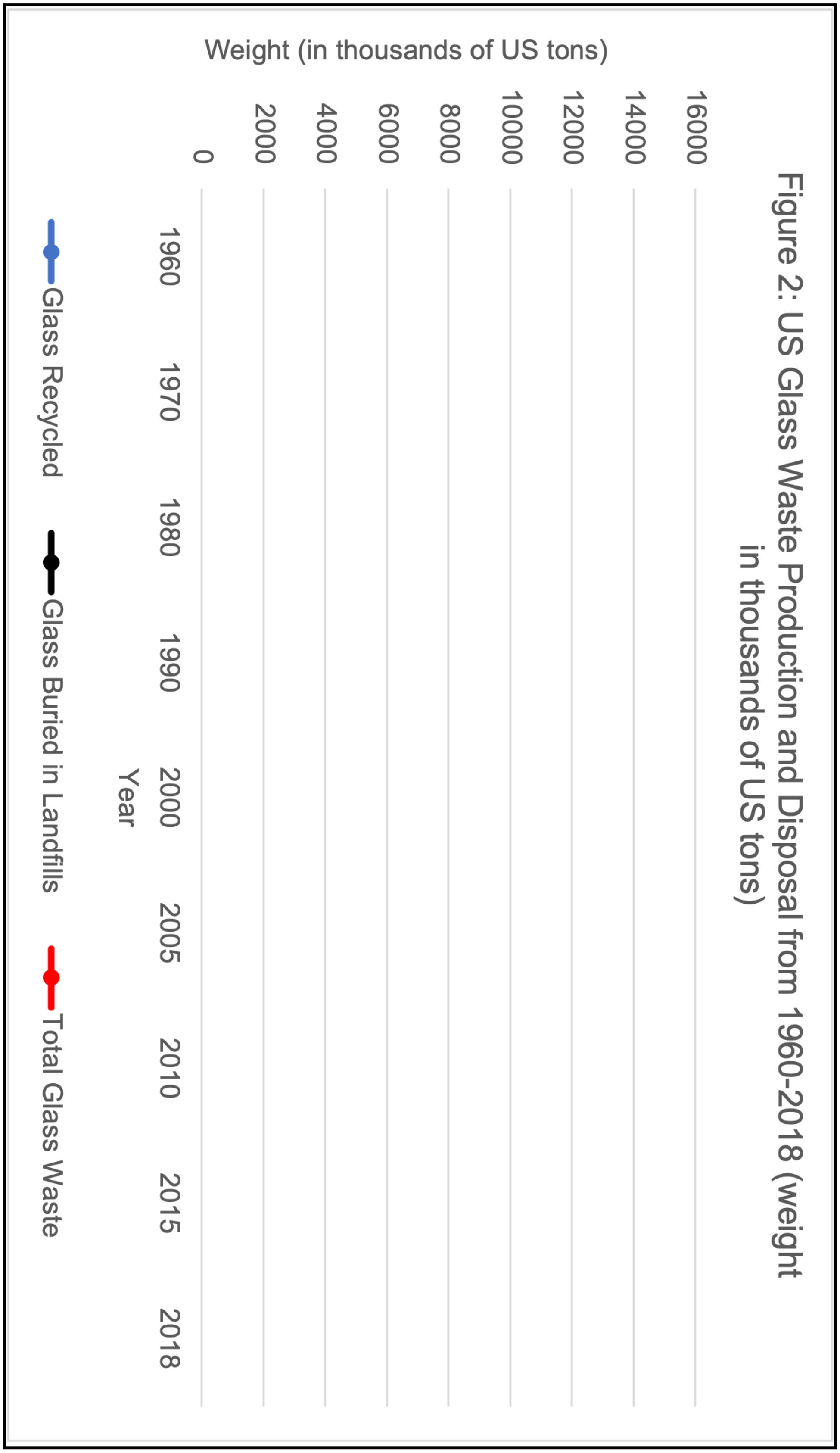


Figure 2: US Glass Waste Production and Disposal from 1960-2018 (weight in thousands of US tons)
Weight (in thousands of US tons)
16000
14000
12000
10000
8000
6000
4000
2000
0
1960
1970
1980
1990
2000
2005
2010
2015
2018
Year
Glass Recycled
Glass Buried in Landfills
Total Glass Waste

Appendix G

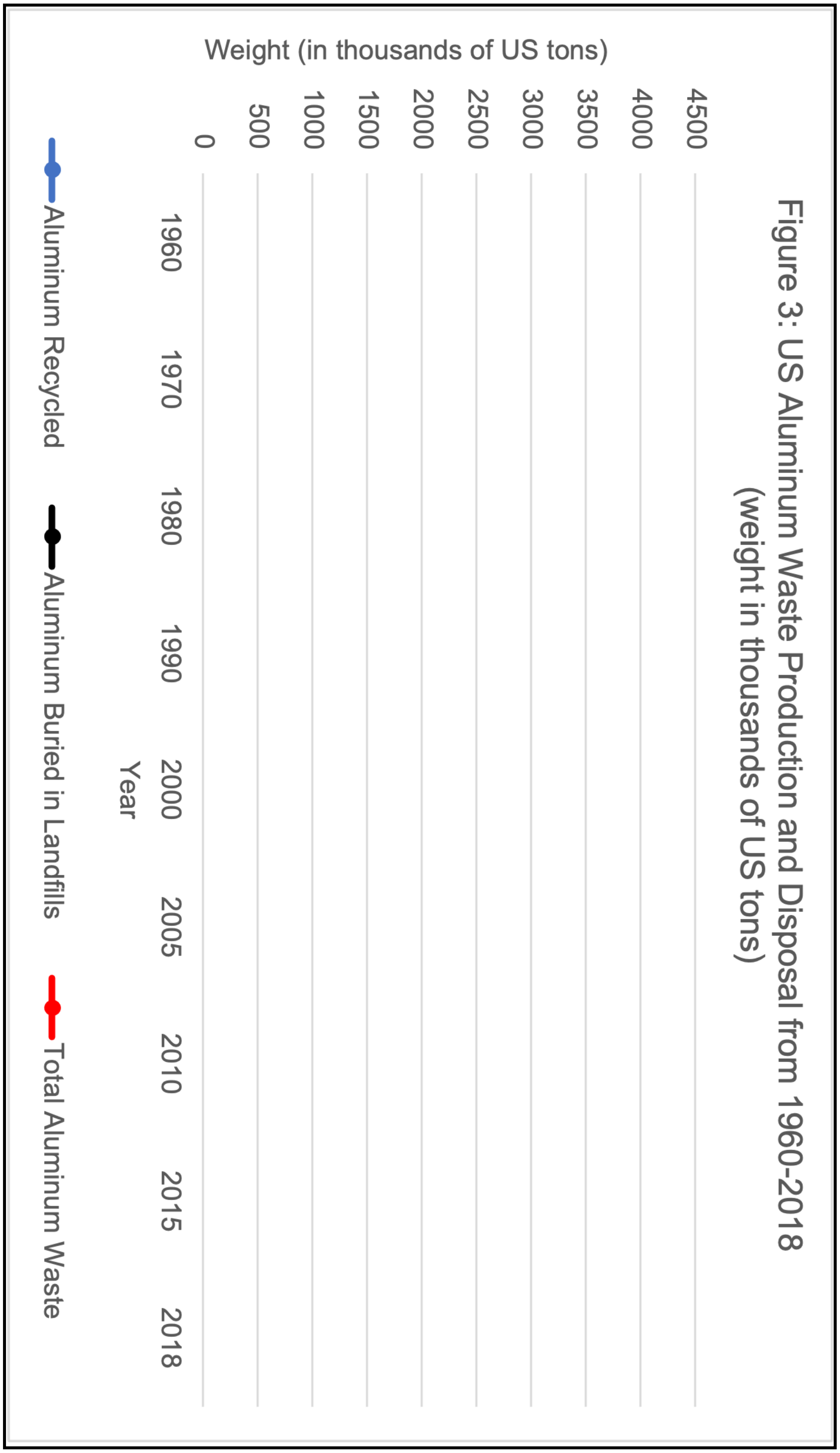


Figure 3: US Aluminum Waste Production and Disposal from 1960-2018
(weight in thousands of US tons)
Weight (in thousands of US tons)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1960
1970
1980
1990
2000
2005
2010
2015
2018
Year
Aluminum Recycled
Aluminum Buried in Landfills
Total Aluminum Waste

Appendix H

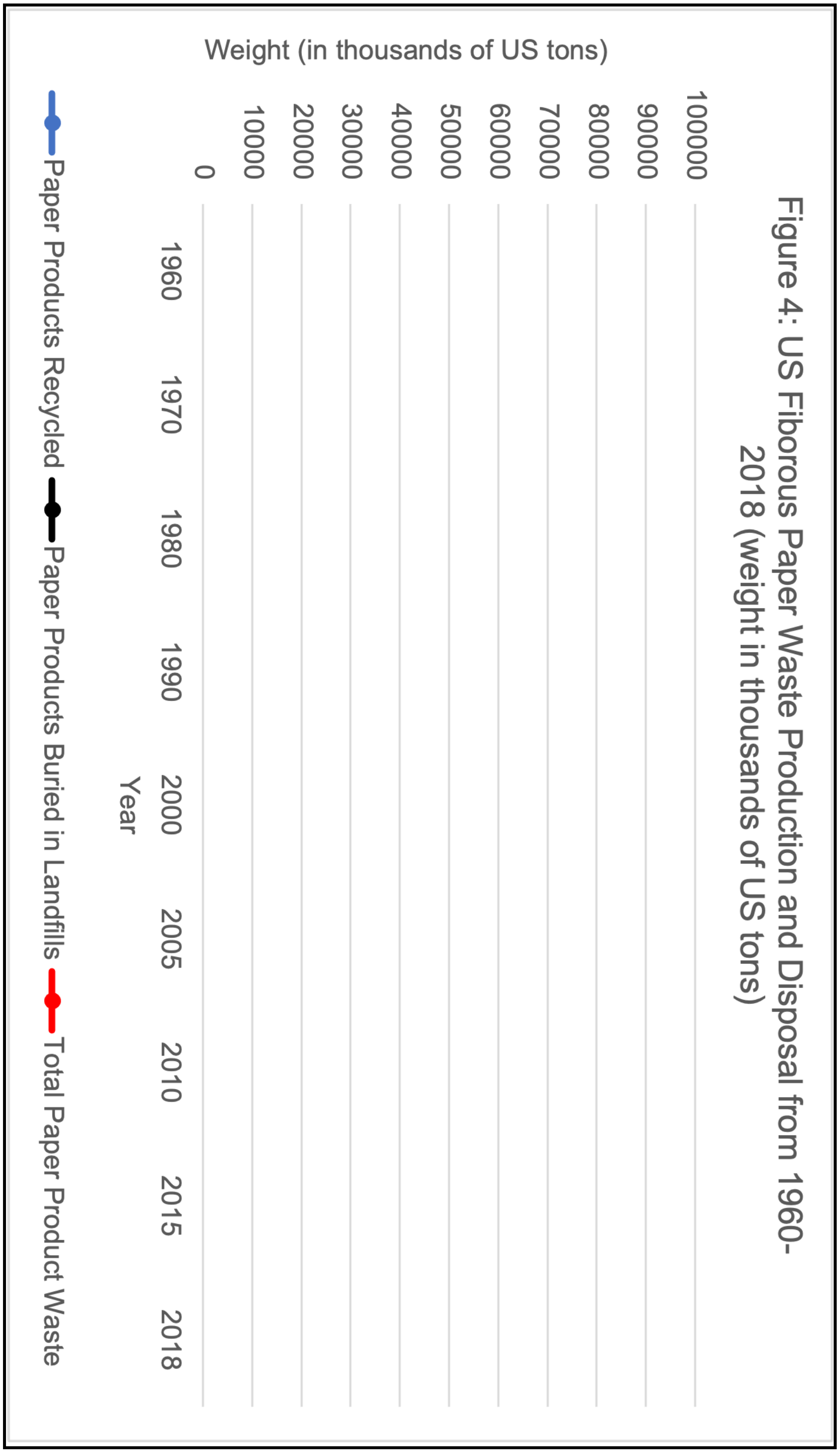


Figure 4: US Fiborous Paper Waste Production and Disposal from 1960-2018 (weight in thousands of US tons)

Appendix I

Data Interpretation Template

Part 1

Describe the general trends in each category of data on your graph:

Total Waste	
Recycled Waste	
Buried Waste	

At what time point did each data category reach its peak? Between which two decades was there the largest increase and decrease in weight of waste? (Hint: look at the slope of the line between consecutive data points)

Category	**Peak**	**Increase**	**Decrease**
Total Waste			
Recycled Waste			
Buried Waste			

Part 2

Compare and contrast the graphs for your material with other members of your group. Describe several similarities and differences. You only need to complete the sections that include your material. Make sure to note the scale of the y-axes when making comparisons.

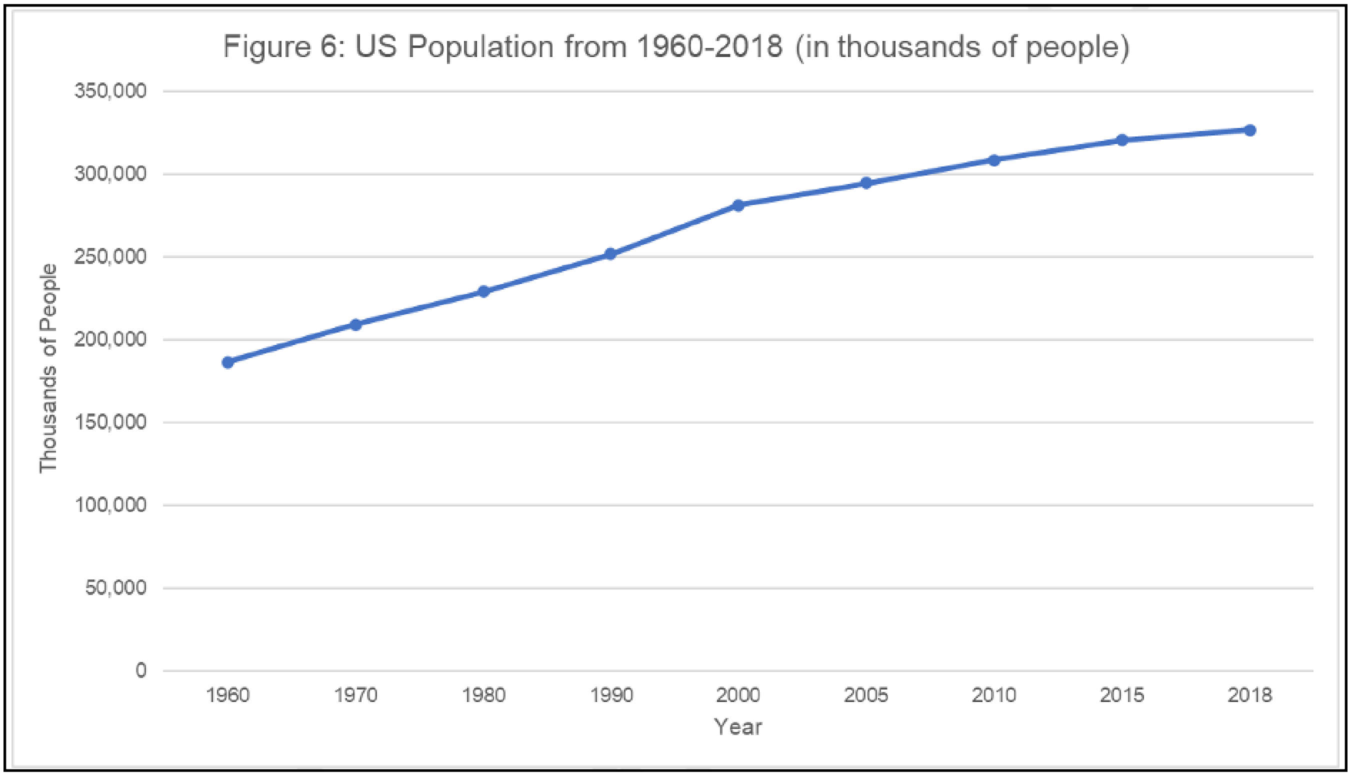
Comparison	Similarities	Differences
Plastic vs. Glass		
Plastic vs. Aluminum		
Plastic vs. Paper		
Glass vs. Aluminum		
Glass vs. Paper		
Aluminum vs. Paper		

Appendix I (Cont.)

Data Interpretation Template

Part 3

Review the US Population graph and use this information to answer the questions in the chart below.

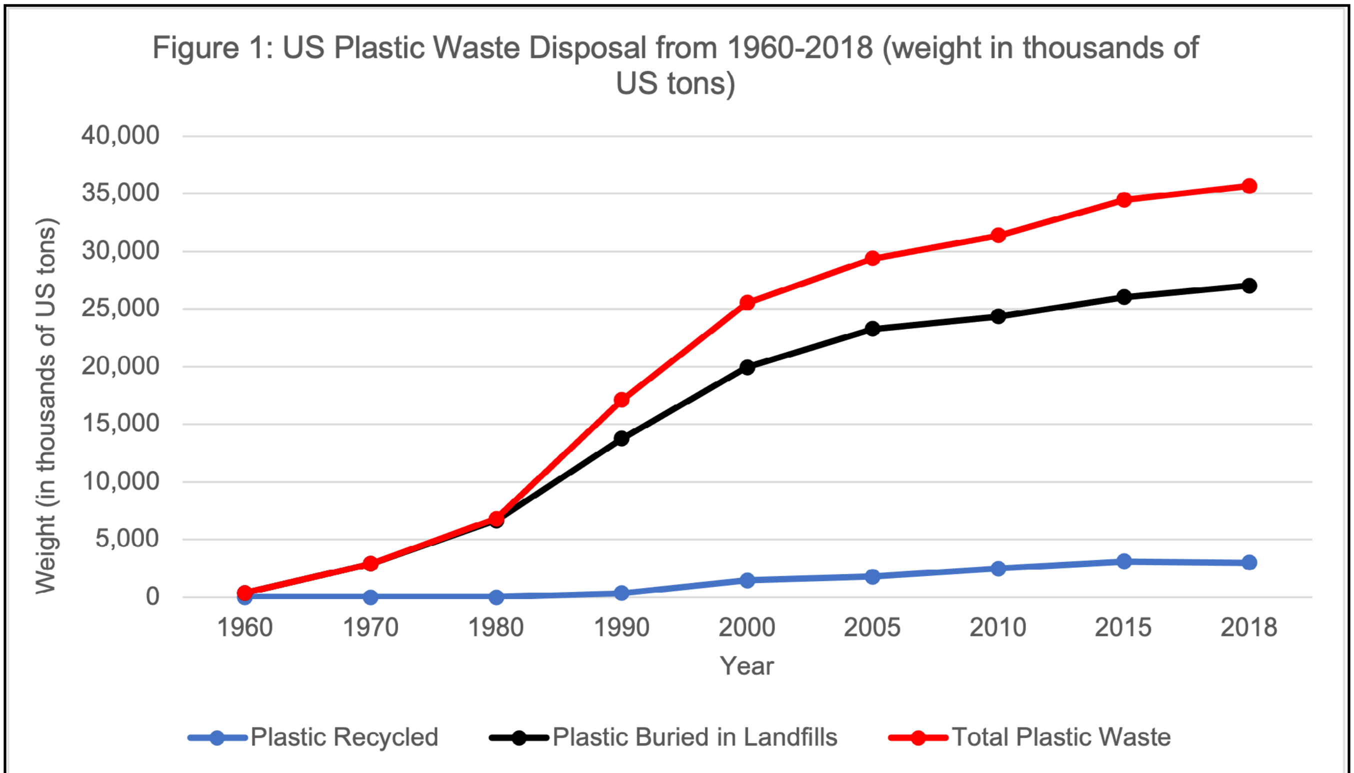


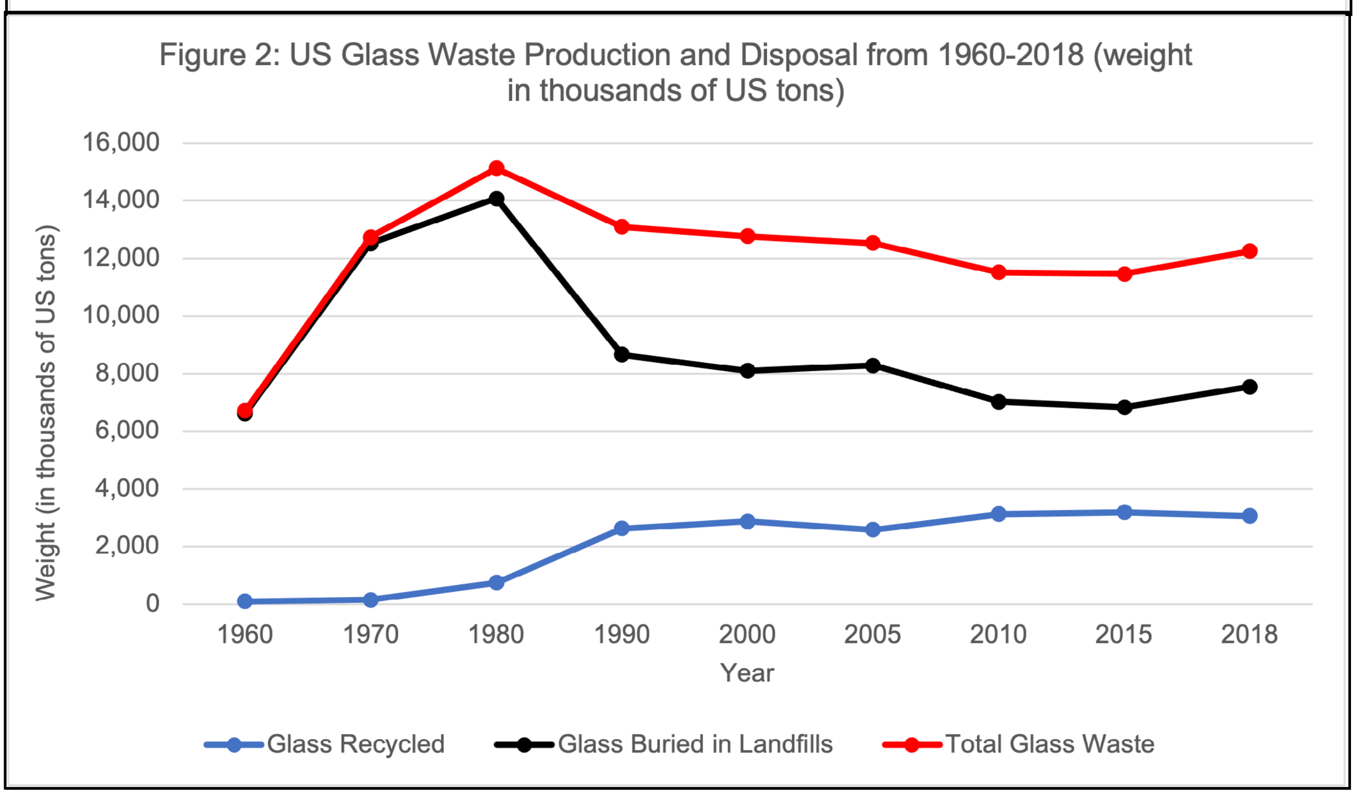
Describe any connections you can make between the trend in population and the trends in your data:

Total Waste	
Recycled Waste	
Buried Waste	

Appendix J

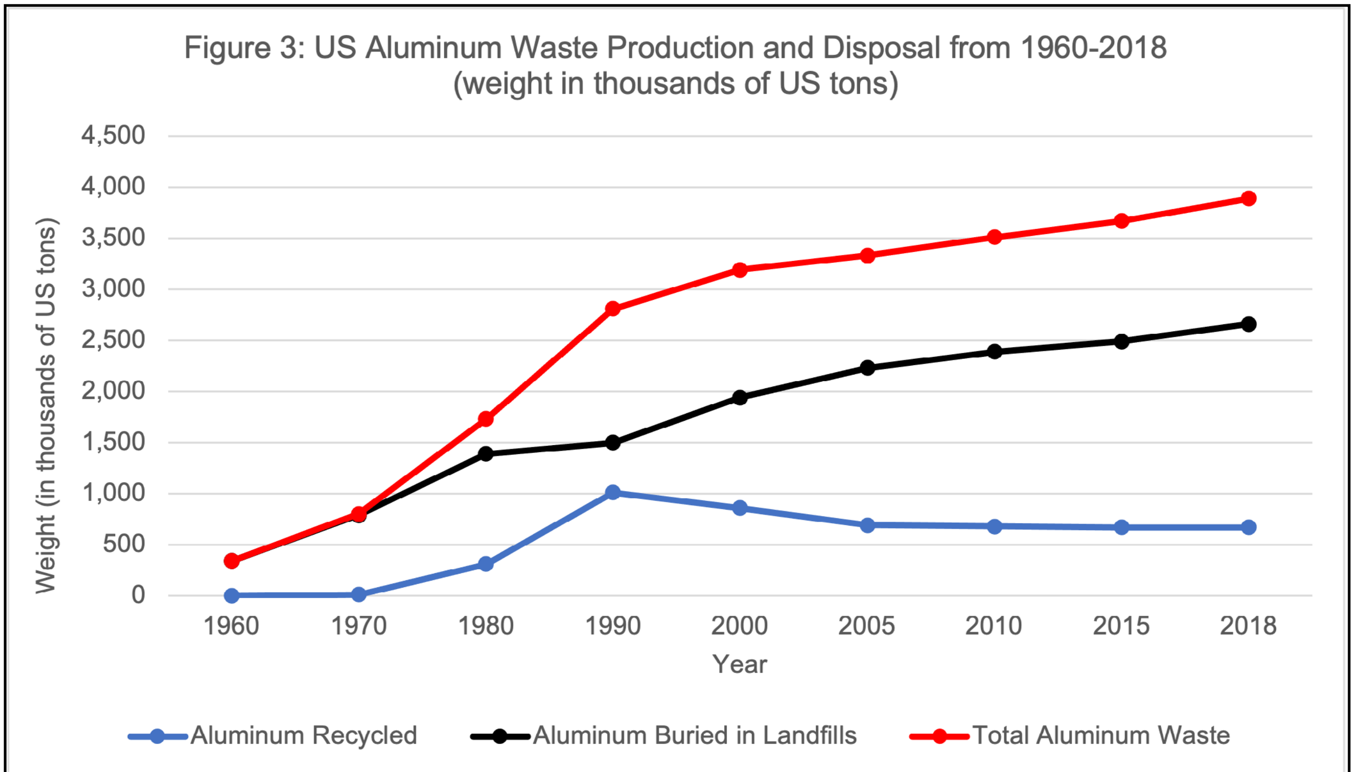
FOR FACILITATOR USE ONLY

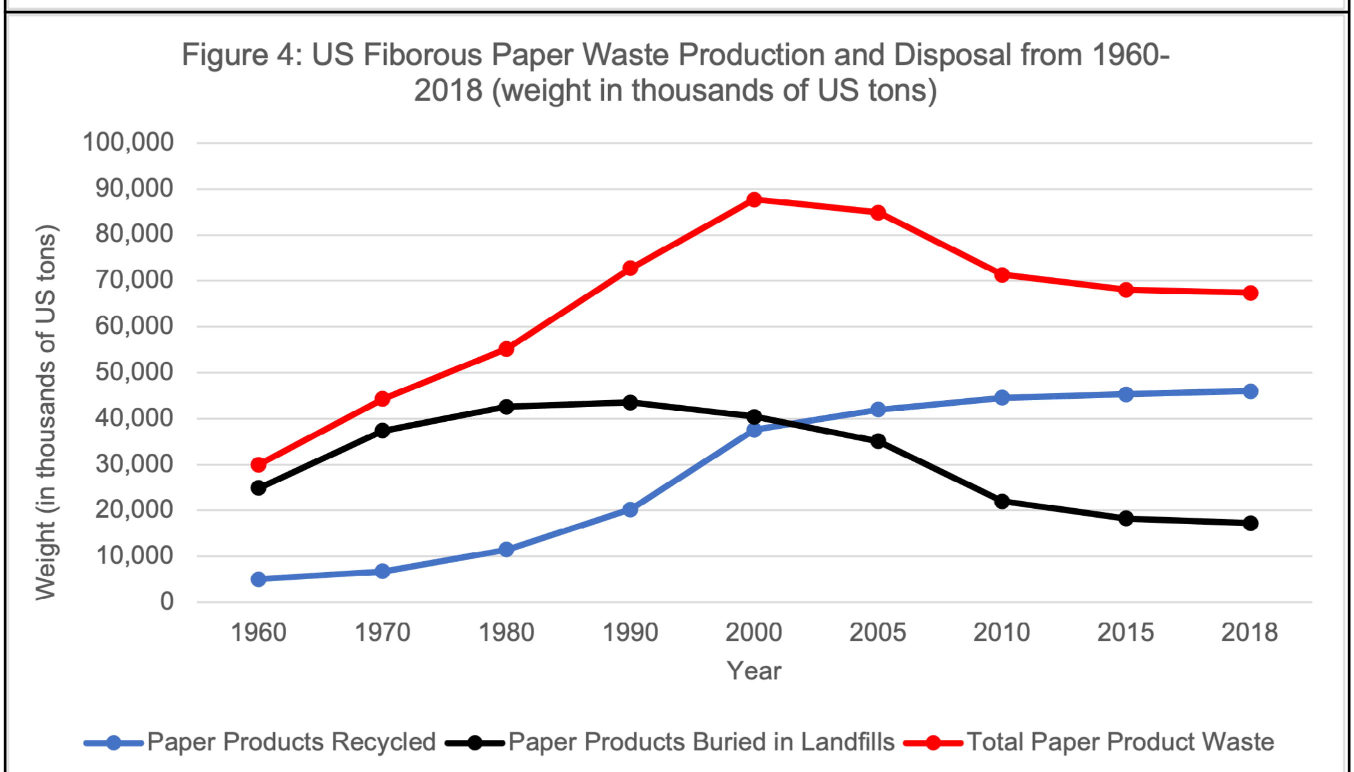




Appendix J (Cont.)

FOR FACILITATOR USE ONLY





Send us your Feedback!

Have you tried one (or more!) of the activities? Let us know how it went! We work with the Center for Applied Research and Education Improvement at the University of Minnesota to evaluate this project. Click on the button below to fill out their short evaluation form and help us collect valuable feedback for improvement!

4hpolymers.org/evaluation

MODULE

2

GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation

NSF Center for Sustainable Polymers

4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

National Science Foundation

NSF Center for Sustainable Polymers

Module 2 Comparing the Properties of Aluminum, Glass, Paper, and Plastic

Driving Questions:

- **Why are specific materials selected for specific use cases?**
- **Why have plastics become one of the most utilized materials in the world?**

Introduction

MODULE SUMMARY

Youth make comparisons and draw inferences about the physical characteristics of plastic, glass, aluminum, and paper through observation of household items. Youth create an inventory and reflect upon the materials present in the items they interact with daily in school and personal contexts. Youth begin to understand that the applications of different materials depend on the advantages and limitations of each material's properties, characteristics, and abilities.

Time Required:

- Set-up for activity: 15 minutes
- Activity: 60 minutes

TIPS AND CALLOUTS

Facilitator Tips

These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices

The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Identify the physical attributes of materials (plastic, glass, aluminum, and paper) • Describe the most common uses of these materials and how these properties address application needs. • Provide an explanation regarding why differences in material uses exist between different groups.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Analyzing and Interpreting Data • Constructing Explanations and Designing Solutions
CONCEPTS & VOCABULARY	• **Durability**: ability to withstand impacts, scratches, and general use without compromising function. • **Long-Term Use**: items that are refilled, reused, or repurposed many times. • **Malleable**: ability to be formed into many shapes. • **Multiple-Use**: items that are used multiple times, but not refilled or repurposed. • **Plastic alloy**: any kind of plastic material that is made up of multiple different kinds of plastic; a mix of at least two (but sometimes more) types of plastic blended together. • **Single-Use**: also called "disposable"; these items are used once and then discarded. • **Versatility**: ability to be adapted to a variety of different functions.

Facilitator Preparation

SUGGESTED GROUPINGS

- ☐ Pairs or small groups

MATERIALS NEEDED

- ☐ Copies of Appendix A: Data Collection Matrix (one per youth)
- ☐ Copies of Appendix B: Personal Inventory (two per youth)

Facilitator Tip
If your timing and setting permit, provide youth with the "My Personal Inventory" page a few days or a week before conducting this activity so they can track their actual use during that time. Then, have youth bring this completed inventory with them for the following collaborative portion of this activity.

- ☐ Copies of Appendix C: Graphs for Items by Use Case (one of each graph per group of youth, plus one of each graph per youth for application activity)
- ☐ Household items made of glass (at least 3)
    - ☐ Examples: Bottles, jars, drinking glasses, flower vases, picture frames
- ☐ Household items made of paper (at least 3)
    - ☐ Examples: Boxes of different sizes, milk/creamer containers, playing cards
- ☐ Household items made of aluminum (at least 3)
    - ☐ Examples: Aluminum beverage cans, aluminum pie pans, aluminum foil
- ☐ Household items made of plastic (at least 3; at least 1 from each of the following three categories)
    - ☐ Flexible Plastics: Grocery bags, sandwich bags, trash bags, bubble wrap
    - ☐ Semi-Flexible Plastics: Beverage bottles, straws, garden hose, notebooks
    - ☐ Durable Plastics: PVC pipe, sun/eyeglasses, CD cases, tape dispensers

Facilitator Tip
For plastic items, look for materials that are different shapes. This reinforces the fact that plastic is malleable and can be shaped easily. These properties also help make plastic more common.

Depending on your setting and time availability, you may want to have the youth collect the objects listed. This could happen either before the activity or as a scavenger hunt during the activity.

- ☐ Writing materials (one set per youth)

Facilitator Tip
Some items may be made of multiple materials even though they fall generally into a single material category. For example, cardboard drinking containers can be lined with aluminum and/or plastic (including juice boxes, which are comprised of 75% cardboard, 20% plastic, and 5% aluminum). As youth are assessing the items at each station, ask them to inspect the items closely and note if any materials often co-occur (i.e., plastic and cardboard).

GETTING READY

- ☐ Create four stations (i.e., aluminum, glass, plastic, paper) with the corresponding household items made of each material.
- ☐ Divide your youth into four small groups.
- ☐ Gather writing materials and make copies of the Data Collection Matrix (Appendix A), the Personal Inventory (Appendix B), and the Graphs for Items by Use Case (Appendix C), as outlined in "Materials Needed".

Background Information for the Facilitator

Plastic has quickly risen to be one of the most useful and prevalent products in the United States and around the world- but why? The answer comes from two defining characteristics of plastic: its strength and its versatility. Plastic and **plastic alloys** are very light for their respective **durability** and can withstand impacts with little damage. Further, plastics are **malleable** and can be molded into a variety of shapes and styles, so they are very **versatile** with respect to their potential applications. Plastics are also incredibly long-lasting: they are not susceptible to water damage, cannot be decomposed by bacteria or fungi, and some are highly heat resistant. This can be a large hindrance to plastic disposal, but is an advantage for prolonged-use plastic products.

Other materials, such as glass, paper and aluminum are selected for use in commercial goods, household items, and packaging based on their cost and physical properties. For example, glass is preferred for technology screens due to its high transparency to light and moderately high durability. In beverage bottles, glass also reduces the likelihood that harmful chemicals (or chemical tastes) will seep into the liquid inside. Paper is biodegradable, so products made with paper and/or cardboard are often seen as more environmentally friendly, and paper cartons (when lined with plastic) are lighter and more durable than glass bottles for storing liquids. Aluminum is also lightweight and durable, more so than glass, so is often chosen for packaging foods and beverages. Aluminum can also withstand the pressure needed to hold carbonated beverages, spray paint, and other pressurized goods, while maintaining a tight seal to protect internal goods from light or air damage.

Activity

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Describe various uses of different types of materials (e.g., aluminum, glass, paper, and plastic) we see in our everyday lives.
- Compare these uses.
- Discuss pros and cons of the different materials.

PROCEDURE PART A

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. Distribute the groups of youth so there is one group at each material station.
2. Provide each youth with a Data Collection Matrix and ensure they each have a writing utensil.
3. Prompt each youth to fill out the "Observations" section of their own Data Collection Matrix, based on the material station in front of them.
4. Once every youth has completed their observations, ask the groups to rotate to the next station.
5. Prompt each youth to fill out both the "Observations" and "Comparisons" sections for this new material.
6. Continue group rotations (steps 4 and 5) until all groups have been to all stations.
7. Ask the groups of youth to spread around the working space. Encourage the groups to discuss their observations and comparisons.
8. Prompt the youth to discuss and write down their inferences about why certain products are made of specific materials (under the "Inferences" column).
9. Regather the group and ask youth to share their observations, comparisons, and inferences.

Science and Engineering Practices
Analyzing and interpreting data

PROCEDURE PART B

1. Pass out one copy of the "My Personal Inventory" page to each youth and ask them to individually fill out the worksheet.

Facilitator Tip
Provide youth with the "My Personal Inventory" page a few days or a week before conducting this activity so they can track their actual use during that time. Then, have youth bring this completed inventory with them for the following collaborative portion of this activity.

Facilitator Tip
If the youth struggle to develop this inventory, prompt them to go through their backpacks/purses and catalog items, or imagine a typical day (from morning to night) and note some of the items they include in their daily routine.

2. Once every youth has completed their inventory, ask the youth to rejoin their smaller groups and discuss their lists.
3. Ask the youth to compare their inventory lists and to look for commonalities. Ask each group to compile a top 5 most frequently list for each use type (single-use, multi-use and long-term use) based on all group members inventories.
4. In their small groups or as one large group, create three graphs (single-use, multi-use, long-term use) that depict the main material types and number of items per type.
    a. X-axis is primary material (aluminum, glass, paper, plastic)
    b. Y-axis is number of items
5. Regather the group of youth and discuss the data.
    a. What material is the most common overall? Ask the youth to explain why they think this is the case.

b. What material is most frequently found in single-use items? Least? Ask the youth to explain why they think this is the case.

c. Discuss strategies to reduce single-use item consumption across material types.

Science and Engineering Practices
Constructing Explanations and Designing Solutions

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- Based on your observations and comparisons of the different categories of products in Procedure Part A, describe any realizations you had about the materials used for those manufactured goods.
- After reviewing the graphs from the personal inventories of items used daily, describe your insights into the trends you identified.

CONCEPT/TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

- Explain your thoughts on why some materials might be selected for specific use cases.
- Explain why you think plastics have become one of the most utilized materials in the world.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of youth' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

Option 1: Ask each youth to take another copy of the personal inventory to one of these three groups:

1. A group of upper elementary/middle school youth (e.g., a tutoring group, another 4-H group)
2. A group of other high school youth (e.g., a sports team, a peer group, another 4-H group)
3. A group of adults (e.g., family members)

Prompt the youth to have this other group of individuals fill out the personal inventory and then compare the similarities and differences to their own results. What were some similarities? What were some differences?

Option 2: Prompt youth to use their computers, tablets, smartphones, and/or poster paper and writing tools to create infographics using the top items from their personal inventories and the waste mitigation strategies they come up with as a group. Ask the youth to tailor their infographics to one of the following audiences:

- A group of upper elementary/middle school youth (e.g., a tutoring group, another 4-H group)
- A group of other high school youth (e.g., a sports team, a peer group, another 4-H group)
- A group of adults in their lives (e.g., family members)
- Adults in their communities (e.g., for a local community center, grocery store, etc.)
- City council members, or another local governing body

REFERENCES

Aluminum cans packaging for a sustainable future. (n.d.). The Aluminum Association. https://www.aluminum.org/product-markets/aluminum-cans

Berger, K. R. (2002). A brief history of packaging. *University of Florida Institutional Repository.* http://ufdc.ufl.edu/IR00001524/00001

Conway, C. (2007, April 1). Taking aim at all those plastic bags. *The New York Times.* https://www.nytimes.com/2007/04/01/weekinreview/01basics.html

National Research Council. (1994). *Polymer science and engineering: The shifting research frontiers.* [eBook edition]. The National Academies Press. https://doi.org/10.17226/2307

Neuman, S. (2019, December 10). Aluminum's strange journey from precious metal to beer can. *NPR Short Wave.* https://www.npr.org/2019/12/05/785099705/aluminums-strange-journey-from-precious-metal-to-beer-can

Rana, K. (2020). *Plasticless: A comparative life-cycle, socio-economic, and policy analysis of alternatives to plastic straws.* https://www.digitalcommons.mtu.edu/cgi/viewcontent.cgi?article=2178&context=etdr

Robertson, G. L. (2002, July 1). The paper beverage carton: Past and future. *Food Technology Magazine.* https://www.ift.org/news-and-publications/food-technology-magazine/issues/2002/july/features/the-paper-beverage-carton-past-and-future

Rohrig, B. (2015, May). *Smartphones: Smart chemistry.* ACS. https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2014-2015/smartphones.html

Science matters: The case of plastics. (2021). Science History Institute. https://www.sciencehistory.org/the-history-and-future-of-plastics

Why choose glass?. (n.d.). The European Container Glass Federation. https://www.feve.org/about-glass/

Widdel, F. (2017, May 2). *The curse of durability.* Max-Planck-Gessellschaft. https://www.mpg.de/11264611/the-curse-of-durability

Appendix A

Data Collection Matrix

Material Type	**Observations** Summarize what you notice about the physical characteristics of the objects made of this material. *	**Comparisons** Explain the similarities and differences you see between these objects and the objects made of other materials.	**Inferences** Describe a few reasons why you think this material is used to create the objects in front of you.
Aluminum			
Glass			
Paper			
Plastic			

* Some possible physical characteristics include the strength, rigidity/flexibility, durability, and malleability of the material and/or products.

Appendix B

Personal Inventory [Following Page]

My Personal Inventory

Name: Date:

Items I Use Daily	Plastic	Aluminum	Paper	Glass	Other	Single Use[1]	Multiple Use[2]	Long-Term Use[3]	If single use, why? If multiple use, how? (Refill, Repurpose, etc.)
Ex. Reusable Water Bottle								**X**	**I have used the same bottle for five years.**
Ex. Earbuds		**X**						**X**	**I have used the same pair for three years.**

[1] Single Use = The item is meant to be used once (i.e., it is not refillable, you do not reuse or repurpose the item).

[2] Multiple Use = This item is meant to be used multiple times, but is not refillable or easily repurposed.

[3] Long-Term Use = The item is never entirely empty/used, or once the item is empty/used, you refill or repurpose it.

Use a **checkmark** to mark the primary material in your item.

Use an **X** to mark the other materials in your item, as well as if the item is single-, multi-, or long-term use.

Appendix C

Graphs for Items by Use Case [Following Pages]

Figure 1: Frequency of Single-Use Items by Primary Material Type

Figure 2: Frequency of Multi-Use Items by Primary Material Type

Figure 3: Frequency of Long-Term Use Items by Primary Material Type

Send us your Feedback!

Have you tried one (or more!) of the activities? Let us know how it went! We work with the Center for Applied Research and Education Improvement at the University of Minnesota to evaluate this project. Click on the button below to fill out their short evaluation form and help us collect valuable feedback for improvement!

4hpolymers.org/evaluation

MODULE
3
GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation

NSF Center for Sustainable Polymers

4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

National Science Foundation

NSF Center for Sustainable Polymers

Module 3 Life Cycles of Products We Use and their Environmental Impacts

Driving Questions:

- **What are the environmental impacts of common packaging materials – aluminum, glass, and plastic – throughout their life cycle, from extraction of natural resources and product production through consumer use and disposal?**

Introduction

MODULE SUMMARY

Youth will conduct web-based research on the life cycles of glass, aluminum, and plastic and learn about the environmental impacts associated with each life cycle stage. Specifically, youth will investigate the environmental effects relative to the production of aluminum, glass, and plastic beverage containers from the time natural resources are extracted through to product production, consumer use, and disposal (landfill waste, recycled material, or repurposed product). Youth will then have opportunities to engage in real-world applications of their new knowledge to help address environmental issues associated with material waste in their communities.

Time Required:

- Set-up for activity: 15 minutes
- Activity: 60 minutes

TIPS AND CALLOUTS

Facilitator Tips
These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices
The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Describe the environmental impacts of natural resource extraction, product production, use, and disposal of aluminum, glass, and plastic beverage containers. • Communicate key environmental impacts of one material's full life cycle. • Design an action and/or education project in their local communities to help reduce the environmental impacts of aluminum, glass, and plastic products.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Analyzing and Interpreting Data • Obtaining, Evaluating, and Communicating Information
CONCEPTS & VOCABULARY	• **Environmental Impact**: the consequence of an action or policy on environmental quality· • **Global Warming**: the long-term warming of the Earth's climate system due, principally, to human activities (e.g., burning fossil fuels). • **Greenhouse Gas**: a gas in the atmosphere (e.g., carbon dioxide; methane) that absorbs infrared radiation efficiently and contributes to global warming. • **Material Life Cycle**: the life cycle of a product from the time raw materials are extracted through to production, distribution, use, and end-of-life management. • **Methane**: a type of greenhouse gas that is very efficient at absorbing infrared radiation and contributes to global warming. Main sources of methane gas production are oil and gas systems, livestock, and landfills.

CONCEPTS & VOCABULARY

- **Microplastics**: plastic fragments (less than 5mm in diameter - the size of pencil eraser) that are produced for certain products or result from larger plastic products degrading. Microplastics comprise approximately 90% of plastic pollution in the open oceans and are detrimental to marine life.
- **Perfluorocarbons**: greenhouse gases that trap solar radiation efficiently and contribute to global warming. The production of aluminum is a major source of perfluorocarbons.
- **Polyethylene terephthalate (PET)**: a type of plastic that is clear, strong, and lightweight. PET plastics are used commonly to package foods and beverages (e.g., soft drinks; water).
- **Polystyrene**: a synthetic polymer that can be solid or foamed. Used commonly in the food-service industry for trays (solid) and disposable cups, plates, and bowls (foamed).
- **Recycle**: the process of converting waste materials into new objects.
- **Recycling Codes**: symbols created by plastic manufacturers to help individuals identify the kind of plastic resin used to make the container. These designations help consumers determine if a container will be accepted by a local recycling program or not.
- **Repurpose**: using a product for a purpose other than it was designed.
- **Reuse**: the act of reusing a product for the same purpose that it was designed (e.g., a refillable water bottle).
- **Strip Mining**: a type of mining when a body of ore (e.g., coal) is near the surface of the earth and is extracted by first removing a long strip of soil and rocks (the overburden).

Facilitator Preparation

SUGGESTED GROUPINGS

- ☐ Three pairs or small groups of youth

MATERIALS NEEDED

- ☐ Copies of material life cycle (Appendix A): one per group
- ☐ Copies of activity tables (Appendix B): one per group
- ☐ Copies of presentation tables (Appendix C): one per youth
- ☐ Technology (i.e., desktop computer, laptop, tablet, smartphone): at least one per group
- ☐ Writing utensils (one per youth)

GETTING READY

- ☐ Make copies of Appendices A and B (one per group)
- ☐ Make copies of Appendix C (one per youth)
- ☐ Arrange youths into three groups (glass group, plastic group and aluminum group). 2-5 youths per group is ideal. If you have more than 15 youth, you can have multiple groups working on the same material.

Background Information for the Facilitator

The products we rely on in our daily lives all come from somewhere. The question we often ask ourselves is how environmentally friendly is the process required to get those products into our hands or homes? Additionally, what impacts does one product have on the environment? These are questions that a Life Cycle Assessment tries to answer by examining the environmental impacts of products throughout their production, use, and disposal/reuse. Technical Life Cycle Assessments are quite complex, however, by using the general approach of a Life Cycle Analysis we can become better informed about the environmental impacts of products and can use this information to make decisions about our consumption patterns. A product's life cycle has several main stages (see Life Cycle Diagram in Appendix 1). These stages include:

1. Raw material extraction: The processes required to obtain the "ingredients" necessary to make a material.
2. Material production: The procedures necessary to make the material from the raw ingredients.
3. Goods manufacturing: The processes needed to turn the material into the products we use.
4. Consumer Use: How products are used by consumers. This may also include **reuse** or **repurposing**.
5. Post-consumer use: All forms of disposal, as well as recycling to create new materials or products.

Each of these stages has environmental impacts, including loss of biodiversity due to the destruction of habitat, air and water pollution, greenhouse gas emissions, energy use, and more. For example, habitat destruction and pollution are main causes of the loss of biodiversity (Hein et al., 2018), and are among principal threats to species classified as "threatened" or "endangered" (Hoffman et al., 2008). Industrial activities, including the mining of natural resources needed for the production of glass (e.g., silica sand), aluminum (e.g., bauxite ore), and plastics (e.g., oil; natural gas), contribute to habitat destruction and environmental pollution. However, there are federal and state laws that regulate mining operations and are designed to help mining companies mitigate negative impacts on habitats and reduce pollution. Among the federal laws include the Clean Air Act, Clean Water Act, and Resource Conservation and Recovery Act (EPA, n.d.). While it is difficult to directly compare the environmental impacts of individual products – glass, aluminum, and plastic – because of variations and complexities in each stage of their life cycles, understanding the types and nature of the impacts is important to increasing environmental literacy and being an informed consumer.

Aluminum
Life Cycle Summary (Example: Aluminum Beverage Container)

An aluminum can's life cycle starts as an ore called "Bauxite", found especially in Africa, Asia, Australia, and South America. Bauxite is mined through a process called "**strip-mining**" or "surface mining", which entails cutting down any plants or trees and then removing the top layers of soil to reach the layers of the Earth that hold the ore. The soil disruption and mining often lead to soil imbalances of air, acidity, and minerals that created fertile soil, so the original vegetation is not always restored. This can disturb native animal species, which creates ripple effects throughout the entire ecosystem. Strip mining of Bauxite can also contaminate local water supplies for animals and humans. The conversion of Bauxite to aluminum requires great amounts of electricity, which is often derived from burning fossil fuels. This is directly related to increased carbon dioxide levels in the atmosphere, as well as increased particulate matter in the air surrounding the electrical production facilities. Further, the production of aluminum is a large contributor to releasing **perflorocarbons (PFC)**, a strong **greenhouse gas**, which contributes to **global warming**. If **recycled** cans are used instead of raw Bauxite, the cans are melted down and converted back into long, rolled sheets of aluminum. One environmental advantage of using recycled cans is that you can skip the entire Bauxite extraction and processing steps, allowing manufacturers to save 95% of the electricity used to make cans from Bauxite aluminum (GreenSpec, n.d.).

Many of the commercial applications of aluminum are visible in daily life: appliances, some cans, electronics, kitchenware, power lines and other cabling, and vehicle parts all contain aluminum. Just as the applicability of aluminum is vast, so are the characteristics of aluminum goods. Some products, like cans, are used once and then discarded. Other products, like appliances and electronics, are used for longer periods; some power lines and car parts may be operational for decades. In 2018, consumers disposed of 3.89 million tons of aluminum waste. 68% of this waste was thrown in the landfill, while only 17% was recycled. Only 35% of the single-use items like beverage cans, aluminum foil, and other food packaging products, were recycled (EPA, 2018). Recycled aluminum products, like aluminum cans, can be melted down and molded into new aluminum products. However, upwards of 15% of the aluminum from the recycled cans can turn into dross, a useless and hazardous dust-like byproduct that poses a severe threat to the environment and people's health. On the other hand, landfills release **methane** gas as items decompose. Methane is a greenhouse gas that contributes to global warming, and can also release other toxins into the local soil, water, and air.

Glass

Life Cycle Summary (Example: Glass Beverage Container)

A glass bottle's life cycle starts as a mix of raw materials including silica sand (SiO_2), sodium oxide (Na_2O) from soda ash, calcium oxide (CaO) from limestone/dolomite, dolomite (MgO), and feldspar (Al_2O_3). The raw materials needed to make glass bottles are readily available and can be obtained by mining. Mining can be disruptive to the ecosystem around the mines. For example, forested areas might need to be destroyed to access a mine site and runoff could pollute local water systems. Modern glass production takes environmental impacts into consideration and producers are becoming more proactive about sustainable mineral extraction and mine site rehabilitation.

The production of glass from the raw ingredients requires heating them to a temperature of 1,500 degrees Celsius. Heating the ingredients to this temperature takes a lot of energy, and the manufacturing process of virgin glass uses a lot of water, too. In addition, sulfur oxides are released during the melting process, and nitrogen oxides are generated if the glass is heated by burning gas. Sustainable glass producers are actively seeking ways to utilize materials that require less energy to melt and employ the use of furnaces that run on alternative energy sources.

Surveying our everyday lives, it is obvious that glass products are vital to us: light bulbs, drinking bottles, electronics, food jars, some kitchen and tableware, wall insulation, and windows are all made of glass. Interestingly, despite their names, eyeglasses and sunglasses are often not made with actual glass! The lifespan of glass products vary. Some products, like bottles and food jars, are often used once and then discarded. However, other products, like bulbs and electronics, are used for longer periods; construction materials (like wall insulation and windows) and tableware may be used for the foreseeable future. It is also rather straightforward to find ways to repurpose single-use glass items, like glass jars. Even still, in 2018, US consumers disposed of 12.25 million tons of glass waste. 62% of this waste was buried in the landfill and about 25% was recycled. Some recycled glass products, like food bottles and jars, can be easily melted down and turned into new glass products, with very little material loss. However, other products are made of composite glass that contains other materials, and therefore must be recycled separately from pure glass. Glass must also be sorted by color when it is recycled, and only certain glass colors can be mixed or used for certain products. This can be expensive, and sometimes recycled (but unsorted) glass is sent to the landfill instead of investing the time to sort it. Improper sorting or contamination of glass can also render the recycled melted glass unsuitable for production. Some companies incorporate this rejected glass into roads, but poor storage of the glass and contact with water can cause toxins and heavy metals to seep into local water supplies. However, in the landfill, a glass bottle could take up to 1 million years to degrade (Peace Corps, n.d.); further, as discussed above, landfills release methane gas and other toxins into the local soil, water, and air.

Plastic

Life Cycle Summary (Example: Plastic Beverage Container)

Polyethylene terephthalate (PET) plastic is a durable, lightweight plastic often used to make containers for the food and beverage, pharmaceutical and personal care industries. Making PET plastic begins with drilling for crude oil. That oil is brought by tanker trucks to a refinery where they use fractional distillation to separate the crude oil into easier to use components. Those components include Ethylene glycol and terephthalic acid. PET is formed when these molecules attach to each other to make a chain.

Accessing the petroleum based raw materials for PET plastics requires drilling which can disrupt wildlife habitats and generate air and water pollution. In addition, the manufacturing of PET resin generates toxic emissions that can negatively impact air quality.

By surveying our everyday lives we become aware that plastic products are a part of most things we do. Plastic is versatile, durable, and often lightweight, making it an appealing material for many different types of goods. Construction materials and equipment, clothing, food packaging, goods packaging, house and kitchenware, storage, vehicle parts, and more are either made of plastic or have plastic components. Many packages and disposable goods are single-use plastics, while cleaning and personal care products can be used multiple times but still end up in the landfill when they are empty. Other items, like refillable bottles and dispensers can be used indefinitely. In this way, plastic itself is not inherently bad, but we must be aware how we are using (and disposing) of it. In 2018, the US created 35.68 tons of plastic waste; 76% of that plastic waste was thrown in the landfill while only 9% was recycled. In landfills, it can take over 400 years for a plastic bottle to degrade, and degrading plastic can release **microplastics** into the environment. These microplastics can make their way into local waterways, causing both animals and humans to ingest them. Plastic recycling is feasible, but **recycling codes** can often make recycling confusing for consumers and sorting plastics is costly. Further, not all plastics can be recycled; bubble wrap, food wrappers, plastic bags, and **polystyrene** are common plastic products but cannot be recycled.

Activity

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Explain your understanding of how beverage containers – aluminum, glass, or plastic – are produced.
- Describe different ways you understand aluminum, glass, or plastic beverage containers can be disposed or repurposed.
- Discuss environmental impacts you know of regarding the production, use, and/or disposal of glass, or plastic beverage containers.

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. Divide the youth into three groups: aluminum, glass, and plastic.
2. Provide the youth with the Material Life Cycle (Appendix A). Prompt them to brainstorm what they think the key elements and possible environmental impacts of each stage of their material's life cycle could be.
3. Distribute one copy of the material activity table (Appendix B) to each of the corresponding groups.
4. Ask the youth to navigate to the links provided on their Activity Table and fill out the sections on their worksheet.

Facilitator Tip

Encourage the youth to look into other links on their own. Remind the youth that quality/reliable sources include those ending in .org, .edu, and .gov.

Remind youth that the perspective of the group providing a web resource can impact the information provided. Youth should determine if the information they are accessing is coming from environmental groups, industry sources, academic sources or otherwise.

5. Once they have completed their table, prompt the youth to compare their original brainstormed ideas to the information they gathered.

Science and Engineering Practices
Analyzing and interpreting data

6. Using their technology (e.g. Google Slides, Microsoft PowerPoint, Prezi), ask the youth to prepare a quick presentation about the elements of their material's life cycle that they think are most impactful on the environment and/or what they found most surprising.
7. Reconvene all of the groups and have them present to one another. Distribute the Presentation Notes Sheet (Appendix C) to each youth and prompt them to take notes on other groups' presentations.

Science and Engineering Practices
Obtaining, Evaluating, and Communicating Information

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- Describe what you learned about the life cycles of aluminum, glass, and plastic.
- Discuss some of the environmental impacts you learned about relative to natural resource extraction, product production, use, and disposal of aluminum, glass, paper, and plastic beverage containers. Discuss strategies you believe the beverage industry and/or consumers could employ to help mitigate some of the adverse environmental impacts.
- Discuss advantages and disadvantages of beverage containers made of aluminum, glass, and plastic.

CONCEPT/TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of young peoples' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

1. Develop a presentation about the impacts of manufactured goods production on the environment. Give this presentation to other youth or to community groups.
2. Lead community drives to promote/improve recycling efforts.
3. Choose one material type (glass, plastic or aluminum) and conduct more research in order to compare how different stakeholder groups communicate about the environmental impacts of the material. For example, youth could compare the messaging from industry sources with that of environmentalists and prepare a short presentation on their findings.

REFERENCES

Aluminum production & environmental impact. (n.d.) greenspec. https://www.greenspec.co.uk/building-design/aluminium-production-environmental-impact/

Bauxite in Malaysia: The environmental cost of mining. (2016, January 19). *BBC.* https://www.bbc.com/news/world-asia-35340528

Cho, R. (2020, March 13). Recycling in the U.S. is broken. How do we fix it? *Columbia Climate School State of the Planet.* https://www.news.climate.columbia.edu/2020/03/13/fix-recycling-america/

EPA. (n.d.). *Aluminum industry.* https://www.epa.gov/f-gas-partnership-programs/aluminum-industry

EPA. (2021, July 2). *Aluminum: Material-specific data.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/aluminum-material-specific-data

EPA. (2020, November 12). *Glass: Material-specific data.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/glass-material-specific-data

EPA. (n.d.) *How do I recycle?: Common Recyclables.* https://www.epa.gov/recycle/how-do-i-recycle-common-recyclables

EPA. (n.d.) *Materials management basics.* https://www.epa.gov/smm/sustainable-materials-management-basics

EPA. (n.d.) *Plastic pollution.* https://www.epa.gov/trash-free-waters/plastic-pollution

EPA. (2021, September 30). *Plastics: Material-specific data.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data

EPA. (n.d.) *Reduce, reuse, recycle.* https://www.epa.gov/recycle

EPA (n.d.) *Summary of the Clean Air Act. Laws and Regulations.* https://www.epa.gov/laws-regulations/summary-clean-air-act

EPA. (n.d.). *Wastes – Resource conservation – Common wastes & materials – Paper recycling.* https://archive.epa.gov/wastes/conserve/materials/paper/web/html/index-2.html

EPA. (n.d.) *What are PFCs and how do they relate to per- and polyfluoroalkyl substances (PFASs)?* https://www.epa.gov/pfas/what-are-pfcs-and-how-do-they-relate-and-polyfluoroalkyl-substances-pfass

Frequently asked questions: Plastics recycling. (2020, August 17). Cal Recycle. https://www.calrecycle.ca.gov/plastics/faq

Glass recycling facts. (n.d.) Glass Packaging Institute. https://www.gpi.org/glass-recycling-facts

Hein, T., Funk, A., & Trauner, D. (2018). Endangered Danube: What can we do? In Andelkovic, M. (Ed.), Proceedings of the 8th Danube Academies Conference (Belgrade, 21-22 September 2017) (pp. 9-16). Serbian Academy of Sciences and Arts.

Hoffmann, M., Brooks, T. M., da Fonseca, G. A. B., Gascon, C., Hawkins, A. F. A., James, R. E., Langhammer, P., Mittermeier, R. A., Pilgrim, J. D., Rodrigues, A. S. L., & Silva, J. M. C. (2008). Conservation planning and the IUCN red list. Endangered Species Research, 6(2), 113-125. doi: 10.3354/esr00087

How cans are made. (n.d.). Can Manufacturers Institute. https://www.cancentral.com/can-stats/how-cans-are-made

Hustrulid, W. F. (2011, February 16). Strip mining. *Encyclopedia Britannica*. https://www.britannica.com/technology/strip-mining

Imteaz, M. A., Ali, M. M., & Arulrajah, A. (2012). Possible environmental impacts of recycled glass used as a pavement base material. *Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA*, *30*(9), 917–921. https://doi.org/10.1177/0734242X12448512

Industries. (n.d.) The Aluminum Association. https://www.aluminum.org/industries

King, H. M. (n.d.). *Bauxite.* Geology.com. https://www.geology.com/minerals/bauxite.shtml

Knott, S. (2019, October 28). Mining Ghana's bauxite would bring in billions from China. But it could also taint the water for 5 million people. *The Washington Post.* https://www.washingtonpost.com/world/africa/mining-ghanas-bauxite-would-bring-in-billions-from-china-but-it-could-also-taint-the-water-for-5-million-people/2019/10/25/e4726518-e3a7-11e9-b0a6-3d03721b85ef_story.html

Mahinroosta, M., & Allahverdi, A. (2018). Hazardous aluminum dross characterization and recycling strategies: A critical review. *Journal of Environmental Management, 223.* 452-468. https://www.doi.org/10.1016/j.jenvman.2018.06.068

NASA. (n.d.) *Overview: Weather, global warming and climate change.* Global Climate Change. https://climate.nasa.gov/resources/global-warming-vs-climate-change/

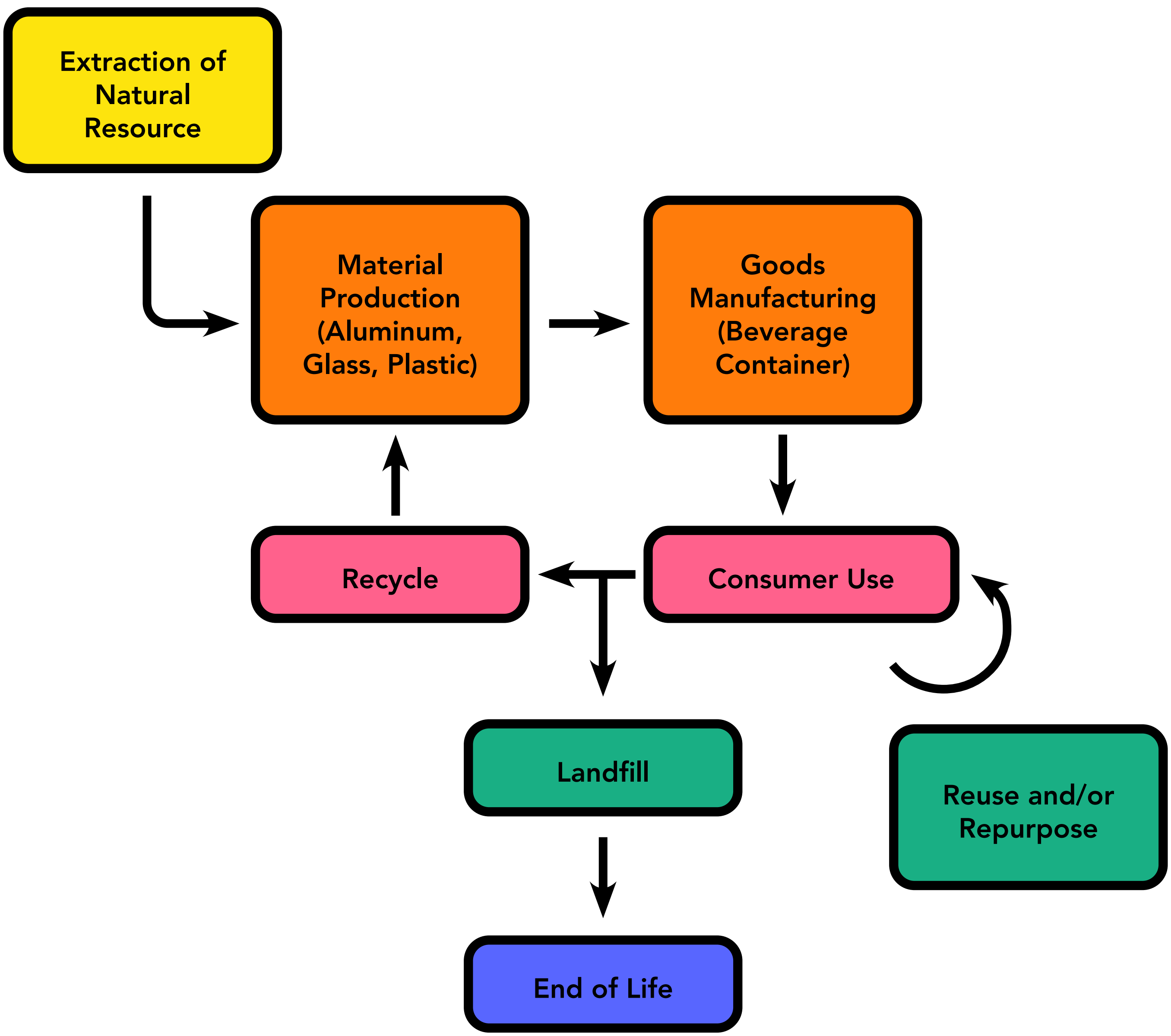
Open Library. (n.d.) *Environmental science.* Pressbooks. https://ecampusontario.pressbooks.pub/environmentalscience/back-matter/appendix/

Reclamation of coastal areas. (n.d.) *Encyclopedia Britannica.* https://www.britannica.com/science/land-reclamation/Reclamation-of-coastal-areas

Timeline for Decomposition. (n.d.). Peace Corps. https://www.peacecorps.gov/educators/resources/timeline-decomposition/

Appendix A

Life Cycle of Materials Diagram



Appendix B

Activity Tables for each material (following pages)

Aluminum Group: What do you think the main elements and environmental impacts of aluminum are at each of its life cycle stages?

Extraction of Raw Materials	Material Production
Key Steps	Items Made from Aluminum
Environmental Impacts	Explain what you think happens to these products. Do you think they are used once and then discarded, refilled, or repurposed?

Aluminum Group: What do you think the main elements and environmental impacts of aluminum are at each of its life cycle stages?

Consumer Uses	Disposal
Key Steps	Disposal Types & Rates Amount of aluminum landfilled: Amount of aluminum recycled: Total amount of aluminum disposed:
Environmental Impacts	Environmental Impacts

Glass Group: What do you think the main elements and environmental impacts of glass are at each of its life cycle stages?

Extraction of Raw Materials	Material Production
Key Steps	Items Made from Glass
Environmental Impacts	Explain what you think happens to these products. Do you think they are used once and then discarded, refilled, or repurposed?

Glass Group: What do you think the main elements and environmental impacts of glass are at each of its life cycle stages?

Consumer Uses	Disposal
Key Steps	Disposal Types & Rates Amount of glass landfilled: Amount of glass recycled: Total amount of glass disposed:
Environmental Impacts	Environmental Impacts

Plastic Group: What do you think the main elements and environmental impacts of plastic are at each of its life cycle stages?

Extraction of Raw Materials	Material Production
Key Steps	Items Made from Plastic
Environmental Impacts	Explain what you think happens to these products. Do you think they are used once and then discarded, refilled, or repurposed?

Plastic Group: What do you think the main elements and environmental impacts of plastic are at each of its life cycle stages?

Consumer Uses	Disposal
Key Steps	Disposal Types & Rates Amount of plastic landfilled: Amount of plastic recycled: Total amount of plastic disposed:
Environmental Impacts	Environmental Impacts

Appendix C

Presentation Notes: Please take notes during the other group's presentations about the following topics.

My assigned material: ________________________________

Aluminum Group

Most important/surprising environmental impacts to me:

Similarity to my material:

Difference from my materia

Glass Group

Most important/surprising environmental impacts to me:

Similarity to my material:

Difference from my material:

Plastic Group

Most important/surprising environmental impacts to me:

Similarity to my material:

Difference from my material:

Send us your Feedback!

Have you tried one (or more!) of the activities? Let us know how it went! We work with the Center for Applied Research and Education Improvement at the University of Minnesota to evaluate this project. Click on the button below to fill out their short evaluation form and help us collect valuable feedback for improvement!

4hpolymers.org/evaluation

MODULE

4

GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation

NSF Center for Sustainable Polymers

4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

National Science Foundation
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Module 4

All About Polymers!

Driving Questions:

- **What is it about plastic that makes it so versatile?**

Introduction

MODULE SUMMARY

Youth use model polymer chains to explore how structure influences material properties. Youth will also observe biodegradation using a variety of material samples. With these two activities, youth will understand the same reasons that make plastics a strong material also contribute to their detrimental environmental effects. **Note: The biodegradation experiment involves a two-week waiting period.**

Time Required:

- Set up for activity: 10 minutes
- Activity 1: 30-50 minutes
- Activity 2: 20-30 minutes per session, two sessions separated by a two week waiting period. Total active time: 45-70 minutes.

TIPS AND CALLOUTS

Facilitator Tips

These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices

The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Define "polymer". • Provide examples of natural and artificial polymers. • Communicate the pros and cons of different material properties and functions.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Developing and using models • Analyzing and interpreting data • Obtaining, evaluating, and communicating information
CONCEPTS & VOCABULARY	• **Biodegradation**: decomposition by bacteria and other microorganisms. • **Degradation**: breaking down into smaller pieces. • **Monomer**: smaller molecules connected in a repeating pattern, forming long polymer chains. • **Plastic**: a type of material made from polymers that can be molded into solid objects. • **Polymer**: a chemical compound formed from long repeating chains of smaller molecules.

Facilitator Preparation

SUGGESTED GROUPINGS

- ☐ Pairs, combining into small groups of 4

MATERIALS NEEDED

- ☐ **Activity 1: Build it and Break it**
  - ☐ Paperclips (40 per person)
  - ☐ Stopwatch (1 per pair) or access to clock for timing in seconds
- ☐ **Activity 2: Investigating Biodegradation**
  - ☐ Spades, trowels, small shovels (1 per group)
  - ☐ Buckets of garden soil/dirt if no access to outdoor location

Facilitator Tip

Soil labeled "seed starting mix" is often sterilized and will not work for this experiment. Biodegradation occurs through microorganisms and a sterilized soil will not have microorganisms present and alive.

  - ☐ Material samples (4 inches x 4 inches):
    - ☐ Styrofoam
    - ☐ Biodegradable plastic bag

Facilitator Tip

Biodegradable bags can be found in many stores near the regular trash bags. Pet stores may also carry biodegradable bags used to collect pet waste.

    - ☐ Plastic shopping bag
    - ☐ Cardboard
    - ☐ Aluminum foil
    - ☐ Food item (piece of bread, lettuce leaf)

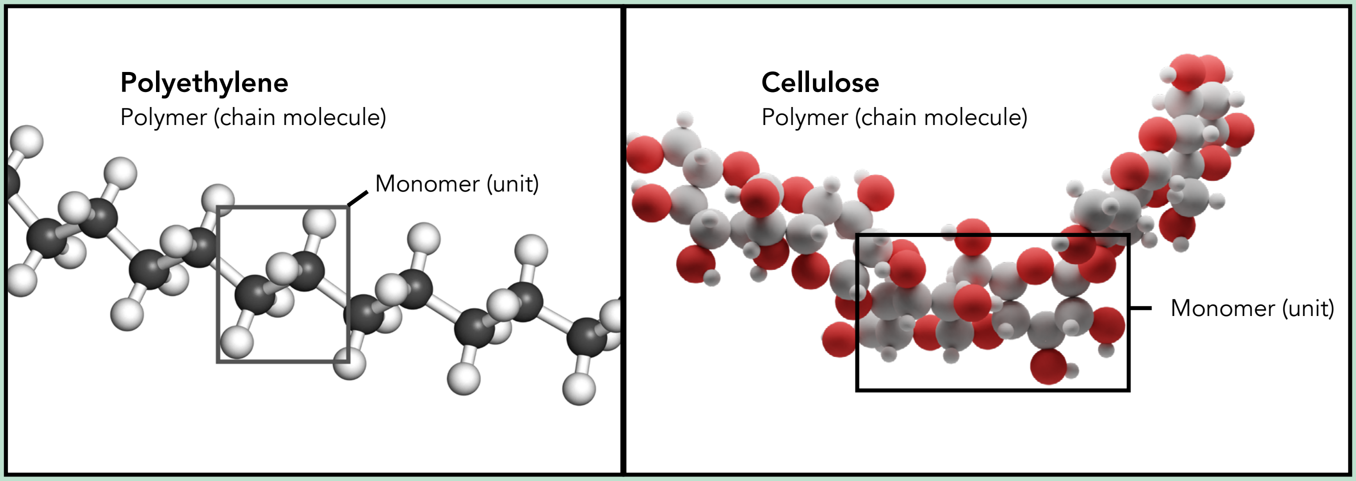
- ☐ Graph or gridded paper
- ☐ Pens, pencils
- ☐ Appendix A: Data collection sheet

GETTING READY

- ☐ Consider how you will sort youth into pairs or small groups.
- ☐ Identify an appropriate outdoor space (or prepare buckets) to bury material samples. Samples should be left undisturbed for 2 weeks.

Background Information for the Facilitator

With the many different types of materials in the world, perhaps no material is as versatile as **polymers**. Polymers are long chain molecules composed of smaller, repeating units (these repeating units are called **monomers**).



There are many different types of naturally occurring polymers, such as DNA and cellulose. Polymers can also be artificially manufactured, like the many types of **plastic** used in consumer products. The words "polymer" and "plastic" are often used interchangeably, but remember - all plastics are polymers, but not all polymers are plastic!

The polymers that make up the plastic products we use everyday are incredibly versatile. Some plastics are transparent, allowing us to see what is packaged inside. Other types of plastic are incredibly strong and tough to provide protection, like helmets or automobile parts. Many types of plastics are lightweight for easier transportation, like airplane components or disposable shopping bags. One common characteristic of plastics is that they are durable and able to withstand many different forces.

What makes plastics so strong and durable? It's their structure! The long polymer chains can be connected in many different ways. One of the most common types of plastics in consumer products is polyethylene (PET). This polymer is made from ethylene monomers refined from oil/petroleum. Carbon-to-carbon bonds hold the polymers chains together and make a durable plastic. There aren't any organisms that can break down the carbon-to-carbon bonds in plastics, so the plastic will not **biodegrade**. Different mechanical forces can cause the plastic to degrade (such as UV light) into smaller pieces, but nothing will truly **degrade** the plastic into harmless pieces. This is the superpower and weakness of plastics - they can be incredibly durable while we're using them, but also incredibly long-lasting after we're done.

Activity 1

Build it and Break it

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- What are some of the advantages of plastic bottles over glass bottles? What are some of the disadvantages of plastic bottles compared to glass bottles?
- When you're done using a plastic bottle and are unable to find a recycling bin, what do you do with it? What happens to the plastic bottle after that point? (Ideally, youth would describe a plastic bottle being placed in the trash and ending up in a landfill or possibly the environment.) How long will that plastic bottle remain in the landfill or if it escapes into the environment as litter?

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. Have each individual youth construct one polymer chain by linking 10 of their paper clips together end-to-end. Youth should explore how flexible their chain is and how much pull/pressure they can exert in different directions. Youth should construct three more polymer chains (separate from the first) by linking the remainder of their paper clips (in groups of 10) in an end-to-end fashion. Each youth will end up with a total of 4 paper clip chains.

Science and Engineering Practices
Developing and using models

2. Have youth pair up. Youth should align their polymer chains in parallel rows; the individual polymer chains should be next to each other but not physically connected. Have youth take turns picking up all eight polymer chains and explore how flexible their "combined" polymer chains are and how much pull/pressure they can exert in different directions. They can also gently toss the chains in the air to see how easily the chains separate.
3. Each pair should now undo their polymer chains, returning each chain into individual paper clips. Youth should time themselves to see how fast they can unlink the polymer chains.

4. Have each pair combine into small groups of about 4-6. Each small group should combine their allotment of paperclips (i.e. each group of 4 should have 160 paperclips). Allow youth to link their individual paperclips into polymer chains (chains should roughly be 10 paperclips in length) that link together physically (by connecting paper clips) in any fashion; for example, chains can connect at multiple midpoints rather than just end-to-end. Youth should again explore how flexible their chain is and how much pull/pressure they can exert in different directions.
5. Each small group should now undo their combined polymer chain. Youth should time themselves to see how fast they can unlink the polymer chain into individual paperclips.

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- What differences did you notice between the individual paperclip chain, the adjacent paperclips chains, and the interconnected paperclip chain? How difficult was it to disassemble the different chain types?
- What if the "polymer chain" was made of something other than paperclips (like rubber bands, paper links, or doughnuts!) - how would that affect the properties of the structure? How could you disassemble the chains?

Facilitator Tip
If you have additional material types available, youth can try the same linking activity using a different material and comparing the experience to the paperclip polymer chain.

CONCEPT AND TERM DISCOVERY/INTRODUCTION

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of young peoples' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

- Research how long it takes for different plastic items to degrade. Create infographics that illustrate this time scale and encourage your community to dispose of plastics responsibly.

Activity 2

Investigating Biodegradation

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- What have you heard about composting? What is happening with that process?
- What are some of the advantages of composting versus disposing of trash in a landfill?

Facilitator Tip
You could use a KLW chart to capture what youth want to know (or think they **k**now) about composting, what they want to **l**earn, and what they **w**onder about.

- What kinds of things will biodegrade in a composting facility? What kinds of things won't biodegrade?

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. **Session 1**: Using graph or gridded paper, youth should trace the shape of each sample to log its original size and shape. Youth should also make predictions on what they think the final size and shape of each sample might be on the data collection sheet (Appendix A).
2. Identify where you will be able to dig small holes in the soil. If no suitable location outside exists, you may place the samples in buckets of gardening soil/dirt (you should water these buckets occasionally, about once every 2-3 days. In cold weather/climates, you may have more success keeping the containers indoors, preferably in a sunny location). The samples should be left in a place undisturbed for 2 weeks.

3. Dig out a small hole about 12 inches x 12 inches (30 cm x 30 cm) across and 4 inches (10 cm) deep. Place samples of each material into the hole, making sure the samples are not touching each other. Cover with soil and place a marker over the samples to help you find them later. Be sure to wash hands after working with the soil.

Science and Engineering Practices
Planning and carrying out investigations

4. **Session 2**: After 2 weeks, return to the sample site and carefully dig up the samples. Samples may be fragile so place them in a tray or box to move them.
5. Using graph or gridded paper, have youth trace the shape of each sample to log its resulting size and shape. On the paper, youth should mark any squares where they notice the material is changing or breaking down and make any additional notes about each sample.
6. Youth should organize the samples into most biodegradable and least biodegradable categories. Ask youth to compare and contrast the material samples that were biodegradable and those that were not biodegradable.

Facilitator Tip
If this activity is being done in a setting with prolonged instruction, you can carefully re-bury the samples for another 2 weeks and re-examine.

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- If this experiment was carried out over the next month, or even the next year, what would you expect to see?

Science and Engineering Practices
Analyzing and interpreting data

- What variables might have affected the biodegradability of the samples? How would you design this experiment differently next time? What other materials would you want to test?

CONCEPT AND TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

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1. After completing the "Investigating Biodegradation" experiment (Activity 2), conduct the follow-up experiment suggested by youth during the reflection phase.
2. Research composting options in your community. Are there resources for backyard composting? Industrial composting via drop off or collection service? Create infographics that explain what items are allowed/not allowed for backyard and/or industrial composting.

REFERENCES

Biodegradability Experiment. (2015, February 23). Science Learning Hub. https://www.sciencelearn.org.nz/resources/1549-biodegradability-experiment

How it works team. (2019, April 21). *Plastic: The science behind the indestructible*. How It Works Daily. https://www.howitworksdaily.com/plastic-the-science-behind-the-indestructible/

Appendix A

Data Collection Sheet

Name of material	Original Size and Description	Prediction after 2 weeks

After 2 weeks:

Name of material	Final Size and Description	Is this material biodegradable?

What material showed the most evidence of biodegradation? What material showed the least evidence?

What follow up experiment would you do or what additional questions would you investigate?

Send us your Feedback!

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4hpolymers.org/evaluation

MODULE
5
GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation | NSF Center for Sustainable Polymers

4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

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Module 5

The Plastic Life Cycle

Driving Questions:

- **What happens to all the plastic we continue to consume?**
- **What impacts does plastics have on the environment?**

Introduction

MODULE SUMMARY

Youth simulate becoming a particle of "plastic" and follow it from one learning station to another throughout its material life cycle, being extracted, manufactured, consumed, and disposed. The resin code the plastic is manufactured in to, and chance encounters (dice rolling) determine end-of-life: refuse/landfill (or ocean), recycle, recovery/energy, or reuse.

Time Required:

- Setup: 30-60 minutes
- Activity: 60 minutes

TIPS AND CALLOUTS

Facilitator Tips
These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices
The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Describe the consequences of each post-life option for plastic products. • Obtain, evaluate, and communicate information about environmental impacts resulting from plastic disposal.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Constructing explanations and designing solutions
CONCEPTS & VOCABULARY	• **Disposal/Trash**: the action or process of throwing away or getting rid of something. • **Petroleum**: oil extracted from the earth that can be used for fuel or made into plastic. • **Pollution**: contamination by waste, chemicals, or other harmful substances to an environment. • **Reduce**: decreasing consumption of plastic; consumers buying less plastic; or manufacturers using less plastic. • **Reuse**: the act of reusing a product for the same purpose that it was designed (e.g., a refillable water bottle). • **Recycle**: the process of converting waste materials into new objects. • **Recovery (Energy)**: Incinerating plastic to generate energy. • **Repurpose**: using a product for a purpose other than it was designed. • **Landfill**: site where waste from the community is taken. • **Litter**: items not disposed in recycling, compost, or trash receptacles are instead disposed of in the environment.

Facilitator Preparation

SUGGESTED GROUPINGS

- ☐ Pairs or small groups of 3

MATERIALS NEEDED

- ☐ 2, 20-sided die (these are available online or in toy/game stores).
- ☐ 3, 6-sided die
- ☐ *Learning Station Set-Up Map (Appendix A)
- ☐ *Learning Station Instructions (Appendices B-J)
- ☐ *Petroleum Barrel Cards for Station 1 to Station 2 (Appendix K)
- ☐ *Plastic Resin Cards for Station 2 (Appendix L); or real plastic items corresponding to various resin symbols.

Note: The materials will be divided among learning stations. Set up the learning stations using the guide provided in Appendix A.

GETTING READY

- ☐ Make copies of Appendices to place at respective learning stations.
- ☐ Make copies of the product cards (Appendix L) and cut them out. While the index cards may be used, the learning experience may be strengthened by providing real plastic items, corresponding to various resin symbols.
- ☐ Organize learning stations, and set up materials, as shown in Appendix A.
- ☐ Position plastic card/items at the Extraction Station 1 at least 3 per group (for example, 3 items x 5 groups = 15 plastic card/items).

Background Information for the Facilitator

Where does plastic go once you are done with it? The simple, and disturbing, answer is that the vast majority of non-degradable plastic waste is dumped into landfills or scattered through the environment and ocean; over 75% of plastic waste is landfilled, 16% combusted for electricity generation, and 9% recycled (the EPA does not measure other post-life alternatives, such as reusing, reducing, or rot/composting). One author put it this way:

> *The simple fact is, there is just too much plastic — and too many different types of plastics — being produced; and there exist few, if any, viable end markets for the material. – Michael J. Sangiacomo (op-ed, San Francisco Chronicle, Dec. 24, 2018)*

Life Cycle Impacts

Beyond the negative environmental impacts of plastic at the end of their life, there are impacts thorough the plastic life cycle, from extraction of raw materials (petroleum), to manufacturing, and transportation. A life cycle assessment provides a more systematic understanding and holistic perspective of the totality of impacts, from the production of greenhouse gas emissions to energy use, water use, human toxicity, and land use. While this module focuses on helping youth understand the life cycle of plastic, it is important to know that a life cycle analysis can be completed for other materials (e.g., paper, aluminum, and glass) to learn about the total environmental impacts of a product; understanding the full life cycle can help avoid problem shifting when other impacts are largely invisible to the consumer.

Material End-of-Life

Plastic – due to its strong chemical bonds – means it may take years to decompose. Most plastic never fully decomposes, larger pieces just become smaller pieces. While the abundance of plastic rests in landfills, some finds its way to the natural environment and ocean (e.g., the Great Pacific Garbage Patch). Roughly 10% of plastic refuse – including extremely harmful microplastics – ends up in the world's oceans (Thompson, 2006; Worm et al., 2017). These facts have led to the assertion that there is a (Micro)plastic crisis. Plastic pieces can be harmful to wildlife and marine animals; e.g., animals may mistake plastic for food and starve, animals may be entangled, or chemical residue may cause liver and cell damage or reproductive harm.

While most of the plastic is landfilled, there are alternative end-of-life routes, popularized by the Rs: Reduce, Reuse, Recycle (& Recovery). This easy-to-remember hierarchy has become ubiquitous in various efforts to reduce environmental impact, although most messages do not emphasize the inherent hierarchy. In this module, youth will experience the material life cycle of a unit of plastic and find their way to various end-of-life options; youth will then discuss what they think are preferences and strategies to mitigate negative environmental impacts of plastics.

Reduce
The most effective method to reduce plastic waste is not to create it. The creation of a product – including extraction of raw materials, manufacturing, and transportation – uses a lot of energy and generates pollution. There are two primary types of reduction: (1) consumer-driven whereby consumers do not purchase (refuse) or purchase used plastic products; and (2) industry-driven where manufacturers and businesses use alternatives or reduce the amount of plastic in an item or its packaging.

Reuse/Repurpose (Upcycle)
Reusing a plastic product helps increase its lifespan. Consumers might repurpose or upcycle an item for a new purpose other than what it was originally intended. Products may be maintained and repaired, rented, or shared to increase lifespan. It is important to note, however, that reusable products are not always better; for example, sometimes alternatives have higher overall environmental impact (e.g., cotton shopping bags require approximately 7,100 uses to equal the total environmental impact of a single-use grocery bag; Bisinella et al., 2018). Additionally, products intended for reuse (like a water bottle) must be sturdier and thus contain more material than single use items. Consumers need to reuse the item many times in order to make it environmentally beneficial. One possible unfortunate scenario is the accumulation of reusable water bottle giveaways, that are not of sufficient quality to incentivize reuse, or where consumers accumulate more bottles than they can use..

Recycle
Recycling is the process of converting waste materials into new products. Recycling reduces the amount of waste sent to landfills, prevents pollution, and may boost the economy through new jobs. The benefit to recycling is contingent upon a reduction in raw material extraction. Unfortunately, technologies involved with recycling are not yet sufficient to prevent degradation of material quality, thus new plastic from newly extracted oil still needed until technology improves. There are several steps to recycling, starting with collecting and processing before moving to manufacturing. The collection of materials for recycling is easy and has been heavily promoted by municipal agencies; recycle bins are ubiquitous at homes, in parks, and stores. Processing the collected items can be difficult and challenging. There needs to be a market for the recycled materials; currently, only a few types of plastics (noted by the resin code symbol) have a market, and thus these plastics must be carefully sorted by type. Until recently, Asia was the largest importer of plastic for recycling, but many counties have banned imports, causing disruption in the global recycling industry. Without adequate recycling infrastructure, most plastic sorted into recycle bins is diverted to landfills.

Recovery
The EPA reports that approximately 16% of plastic waste is used for energy recovery, typically in industrial plants for electricity generation that substitutes plastic waste for other fossil fuels. This process releases pollutants (e.g., CO2) but often only 2/3rds the amount compared to coal. Others have advocated for the use of plastics in iron and steel production as a replacement for coal.

Activity

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Describe what you think happens to plastic items once they reach the end of their intended use.
- Discuss what you know about recycling.

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. Position all groups in the Extraction Station 1 as indicated in Appendix A.
2. Explain to the group that they will follow the path of plastic in its entire life cycle. They will start as petroleum in the ground and have an adventure through the life cycle.
3. Provide each pair/small group with an "petroleum" card (or block of plastic) representing a generic unit of plastic.
4. Let each group proceed to the next learning station – Material Manufacturing 2 – with some time (approximately 30-60 seconds) between each group.
5. Each pair/small group of youth journeys through different paths taken by plastic.
6. Once the youth reach an endpoint (Stations 4, 7, 8, or 9), leave their plastic card/item, and proceed back to the Extraction Station 1.
7. The game ends after each team have gone through the cycle 3 or 4 times; or when there are no more plastic cards/items at the Extraction Station 1.

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- Invite youth to share the story of "who" they were at Station 3.
- Invite youth to make observations and discuss the resulting placements of plastic cards/items. Ask youth to add the number of plastic pieces remaining at each station and divide by the total number of plastic pieces used in the activity to calculate the percentages of plastic at each station. Ask youth to describe and explain their thoughts about the resulting proportion of plastic at each station.
- Ask groups to sort the R's into "most preferred" and "least preferred" methods, include a justification, and then share out with the full group.
    - Reduce
    - Reuse/Repair/Repurpose
    - Recycle
    - Recovery (energy)
    - Trash/Landfill
- Discuss what might help mitigate negative environmental impacts for plastic end-of-life options.

CONCEPT/TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of young peoples' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

- Research an organization that help the community reduce, reuse, or recycle in some way. What services do they provide? How do they help reduce our environmental impact? What do they do with the plastic they receive?
- Look into important moments in history related to reducing, reusing, and recycling. For example, laws, practices, or inventions. How do other countries around the world reduce, reuse, or recycle?
- Create a stop animation challenge that demonstrates and narrates various plastic bottle life cycles (reuse, recycle, landfill).
- Develop a personal plan-of-action to do more of the "preferred" R and less of the "least preferred" R.

Science and Engineering Practices
Constructing explanations and designing solutions

REFERENCES

American Chemistry Council. (2020, March). *U.S. Resin Production & Sales 2019 vs. 2018.* https://plastics.americanchemistry.com/Year-End-Resin-Stats.pdf

Bisinella, V., Albizzati, P. F., Astrup, T. F., & Damgaard, A. (Eds.) (2018). *Life Cycle Assessment of grocery carrier bags.* (n.d.) Danish Environmental Protection Agency. Miljoeprojekter No. 1985 https://www2.mst.dk/Udgiv/publications/2018/02/978-87-93614-73-4.pdf

Devasahayam, S., Raju, G. B., Hussain, C. M. (2019). Utilization and recycling of end of life plastics for sustainable and clean industrial processes including the iron and steel industry. *Materials Science for Energy Technologies, 2*(3), 634-646. https://doi.org/10.1016/j.mset.2019.08.002

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 364*(1526), 2115–2126. https://doi.org/10.1098/rstb.2008.0311

Lebreton, L., Slat, B., Ferrari, F., et al. (2018). Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. *Scientific Reports 8*, 4666. https://doi.org/10.1038/s41598-018-22939-w

Miller, S. A. (2020). Five misperceptions surrounding the environmental impacts of single-use plastic. *Environmental Science and Technology, 54*(22), 14143-14151. https://pubs.acs.org/doi/10.1021/acs.est.0c05295

Parker, L. (2019). The world's plastic pollution crisis explained. *National Geographic.* https://www.nationalgeographic.com/environment/article/plastic-pollution

Sangiacomo, M. J. (2018, December 24). It is time to cut use of plastics. *San Francisco Chronicle.* https://www.sfchronicle.com/opinion/openforum/article/It-is-time-to-cut-use-of-plastics-13489726.php

Shen, M., Haung, W., Chen, M., Song, B., Zeng, G., Zhang, Y. (2020). (Micro)plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. *Journal of Cleaner Production, 254*(1). Retrieved from https://doi.org/10.1016/j.jclepro.2020.120138

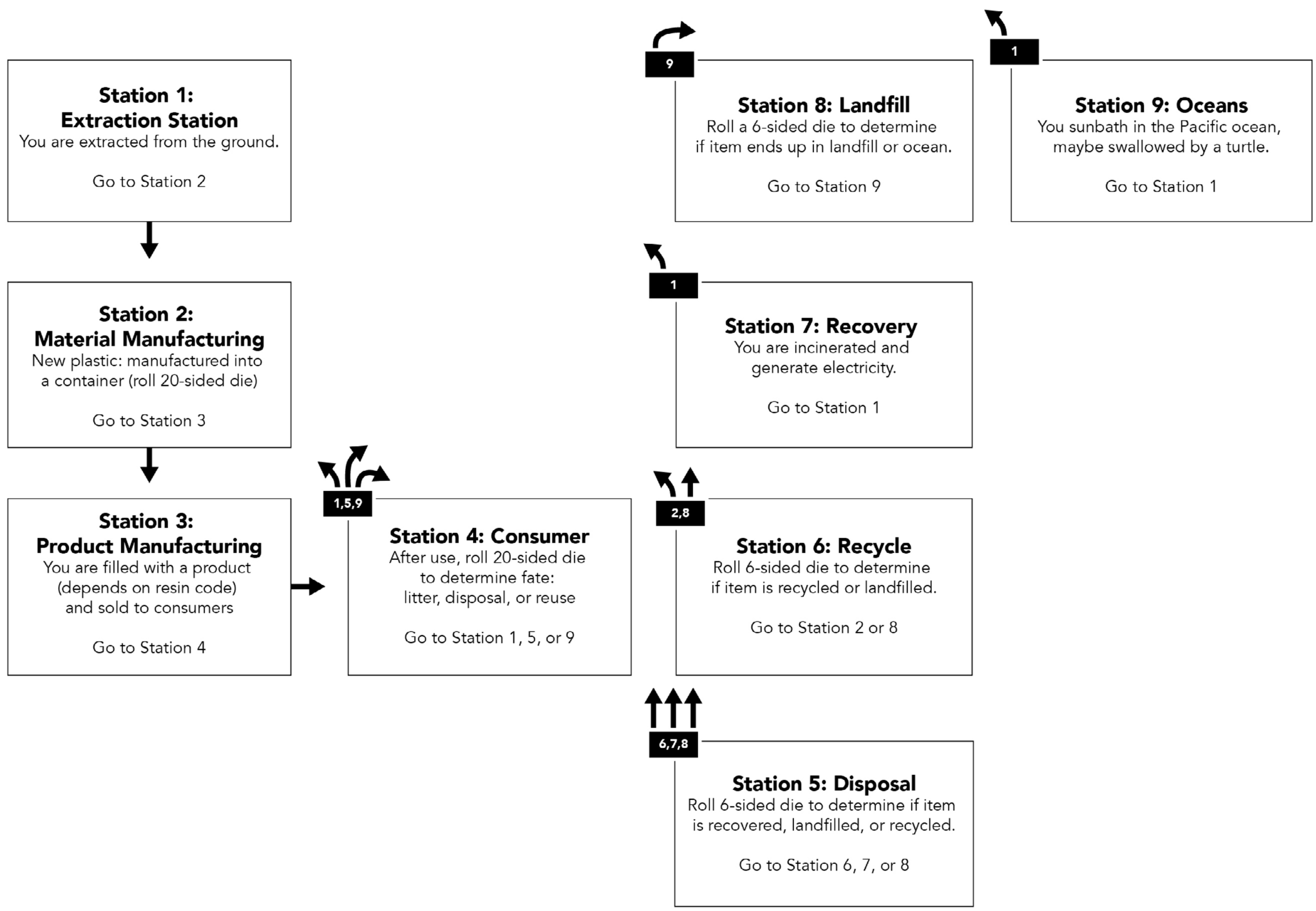
Thompson, R. C. (2006). Plastic debris in the marine environment: Consequences and solutions. In J. C. Krause, H. Nordheim, & S. Bräger (Eds.), *Marine nature conservation in Europe* (pp. 107–115). Bundesamt für Naturschutz.

U.S. Environmental Protection Agency. (2021). *Plastics: Material-Specific Data.* https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data

Worm, B., Lotze, H. K., Jubinville, I., Wilcox, C., & Jambeck, J. (2017). Plastic as a persistent marine pollutant. *Annual Review of Environment and Resources, 42*(1), 1-26. Retrieved from https://doi.org/10.1146/annurev-environ-102016-060700

Appendix A

Diagram of Room Set-Up for Learning Stations



* Probabilities for dice rolls developed to mirror estimated U.S. plastic production and end-of-life options (American Chemistry Council, 2020; Environmental Protection Agency, 2021; Hopewell et al., 2009)

Appendix B

Learning Station 1
Instruction Card

STATION: EXTRACTION

Summary

- Millions of years ago, you were algae and plants that died and sank to the seafloor. You were buried and over millions of years under high pressure and temperature, your remains transferred into petroleum.
- You have been pumped from an underground reservoir into a barrel. You (crude oil) are usually black or dark brown, but can also be yellowish, reddish, tan, or even greenish, depending on the composition of chemicals.

Environmental Impacts

- The extraction of petroleum can disrupt wildlife habitats, release pollutants into the air and water, and the drilling equipment requires energy (typically generated by burning fossil fuels and contributing to greenhouse gas emissions).
- Oil is considered a non-renewable resource because it is available in limited quantities and takes millions of years to be replenished.

Directions:

1. Pick-up an oil barrel card. Read it as you begin your journey to material manufacturing (proceed to Station 2).

Appendix C

Learning Station 2
Instruction Card

MATERIAL MANUFACTURING

Summary

- You (oil) are transported to a refinery by pipeline, land, or sea. At the refinery, oil is distilled into various useful groupings and impurities are removed. Various processes are used to produce dozens of types of plastic, linking together polymer chains (at the molecular level), each with its own properties, structure, and size. There are six primary types of plastic noted by the resin code.

Environmental Impacts

- The transportation of oil to a refinery requires energy, typically by burning fossil fuels and causing greenhouse gas emissions. Refining releases chemicals into the air leading to air pollution and causing a notable odor (although the U.S. has mandated restricts on contaminants and required technologies to reduce emissions).

Directions for Recycled Plastic

1. If you came from the Recycle station, you are manufactured back into the same item.

Directions for Crude Oil – Become New Plastic

1. If you came from the Extraction station, you are manufactured into one of the following (roll a 1d20). On a roll of:

• 1, 2, or 3, you are made into a beverage bottle	1 PETE
• 4, 5, 6, or 7, you are made into a milk jug	2 HDPE
• 8, 9, or 10, you are made into PVC pipe	3 V
• 11, 12, 13, 14, 15, or 16, you are made into a plastic bag	4 LDPE
• 17, 18, or 19, you are made into a food container	5 PP
• 20, you are made into packaging peanuts	6 PS

2. Pickup the corresponding card or item and proceed to Station 3.

Appendix D

Learning Station 3
Instruction Card

PRODUCT MANUFACTURING AND SELLING TO CONSUMERS

Summary

- You are transported to a company that will sell you for use. Depending on the type of plastic product, you might be filled with liquid (for beverage containers) or sold to restaurants (for food containers), or prepared for other uses.

Environmental Impact

- Transportation of plastic containers or products requires energy – trucks, boats, planes – which produce greenhouse gasses. However, because plastic is much lighter than glass, or even aluminum, the energy required for transportation is less when compared to glass and aluminum, thus emitting fewer greenhouse gas emissions.

Directions

1. Create a brief story of who “you” are as a plastic product. Who are you sold to and why? What will the consumer who purchased you use you for?! What type of marketing did the company use to sell you?
2. Proceed to the Consumer Use Station 4

Appendix E

Learning Station 4
Instruction Card

CONSUMER USE

Summary

- You are purchased by a consumer for use. Perhaps the consumer will keep you for a long time, or reuse you for another purpose? Most likely the consumer will dispose of you after your intended use is completed.

Environmental Impacts

- Consumer use in itself likely does not have significant environmental impacts.

Directions: Roll a 1d20. On a roll of:

- 1 = Consumer litters you in the environment and you are washed out to the ocean. Go to the Ocean Station 9.
- 2 to 18 = Consumer disposes of you, proceed to Disposal Station 5.
- 19 or 20 = Consumer keeps you and reuses you for another purpose. Keep product/item here and proceed to the Extraction Station 1 to start anew.
  - Reusing a plastic product helps increase its lifespan. Consumers might repurpose or upcycle an item for a new purpose other than what it was originally intended. Products may be maintained and repaired, rented, or shared to increase lifespan. Consumers need to reuse the item many times in order to make it environmentally beneficial.

Appendix F

Learning Station 5
Instruction Card

DISPOSAL

Summary

- The consumer is done with you (plastic product) and disposes of you. Perhaps the consumer places you in a trash or recycle bin for the municipal waste agency to pick-up?
- Perhaps the consumer returns you to a local recycling center, if your community even has one available, and you are a type of plastic accepted for recycling? Every city has a different standard for what types of plastic they will accept. PET #1 and HDPE #2 plastic bottles and jugs are the most commonly items recycled. Unfortunately, plastics #3 through #7, while collected by many recycling programs, are often sent to landfills, or incinerated instead.

Environmental Impacts

- Local waste disposal company service requires energy for collection and sorting, which contributes to greenhouse gas emissions.

Directions

- If you are PETE (1) or HDPE (2), roll a 1d6. On a roll of:
  - 1 or 2 = Go to Recycling Station 6
  - 3 = Go to Recovery Station 7
  - 4, 5, or 6 = Go to Landfill Station 8
- All other plastic types, roll a 1d6. On a roll of:
  - 1 or 2 = Go to Recovery Station 7
  - 3 to 6 = Go to Landfill Station 8

Appendix G

Learning Station 6
Instruction Card

RECYCLE FACILITY

Summary

- You are sent to a recycling facility to be sorted and hopefully converted into another product! Processing the collected items can be difficult and challenging. Only a few types of plastics (noted by the resin code symbol) can be recycled, and thus plastics must be carefully sorted by type. Unfortunately, without adequate recycling infrastructure, most plastic sorted into recycle bins is diverted to landfills. US recycles on average 8% of all plastic; however, around 30% of plastic bottles are recycled.

Environmental Impacts

- Successful recycling reduces the amount of waste sent to landfills, prevents pollution, and may boost the economy through new jobs.

Directions: Roll a 1d6. On a roll of:

- 1 to 4 = You are successfully recycled. Go to the Station 2: Material Manufacturing!
- 5 or 6 = You are not successfully recycled, perhaps due to a sorting error, contamination, or lack of a market (buyer) for recycled plastic. Go to Landfill Station 8

Appendix H

Learning Station 7
Instruction Card

RECOVERY

Summary

- You find your way to an electrical plant where you are incinerated to generate electricity. Or perhaps you are used in iron and steel production as a replacement for coal.

Environmental Impacts

- Incinerated plastic saves space in landfills and prevents plastics from entering the natural environment or ocean.
- Incineration releases pollutants (e.g., CO_2) but often only 2/3rds the amount compared to coal (although not when compared to gas)
- May release other chemicals leading to air pollution if the incineration process is inefficient or lacks safeguards.
- Some argue that burying plastic in landfills may help keep carbon out of the air, thus helping to reduce overall greenhouse gas emissions.

Directions

- You are incinerated and generate electricity. Keep product/item here and proceed to the Extraction Station 1 to start anew.

Appendix I

Learning Station 8
Instruction Card

LANDFILL

Summary

- Youth find yourself in a landfill, also known as a dump, a site for the disposal of waste. Plastic – due to its strong chemical bonds – means it may take hundreds or thousands of years to decompose. Most plastic never fully decomposes, larger pieces just become smaller pieces.

Environmental Impacts

- Plastics may leach chemicals causing surface water pollution (e.g., streams, lakes, and ponds) or groundwater pollution.
- Some argue that burying plastic in landfills may help keep carbon out of the air, thus helping to reduce overall greenhouse gas emissions. Plastic in landfills may have the lowest impact on climate change, however, is the most detrimental to circularity and fossil resource use and has the most potential to pollute the environment through plastic leakage.

Directions: Roll a 1d6. On a roll of:

- 1 = Something happened on the way to, or in the landfill, and you are set free in the natural environment. Go to the Station 9 Ocean.
- 2 to 6 = You sit in the Earth for thousands of years. Keep product/item here and proceed to the Extraction Station 1 to start anew.

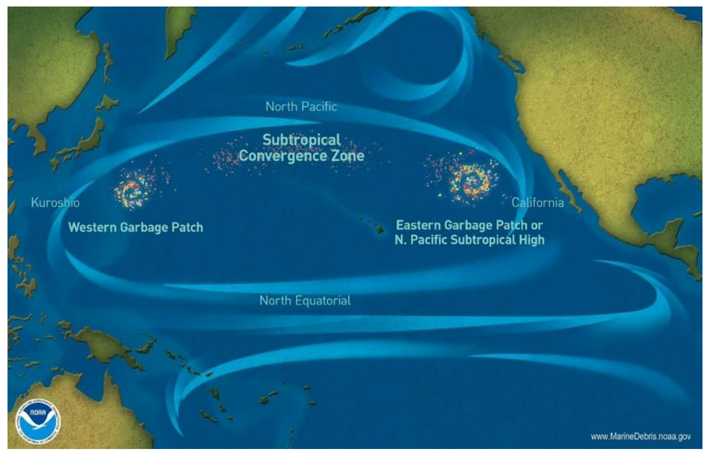
Appendix J

Learning Station 9
Instruction Card

NATURAL ENVIRONMENT AND OCEANS

Summary

- While most plastic waste goes to a landfill, some finds its way to the natural environment and ocean. Over 8 million tons of plastic are estimated to end up in our oceans every year. Plastic waste makes up 80% of all marine debris from surface waters to the deep sea. There is so much plastic waste floating in the Pacific ocean that a spot has been named the Great Pacific Garbage Patch.



Environmental Impacts

- Plastic pieces can be harmful to wildlife and marine animals; e.g., animals may mistake plastic for food and starve, animals may be entangled, or chemical residue may cause liver and cell damage or reproductive harm.

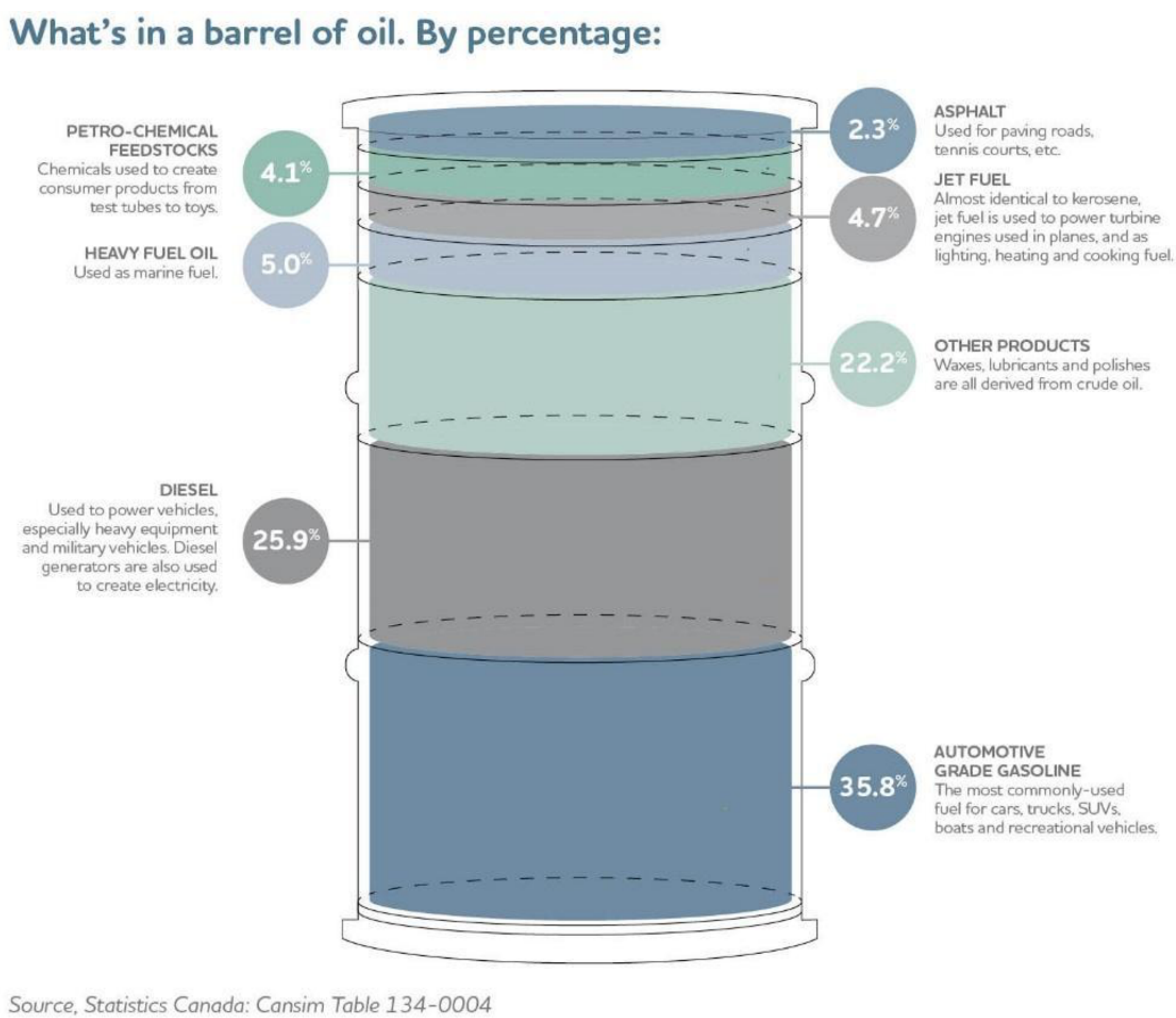
Directions

- You sunbath in the Pacific ocean, stuck forever sitting, swirling in the ocean. Keep product/item here and proceed to the Extraction Station 1 to start anew.

Appendix K

Petroleum Barrel Cards for Station 1 to Station 2

- There are 42 gallons in a standard U.S. barrel of crude oil.
- About 4% is refined into petro-chemical feedstocks (hydrocarbon gas liquids) used to make paints, plastics, and synthetic rubber.



Appendix L

Plastic Resin Cards for Station 2

1. *Cards are on the following pages*
2. *Some pages are intentionally blank for proper printing*

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

1 PETE

PETE

Polyethylene terephthalate

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

1 PETE

PETE

Polyethylene terephthalate

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

1 PETE

PETE

Polyethylene terephthalate

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

1 PETE

PETE

Polyethylene terephthalate

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

2 HDPE

HDPE

High-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

2 HDPE

HDPE

High-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

2 HDPE

HDPE

High-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

2 HDPE

HDPE

High-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

03
PVC

PVC
Polyvinyl chloride

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

03
PVC

PVC
Polyvinyl chloride

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

03
PVC

PVC
Polyvinyl chloride

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

03
PVC

PVC
Polyvinyl chloride

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

LDPE

Low-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

LDPE

Low-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

LDPE

Low-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

LDPE

Low-density polyethylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

PP
Polypropylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

PP
Polypropylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

PP
Polypropylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

PP
Polypropylene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

06
PS

PS
Polystyrene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

06
PS

PS
Polystyrene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

06
PS

PS
Polystyrene

HTTPS://WWW.4HPOLYMERS.ORG/

SUSTAINABLE POLYMERS:
CONFRONTING THE PLASTIC CRISIS

06
PS

PS
Polystyrene

HTTPS://WWW.4HPOLYMERS.ORG/

Send us your Feedback!

Have you tried one (or more!) of the activities? Let us know how it went! We work with the Center for Applied Research and Education Improvement at the University of Minnesota to evaluate this project. Click on the button below to fill out their short evaluation form and help us collect valuable feedback for improvement!

4hpolymers.org/evaluation

MODULE
6
GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation

NSF Center for Sustainable Polymers

4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

National Science Foundation

NSF Center for Sustainable Polymers

Module 6

The Plastics Future: Bioplastics

Driving Questions:

- **How can we develop materials that are like plastic but have fewer negative impacts?**
- **What are the advantages and disadvantages of renewable plastics?**

Introduction

MODULE SUMMARY

In activity 1, youth will explore the properties of different plastic types to understand the advantages and disadvantages based on application. If the group has access to a microwave, youth will create their own bioplastic sample from cornstarch. If no microwave is available, store bought samples of different plastic cups will be tested to explore how the properties of materials affect its function.

In activity 2, youth are challenged to create a sustainable polymer container that can hold a liquid and explore future uses for this type of polymer as they identify and test variables. In Part 1, youth will make the pods following a lab procedure designed by scientists at the NSF Center for Sustainable Polymers. In Part 2, youth will make a change to a variable, make a prediction, and test what happens.

Time Required:

- Set up for activities: 15 minutes
- Activity 1: 40-60 minutes
- Activity 2: 70-105 minutes

TIPS AND CALLOUTS

Facilitator Tips

These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices

The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Communicate the advantages and disadvantages of renewable and traditional polymers. • Obtain, evaluate, and communicate information about the future of renewable polymers.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Obtaining, evaluating, and communicating information • Designing solutions
SUGGESTED GROUPINGS	• 2-4 youth
CONCEPTS & VOCABULARY	• **Biodegradation**: decomposition by bacteria and other microorganisms • **Bioplastic**: polymer often made from starch-containing plants, such as corn and potatoes. Many of these bioplastics are compostable. • **Degradation**: breaking down into smaller pieces. • **Plastic**: a type of material made from polymers that can be molded into solid objects. • **Polymer**: a chemical compound formed from long repeating chains of smaller molecules. • **Renewable resource**: resources that can be replenished, often within one person's lifetime. • **Sustainable**: able to be maintained or run continuously with little or no negative impact on the environment or health. • **Sustainable polymer**: a plastic material that addresses the needs of consumers without damaging our environment, health, or economy.

Facilitator Preparation

ACTIVITY 1: COMPARING POLYMERS

- ☐ 2 polylactic acid (PLA) cups per group (usually labeled #7)
- ☐ 2 polystyrene (PS) cups per group (usually labeled #6)
- ☐ Small bowl, 1 for each small group
- ☐ Tweezers or tongs, 1 for each small group
- ☐ Scissors
- ☐ Hairdryer
- ☐ Boiling water
- ☐ Permanent Marker
- ☐ Optional (with microwave access):
  - ☐ Microwave oven
  - ☐ Per youth:
    - ☐ 1 Zipper-top plastic bag (sandwich or quart size) or small glass bowl
    - ☐ 2 Tablespoons cornstarch
    - ☐ 2 Tablespoons water
    - ☐ 2 drops vegetable oil
    - ☐ Pipette or eye dropper (can be shared)
    - ☐ Food coloring (2-3 drops per youth)
    - ☐ Spoons to stir mixture if using bowls

GETTING READY

- ☐ Locate or provide microwave access.
- ☐ Collect materials for each youth – you may have youth measure out quantities or provide youth with pre-measured amounts.
- ☐ Watch a video illustrating the basic procedure of making a bioplastic: https://youtu.be/xLzaI95x5MQ

ACTIVITY 2: CREATE HYDROPODS

- ☐ Electric blender
- ☐ 1-quart bowl
- ☐ 3- quart bowl
- ☐ Cold water
- ☐ Sodium alginate; ¼ tsp for each group
- ☐ Calcium lactate; 1 tsp for each group
- ☐ ¼ tsp measuring spoon
- ☐ 1 tsp measuring spoon, 1 per group
- ☐ Large spoon for mixing, 1 per group
- ☐ Other round spoons for experimentation (e.g. Tablespoon measuring spoon, melon-ball scoop, ice cream scoop)
- ☐ Other liquids for experimentation (recommended: apple juice, orange juice, lemon juice, sports drink)
- ☐ Paper towels
- ☐ Food coloring
- ☐ Safety goggles for each youth
- ☐ Access to sink with soap to wash hands
- ☐ Bleach wipes or spray to sanitize work surfaces

GETTING READY

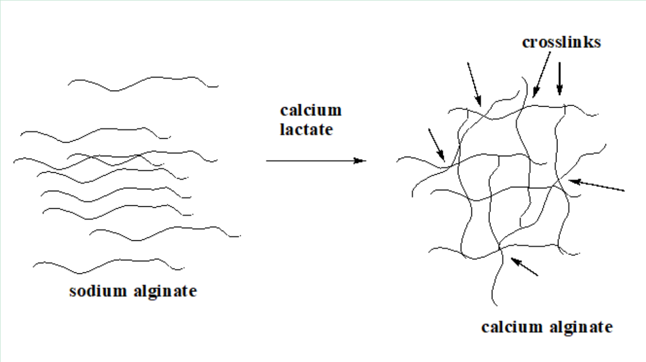
- ☐ Food-grade sodium alginate and calcium lactate can be found at natural food stores or online.
- ☐ Adults should supervise the use of the blender.
- ☐ Wash hands thoroughly before and after the HydroPods activity.

Background Information for the Facilitator

Many of our everyday materials are made from **plastics** – from one-time use water bottles and grocery bags to durable safety equipment like helmets and car parts. Plastics have many advantages because they are durable, lightweight, and easy to produce. The majority of plastic we use comes from petroleum (also known as oil). One major disadvantage of petroleum-based plastic is that it comes from a non-renewable resource. Recycling and re-using can help lessen this disadvantage, however only a small percentage of plastics are recycled. Of all the plastic used for packaging, only 14% is collected for recycling. Most of the plastic we use finds its way to landfills as garbage or escapes out into the environment. Once out in the environment, plastics can cause many environmental challenges because they do not **biodegrade**.

Lessening the negative environmental effects of plastics, while utilizing their many advantages, is one problem many scientists and engineers are working on. Researchers at the NSF Center for Sustainable Polymers (csp.umn.edu) are working to develop **sustainable polymers, bioplastics**, or plastics made from **renewable resources**. The goal for sustainable polymers is to be competitive with traditional polymers in the entire life cycle: economically feasible to manufacture, durable for consumer use, and easily biodegradable at the end of the products' lifetime. The most common bioplastic in today's market is polylactic acid (known as PLA). PLA is made from corn and PLA products can be composted at industrial composting facilities. Some commonly found PLA products include cups, plastic eating utensils, and plastic bags.

Even with new advancements in plastics, bioplastics may also have some disadvantages. Some bioplastics do not have the same material properties as their petroleum-based counterparts and will not serve the same function. For example, PLA cups will melt and deform at high temperatures – meaning you cannot drink a cup of coffee, tea, or hot chocolate from one! Renewable materials are not automatically better for the environment. There are many factors in the creation, processing, transportation, use, and disposal of an item that determine the cost/benefit of using a particular type of material. Despite these challenges, scientists and engineers are still committed to developing solutions to the plastics problem.



Source: https://www.nomaco.com/wp-content/uploads/2019/03/ooho-840x608.jpg

Wondering about the chemistry behind HydroPods? In this module's activity, youth create a HydroPod, a sustainable polymer container that can hold liquid. How does this actually work? The sodium alginate used in this activity comes from algae and is commonly used as a thickener for salad dressings and other liquids. The calcium lactate comes from sugars found in plants and is used as a source of calcium or as a preservative. The sodium alginate is a polymer (made of long chains of repeating units). When the sodium alginate is placed in the calcium lactate a chemical reaction occurs causing the sodium and calcium to switch places. The new calcium alginate polymer chains begin attaching to each other, linking together like a chain link fence. This is called cross-linking. The connected strands of the polymer form the jelly-like outside of the pod with water trapped inside the pod. The pods are squishy because of the liquid water trapped inside.

Activity 1

Comparing Polymers

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Explain what you know about bioplastics. What do you think are the advantages and disadvantages of making bioplastics?
- Explain the following challenge: Your team is tasked to find out which type of plastic cup can hold a hot liquid. The groups will test different plastic samples to determine which would be best suitable for the application.

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

Part 1 (if making homemade bioplastic sample) – skip to Part 2 if not making the sample

1. Each youth should combine the cornstarch and water in a zipper-top plastic bag or small glass bowl. Mix the two by squeezing the bag or stirring.
2. After mixing, youth should add two drops of vegetable oil. If desired, youth may also add a couple drops of food coloring. Mix the contents by squeezing them together in the bag or stirring.
3. Youth should close but not fully seal the bag. Leave a small vent in the zipper top opening. Microwave the bag and contents on high for 20-25 seconds. The bag and contents will be hot, use a pad to remove the bag or an adult should carefully remove the bag from the microwave. If using bowls, microwave bowl for 20-25 seconds. Use hot pad to remove bowl from microwave. Use spoon to stir the bioplastic and remove it from the bowl once it cools enough to touch.
4. Let the plastic cool for 2-3 minutes in the bag. After cooling, youth can touch, shape, and play with their plastic. Safety note: Even though the plastic is made from edible materials, youth should not eat or taste their bioplastic.

Part 2

5. Invite youth to examine each type of plastic (the PLA cup, the PS cup, and the homemade bioplastic – if using). Groups should discuss similarities and differences between the samples and make predictions on how each sample will hold up to heat.
6. Using the entire PLA or PS cup, youth can hold each cup right next to the hairdryer, carefully keeping their fingers out of the hot air. Youth can also use tweezers or tongs to hold the cups in front of the hairdryer. Each group should blow-dry the PLA and PS cups for 30 seconds. (Groups can repeat for a total of 120 seconds, making observations at the end of each 30 second test.)
7. If using homemade bioplastic, select one sample from the group and hold the sample in front of the hairdryer using tweezers or tongs.
8. Cut the second PLA and PS cup into a small sample (about 1-inch square/3-cm square). If using homemade bioplastic, cut a similar sized sample. Using a permanent marker, each sample should be labeled.
9. An adult should place some boiling water into the small bowl and youth should drop their cut sample pieces into the boiling water for three minutes. Remove the samples with tweezers or tongs and let them dry. Youth should make observations of each sample piece.
10. Have youth consider other ways they would like to test the samples (one example would be to test strength and flexibility by bending or snapping). Youth should perform these tests and report their findings to the group.

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- Describe what happened with each plastic sample in the tests.
- What evidence did you gather through your observations that a cup made from PLA, PS, or cornstarch would or would not hold hot liquid?
- In what situations would a cup made from each type of material be useful? In what situations might a particular cup not be useful?

Activity 2

Create HydroPods

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Think about the single-use, disposable plastics you use in everyday life. Describe ways you believe we could engineer solutions to help reduce the use of these types of plastics.
- Thinking about the same single-use, disposable plastics used every day, what could happen to these products when we're done using them? Explain your thoughts on "ideal" and "non-ideal" disposal routes.
- When thinking about the possible solutions to the problems with plastics, what kinds of experts would we need to help address these problems? What kind of knowledge would we need to obtain?

Science and Engineering Practices
Designing Solutions

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle. Youth should work in groups of 2-4 to create a sustainable polymer container that can hold a liquid. First, youth will follow a guided lab procedure before testing a new experimental procedure.

Part 1: Structured Activity

1. Youth should follow safety rules: wash hands with soap and water before the activity, clean/sanitize the work surfaces, clean the inside and outside of all appliances and utensils, thoroughly wash hands after the activity.
2. Measure 1 cup of cold water and place it into the blender. Add 1 to 2 drops of food coloring.
3. Add ¼ tsp sodium alginate into the blender and mix for 20 seconds. Pour this mixture into the smaller (1-quart) bowl.

4. In the larger (2- or 3-quart) bowl, mix together 4 cups of cold water with 1 tsp of calcium lactate. Stir with the large spoon until the calcium lactate is dissolved.
5. Fill a 1 tsp measuring spoon with the sodium alginate mixture from the smaller (1-quart) bowl and carefully lower it into the calcium lactate (larger) bowl so that the solution covers the spoon.
6. Let the spoon of sodium alginate sit in the calcium lactate solution for about 5 seconds and then slowly turn the spoon over so the pod slides into the calcium lactate solution. Pull the spoon straight up out of the bowl. The alginate pod should now be floating in the solution. (If the reaction does not work well and a "pod" does not form, stir in an additional 1/8 tsp of sodium alginate into the smaller bowl with the alginate mixture, then repeat steps 5 and 6.)
7. Repeat as desired to make more pods.
8. Let the pods sit in the calcium lactate solution for 15-20 minutes. If time is an issue, use a smaller measuring spoon as smaller pods will form faster.
9. Using the large mixing spoon, carefully remove the pods from the solution and set them on a paper towel.
10. Using your senses, observe the pods. While the pods are edible, unless food safety measures were carefully followed we do not recommend using your sense of taste. The pods can be opened to observe the properties of the pods. Share your observations with the group.

In the second part of the activity, youth will modify their pod. Youth should make a prediction and then test what happens when they change one variable.

Part 2: Guided Inquiry

1. Ask youth to talk about the variables involved with making the pods. Individual groups should discuss and write down their answers before having every group share. The facilitator and/or youths should document the entire list of variables.
2. After listing all the variables, the group should brainstorm how each variable could be changed. Changes could include using a different type of liquid or changing the size or shape of the spoon. Each group should decide on one variable to change and predict what will happen with this new procedure. Each group should then make their pod following their new plan.
3. If time is short, the entire group can decide on one or two variables to change and do the test together.
4. Analyze the results and interpret what each group observed in their experiments. Small groups should share relevant data and observations with the entire group.

Science and Engineering Practices
Obtaining, evaluating, and communicating information

Facilitator Tip
The pods from this activity are similar to a real, edible water pod, called Ooho!, developed by the company Skipping Rocks Labs. Skipping Rocks Labs makes bioplastics from seaweed and plants.

Ooho! is one recent design for replacing plastic water bottles. Oohos! were used during the 2019 London Marathon, preventing the need for 200,000 plastic water bottles. Users could either pop the pod in their mouth and eat it, or drink the water and throw the pod into a compost bin where it will degrade in only six weeks. Skipping Rocks Labs also makes packets for sauces, juices, and condiments that can be composted with food waste. Learn more at: https://www.notpla.com/

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- Imagine creating a larger or smaller pod – what applications might it be used for? Imagine the pods containing different types of liquids – what could you use them for?
- What are some advantages or disadvantages of these pods? In what ways could a pod be a more sustainable solution to a problem?

Science and Engineering Practices
Designing solutions

CONCEPT AND TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of young peoples' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

- Many companies are making commitments to reduce their use of plastics or to transition to using renewable polymers. For example, LEGO has committed to make all LEGO bricks from sustainable sources by 2030 (https://www.lego.com/en-us/aboutus/sustainable-materials/). Research the sustainability goals of different companies and track their progress towards achieving these goals.
- Consider an "In-Store Observational Assessment" of available PLA vs. non-PLA plastic products. Visit a local supermarket and look for the availability of plastic products (e.g. cups, cutlery). Compare the availability, costs, and uses of PLA and non-PLA plastics.

REFERENCES

Corcoran, E. & Wissinger, J. E. (2020). Activity – Earth-friendly plastics. *Celebrating Chemistry, 8.* https://www.acs.org/content/acs/en/education/outreach/celebrating-chemistry-editions/2020-ccew/earth-friendly-plastics.html

Ellen Macarthur Foundation. (2016, January 19). The new plastics economy: Rethinking the future of plastics. https://www.ellenmacarthurfoundation.org/assets/downloads/Ellen-MacArthurFoundation_TheNewPlasticsEconomy_Pages.pdf

Send us your Feedback!

Have you tried one (or more!) of the activities? Let us know how it went! We work with the Center for Applied Research and Education Improvement at the University of Minnesota to evaluate this project. Click on the button below to fill out their short evaluation form and help us collect valuable feedback for improvement!

4hpolymers.org/evaluation

MODULE
7
GRADES 9-12

Sustainable Polymers

Confronting the Plastic Crisis

A 4-H STEM Curriculum for Grades 9-12

National Science Foundation
NSF Center for Sustainable Polymers

4-H Polymer Science Curriculum for

Grades 9-12

4hpolymers.org

The curriculum is designed for high school youth focusing on the history, prevalence, impacts, and future of plastics. Plastics are versatile materials that come in different shapes, sizes, and exhibit different material properties. Scientists and engineers are working on new ways to create, use, and recycle plastics, so we can use plastics for their many advantages and lessen their effects on our environment. The curriculum is designed to build foundational skills of science and engineering: observation, asking questions and defining problems, planning and carrying out investigations, and communicating. The curriculum is intended for delivery in out-of-school time facilitated by an educator (trained volunteers or program staff). Youth will explore polymer science content through a guided activity helping to prepare them for engagement as teachers of younger youth or to undertake a service project. Each module includes educator background reading and additional tips. We encourage instructors to collect feedback throughout this module and submit via this evaluation form: 4hpolymers.org/evaluation.

National Science Foundation

NSF Center for Sustainable Polymers

Module 7

Emerging Solutions to the Plastic Crisis

Driving Question:

- **What are the advantages and disadvantages in emerging methods to deal with the detrimental impacts of petroleum-based plastic?**

Introduction

MODULE SUMMARY

Youth prepare and deliver a pitch to a panel of investors who listen to pitches for products and decide whether to invest. Youth will prepare a pitch for an emerging technology or other solution to deal with detrimental impacts of plastic. Youth use scientific information, may gather additional information, and include a life cycle assessment. Youth will reflect as a large group on the advantages and disadvantages of each proposal.

Time Required:

- Setup: 5 minutes
- Activity: 60 to 90 minutes

TIPS AND CALLOUTS

Facilitator Tips

These tips provide strategies and helpful suggestions for facilitators.

Science and Engineering Practices

The Next Generation Science Standards (NGSS) identifies eight practices of science and engineering that are essential for all students to learn. Using these practices, youth make sense of phenomena and use these skills to investigate the world and design and build systems.

Module Focus

LEARNING OBJECTIVES	At the conclusion of this activity, youth will be able to… • Communicate possible solutions to mitigate the negative impacts of petroleum-based plastics.
SCIENCE & ENGINEERING PRACTICES (NGSS)	• Performance Standard: HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. • SEP: Construing Explanations and Designing Solutions; Engaging in Argumentation from Evidence • DCI: ESS3.C: Human Impacts on Earth Systems; ETS1.B: Developing Possible Solutions • CC: Stability and Change; Connections to Engineering, Technology, and Applications of Science
SUGGESTED GROUPINGS	• Groups of 3 to 4 youth
CONCEPTS & VOCABULARY	• **Bioplastic**: polymer often made from starch-containing plants, such as corn and potatoes. Many of these bioplastics are compostable. • **Material Life Cycle**: the life cycle of a product from the time raw materials are extracted through to production, distribution, use, and end-of-life management. • **Life Cycle Impact**: cumulative changes to the environment (adverse and/or beneficial) resulting from all stages in a material's life. • **Petroleum-based Plastic**: plastic made from oil extracted from the earth. • **Recycle**: the process of converting waste materials into new objects. • **Sustainable**: able to be maintained or run continuously with little or no negative impact on the environment or health.

Facilitator Preparation

MATERIALS NEEDED

- ☐ computer, laptop, tablet, or other method for groups to conduct online research.
- ☐ digital projector and computer (for students to show their presentation).
- ☐ (optional) art materials and/or props for youth to use in their pitch.

GETTING READY

- ☐ Make copies of Appendices A and B, enough for each group.
- ☐ Prepare computers, laptops, tablets, or other devices for groups to conduct web-based research on the solution they plan to present.

Background Information for the Facilitator

The U.S generates more plastic trash than any other nation, much of that for single-use purposes (items used for a few moments but which will be around for hundreds of years). The vast majority of non-degradable petroleum-based plastic waste is dumped into landfills or scattered through the environment and ocean; over 75% of plastic waste is landfilled (a portion ends up in the world's oceans), 16% combusted for electricity generation, and 9% **recycled**[1]. The chemical properties (long polymer chains) that make plastics so strong, durable, flexible – and overall an amazing material – also make them resist degradation. Plastics that end up littered in the environment can take hundreds or thousands of years to degrade. It is these detrimental environmental impacts of petroleum-based plastic that scientists and engineers, as well as elected officials and environmental activists, are working to solve. There are broad arrays of emerging technologies and social policies being considered in the U.S. to help reduce plastic production, consumption, and post-life waste.

Petroleum-based Plastics
Most plastics produced today are made from oil that is extracted from the ground. Crude oil must be refined, although only 4% of a standard 42-gallon barrel of crude oil may be refined into the chemicals used to make plastics. Resulting plastics must then be manufactured into a product (e.g., bag, beverage container) and transported. After consumer use, they have a varying post-use life. The data surrounding the environmental impacts of plastic show very high rates of carbon emissions because of plastic production. Each of these stages in the **material life cycle** has an environmental impact – positive and/or negative. Because most plastics have been developed with minimal thought for their ultimate disposal, there are increasing concerns that must be addressed with respect to the environmental consequences when these materials are discarded.

Potential Solutions
In this activity, youth will select a concept, conduct research online, and then deliver a pitch for their idea to reduce negative environmental impacts and improve **sustainability** of plastic use. There are no right or wrong answers, particularly as each solution comes with its own advantages and disadvantages. The module is focused on mitigating negative/detrimental impacts from new (virgin) plastic and/or helping to reduce existing plastic waste. Additionally, youth should consider full life cycle impacts starting from (1) collection or extraction of raw (or recycled) materials, (2) manufacturing and potential chemical waste byproducts, (3) consumer use, and (4) end-of-life options. There are several emerging solutions – technological and policy related – offered in Appendix A to get youth started thinking broadly. Youth do not need to limit themselves to the list in Appendix A. Help them think innovatively and big by conducting online research. The solutions to the plastic crisis will not be solved overnight, or by only one solution. Some emerging solutions include:

Bioplastics
Producing **biodegradable** plastics from renewable materials (like corn, soy beans, or generic cellulose) so we can use plastics for their many advantages and lessen their effects on our environment. Some plastics are now designed to biodegrade without polluting the

environment and others are created using renewable resources to lessen the dependence on traditional, petroleum-based plastics. A limiting factor is that most bioplastics (typically polylactic acid / PLA, resin code #7) will degrade only under industrial compost conditions at high temperatures (typically above 50°C or 122°F). These conditions are not found in most landfills and that is where most bioplastics end up.

Plastic Alternatives

Technologies are being developed to use steel or aluminum (or other materials) in new ways to help reduce plastic use. For example, nanotechnology for coatings on cardboard and paper materials to make them more capable to protect items being transported. Or nanotechnology used to produce lighter-weight steel and altered aluminum.

Better Recycling

Improvements to recycling or tax incentives to promote more robust markets for recycling. This might include better feedstock recycling (also known as "chemical recycling") to use in blast furnaces for steel production or used as virgin material alternatives in manufacturing new polymers. Plastics might be made into bricks stronger than concrete (an innovation by Nzambi Matee in Nairobi). Emerging research has shown how to convert plastic waste into vanilla flavoring using genetically engineered bacteria.

Government Laws/Policies

Governments might enact laws, or taxes, to reduce or prevent production involving new (virgin) plastic. Alternately, governments might provide tax incentives to promote markets for reduction and recycling.

Activity

OPENING QUESTIONS/PROMPTS

This is where the activity begins. Asking opening questions helps frame the thinking of the youth, as well as provides educators with some understanding of youths' prior knowledge and experience.

- Explain how you might reduce your plastic use.
- Describe methods you have heard about to reduce everyone's plastic use.

PROCEDURE

Experience Step; this is the hands-on activity; first step in the learning cycle.

1. **Explain the scenario (5 minutes)**. Groups will research an emerging technology or other solution to reduce the detrimental environmental impacts and promote environmental sustainability. They will then deliver a 2-to-3-minute marketing pitch to a panel of investors to try to get them to fund their solution.

2. Hand out the information sheet (Appendix A) and craft your pitch template (Appendix B) to each group. Invite youth to discuss and prepare a pitch that might include a digital presentation (e.g., PowerPoint, Google Slides, or Prezi) and/or using props.

Facilitator Tip
The information sheet is a starting place to help improve their awareness of various emerging technologies or other types of solutions; however, groups are not limited to the ideas on the information sheet. Groups will also need to conduct their own research using the Internet or library to fully form their concept.

3. **Group Preparation (30-45 minutes)**. Allow groups 30 to 45 minutes to review the information sheet, conduct research, and prepare their sales pitch presentation (e.g., PowerPoint, Google Slides, or Prezi) and/or using props.

Science and Engineering Practices
Obtaining, evaluating, and communicating information.

Facilitator Tip
Spend time with each group; if needed, offer suggestions. Try to direct groups to seek answers to their own questions rather than answering questions for them. To help strengthen engagement, provide art materials and/or props for youth to use in their pitch. Invite them to be creative!

4. ***Presentations (15 to 25 minutes)***. Allow each group to present their sales pitch in front of the full group. If time permits, you may engage in a second iteration where groups have 5 minutes to prepare a counterargument to the other groups' claims about their material and offer another pitch.

Science and Engineering Practices
Engaging in an argument from evidence.

REFLECTION: SHARE, PROCESS, GENERALIZE

Share, Process, Generalize (Step two in the learning cycle); youth share their reactions and observations publicly and processes the experience by discussing and analyzing. Help guide youth as they question, share, and compare their observations. You may choose one of the questions below as a prompt. If necessary, use more targeted questions as prompts to get to particular points. Remember these questions are not about getting one right answer.

- What surprised you about the possible solutions pitched by each group?
- Describe additional evidence, if anything, you believe other groups could have included in their pitch.
- Considering each solution proposed, explain positive attributes that you believe would help reduce negative environmental impacts
- Explain what you believe are the advantages and disadvantages in emerging methods to deal with the detrimental impacts of petroleum-based plastic.
- Describe what you know about the advantages and disadvantages to transitioning to renewable plastics.

CONCEPT/TERM DISCOVERY

A critical, intermediate step where the goal is always to have the youth develop their understanding using their own words and as a result of the experience; however, if misunderstandings/misconceptions develop, the facilitator needs to address them. Conceptual understanding develops during discussions among youth during the Reflection phase of the activity; technical terms are also frequently used. During these discussions, facilitators need to assess concepts and/or terms the youth have understood through the activity. Any concepts or terms the youth do not discover or understand will need to be introduced by the facilitators before moving to the Application phase.

CONCEPT APPLICATION

Last step in the learning cycle; this links learning to participants' lives through authentic applications to their own practices. The true test of young peoples' understanding is when they can apply new knowledge and skills to authentic situations. When engaging youth in inquiry-based learning, hands-on activities serve as vehicles for learning new concept knowledge and skills; however, it is the application of new knowledge or skills to independent, real-world situations that is the critical factor in the learning process. Thus, to complete the cycle of experiential learning it is important to intentionally provide youth specific opportunities for authentic applications. Suggestions for real-world applications include:

- In a second session: Presentation in front of a community panel. After youth have presented to each other, receive feedback, and had time to refine their presentation, setup another session where community members form the "shark tank" panel. Invite other educators, community members, or scientists to listen to pitches and provide general feedback on each group's concept.
- Begin involving youth in the teen engagement curriculum, the parallel modules developed to support youth in either teaching younger youth or engaging in a community action project to make a positive contribution.
- Invite youth to select one or more of the solutions they pitched and together, delve further; invite guest speakers who can share even more; invite youth to interview experts; and become advocates for a potential solution to address the plastic crisis.

REFERENCES

EPA. (n.d.). *Plastics: Material-Specific Data*. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data

Newburger, E., & Lucas, A. (2020, June 28). *Plastic waste surges as coronavirus prompts restaurants to use more disposable packaging*. CNBC.

Parker, L. (2020, October 30). U.S. generates more plastic trash than any other nation, report finds. *National Geographic*. https://www.nationalgeographic.com/environment/article/us-plastic-pollution

Pratt Lile, S. (2020, April 30). Three Successful Shark Tank Pitch Examples to Learn From (And Another to Avoid). *Beautiful.Ai*. https://www.beautiful.ai/blog/three-successful-shark-tank-pitch-examples-to-learn-from-and-another-to-avoid

Sadler, J. C., & Wallace, S. (2021). Microbial synthesis of vanillin from waste poly(ethylene terephthalate). *Green Chemistry*, *23*(13), 4665–4672. https://doi.org/10.1039/D1GC00931A

Appendix A

Emerging Solutions to Plastic Production Information Sheet

ISSUE STATEMENT

The U.S generates more plastic trash than any other nation (National Geographic, 2020), much of that for single-use purposes (items used for a few moments but which will be around for hundreds of years). The vast majority of non-degradable petroleum-based plastic waste is dumped into landfills or scattered through the environment and ocean; over 75% of plastic waste is landfilled (a portion ends up in the world's oceans), 16% is combusted for electricity generation, and 9% is recycled (EPA, 2021). The chemical properties (long polymer chains) that make plastics so strong, durable, flexible – and overall an amazing material – also make them resist degradation. Plastics that end up littered in the environment can take thousands of years to degrade. It is these detrimental environmental impacts of petroleum-based plastic that scientists and engineers, as well as elected officials and environmental activists are working to solve.

YOUR CHALLENGE

- Your group needs to research a potential solution to deal with and reduce the detrimental environmental impacts of single use plastic and promote environmental sustainability.
- The scope can include either or both: (1) the production of new virgin plastics from renewable resources; and/or (2) dealing with existing plastic waste that has already been produced.
- Research an emerging technology, solution, or option that is of interest and relevance to you. Feel free to be creative and innovative – even imaginative!
- You will pitch a concept for an emerging technology or other solution to a panel of investors who listen to pitches for products and decide whether to invest.
- Consider discussing ways to overcome potential disadvantages. You may also want to briefly discuss how your technology is more advantageous than other technologies in certain ways.
- There are ideas presented below and you will need to conduct additional research online. Also consider environmental impacts in the full material life cycle (extraction of raw materials, manufacturing, & end-of-life).

EXAMPLES OF EMERGING SOLUTIONS

Bioplastics

- Producing biodegradable plastics from renewable materials (like corn, soy beans, or generic cellulose) so we can use plastics for their many advantages and lessen their effects on our environment. Some plastics are now designed to biodegrade without polluting the environment and others are created using renewable resources to lessen the dependence on traditional, petroleum-based plastics.
- See the U.S. Environmental Protection Agency's information on bioplastics.

Plastic Alternatives

- Nanotechnology for coatings on cardboard and paper materials to make them more capable to protect items during transportation and/or to prevent water leaks.
- Nanotechnology used to produce lighter-weight steel and altered aluminum to use as an alternatives to plastic.
- See the United Nation's Frontier Technologies for Addressing Plastic Pollution (2019).

Better Recycling

- Improvements to recycling or tax incentives to promote more robust markets for recycling (see U.S. Environmental Protection Agency Recycling Goal).
- Better feedstock recycling (also known as "chemical recycling") to use in blast furnaces for steel production or used as virgin material alternatives in manufacturing new polymers)
- Plastics might be made into bricks stronger than concrete.
- Convert plastic waste into vanilla flavoring using genetically engineered bacteria.
- Using additives to combine different plastics in the recycling stream such as PET and PE

Government Laws or Policies

- Governments might enact laws, or taxes, to reduce or prevent production involving new (virgin) plastic. For example, banning plastic bags, straws, and/or cups.
- Governments might provide tax incentives to promote markets for reduction and recycling.
- H.R. 7228: The Plastic Waste Reduction and Recycling Act
- See OECD Taxes on Single-Use Plastics.

Appendix B

Crafting a Pitch

Pitching a new idea to gain the support of an audience can be a challenging task. Communicating big ideas clearly and quickly and inspiring others to agree with your point of view takes practice. As you craft your pitch, focus in on the main idea you want people to walk away with after listening to you. Then, add in other elements that make your pitch memorable.

Science of People found that successful pitches shared the following qualities:

The presenters were credible. *The tone of the pitches was agreeable.* *The presenters were confident.*	*The pitches were interactive.* *The pitches were captivating.* *The pitch was entertaining.* *The pitch featured funny content.*	*The idea was relevant.* *The presentation's message was powerful.* *The story was inspirational.*

Digital Slides and Props – Props and digital slides (using PowerPoint, Google Slides, Prezi, or other software) may help add excitement and better convey your content.

Pitch Template: You may use this pitch template to help you structure your pitch. Feel free to embellish or add other elements from the list above to really help your pitch stand out.

Introduce yourselves and the problem: We are ______________. We have been studying the issue of plastics in our world and we are here to share with you our approach to solving __________________________ (clearly describe the problem).

Pose an opening question: To do this, you can ask the audience to think about their knowledge of plastic use/disposal specifically related to the problem you are going to solve.

For example: When you think about (Problem) have you ever wondered what (Solution) can do to help?

For example: When you think about the amount of plastic waste generated in restaurants that ends up in our landfills have you ever wondered what our government can do to help?

Name your solution: You should be able to state your solution in 1 or 2 sentences.
For example: Local laws can deter the use of plastics in restaurants by banning single use plastics and providing economic incentives for the use of alternative products.

Tell a story: Give some context about why your issue is important and why people should care.

> *During the global pandemic, the frequency of use of single-use plastics in food service surged as more people were ordering take-out and delivery. This increase means that many more plastic forks, food containers and plastic bags will be in our landfills for hundreds of years to come. Restaurants are suffering economic effects of the pandemic, so local governments need to support restaurants and help them shift away from using plastic items with local laws and financial incentives.*

Provide Specifics: Share three facts or statements about your solution. Use reliable sources and provide examples so you are credible to your audience.

Closing: Remind your audience of the problem and why your idea is a promising solution.

Send us your Feedback!

Have you tried one (or more!) of the activities? Let us know how it went! We work with the Center for Applied Research and Education Improvement at the University of Minnesota to evaluate this project. Click on the button below to fill out their short evaluation form and help us collect valuable feedback for improvement!

4hpolymers.org/evaluation