Landmark Lesson Plan:
Man and Materials through History

Grades: 9-12
Subject areas: Chemistry, Materials Science, Polymers and History
Based on "The Development of Bakelite," a National Historic Chemical Landmark

The following inquiry-based student activities are designed for use in high school lesson planning. The handout, video and activities will help students gain insight into the connection between materials science and cultural and technological developments, specifically relating to the development of the world's first synthetic plastic, Bakelite. The discovery of Bakelite marked the beginning of the "Age of Plastics."

The activities are designed as a ready-to-go lesson, easily implemented by a teacher or his/her substitute to supplement a unit of study. In chemistry, the activities relate to the definition of polymers and polymerization reactions. In history, the themes are the periods of human history and the chronology of technological and materials science developments.

All resources are available online at www.acs.org/landmarks/lessonplans.

While these activities are thematically linked, each is designed to stand alone as an accompaniment for the handout and video. Teachers may choose activities based on curricular needs and time considerations.

- Take a few minutes to introduce the lesson with a few conversation starters. Almost anyone can name a dozen familiar products that are made in whole or in part from polymers: smart phones; appliances; containers for beverages, toiletries, and foods; toys; sports gear; automobile parts; cookware; wiring insulation; shopping bags; etc. But some are less visible: medical implants (pacemakers and lenses for cataracts), construction materials (wire insulation, carpets and paints), etc. Modern society is reliant upon the materials we have at hand, and the development of plastics has made many of the lifestyle improvements of the 20th and 21st century possible.
- Show the video **"Plastics go Green"** (9 min.).
- Have students read the handout on **Man and Materials through History**.
- Distribute the **Activities** selected for the class.
- After class use the **Answer Guide** for student feedback and discussion.

Student Activities with Objectives

Recognizing Polymers: Classifying Everyday Materials (10-20 min.)
- Students explore their beliefs about what polymers are using familiar examples.
- Students learn that polymers, both natural and man-made, are all around us.

Technology Timeline: Chronology of Materials (10-15 min.)
- Using the handout, students place the various material developments on a timeline to give them some perspective of how long ago various technologies came into existence.

Polymer Structures (25-30 min.)
- Students gain an idea of what some of the monomer subunits actually look like and how they bond together chemically.

Man and Materials through History

Human history is shaped by the materials we develop and use. Some 5,000 years ago, humans learned how to turn copper and tin ore into metallic bronze, and the Stone Age became the Bronze Age. Nearly two thousand years later, humans learned to turn iron oxide into iron and steel and the Bronze Age became the Iron Age. Today, we do more than mix and modify natural materials to improve them. We create entirely new materials by manipulating the structure of chemicals. This era was inaugurated in 1907 by Leo H. Baekeland, inventor of the first synthetic plastic, Bakelite.

Human history is tied to the materials past cultures have had available to them, and more recently to the materials we've been able to create. Ancient cultures began their existence making use of the stone, soil, plants and bones found in their local environments. The only metals available to these cultures were native metals like gold and copper that are found in rare instances in metallic form directly from the Earth. For nearly 2.3 million years, humans lived using only these naturally occurring and easily obtained materials in a period known as the Stone Age.

Around 3000 BCE, a technique of producing metal from mineral-rich ores was developed and the Bronze Age started. Cultures learned to produce copper and later alloys such as bronze (a mixture of the elemental metals copper and tin) by smelting. The technique uses heat and chemical reactions to produce metal from the more complex mixture of minerals found in ore. These metals were useful for their strength and ability to be shaped. They replaced stone as the most important material for tool making and artwork.

The discovery of a method for producing iron and steel (an alloy of iron and carbon) from ore was developed around 1200 BCE, and the Iron Age began. Making iron is a more complicated smelting process than that for copper and bronze. It requires a more consistent temperature and therefore a greater mastery of furnace technology. Steel tools and weapons are nearly equal in weight to those made of copper and bronze, however they are stronger, making steel a more desirable material.

As cultures grew more technologically capable, they gradually developed some of the familiar tools and technologies we know today. Agriculture, a key development in the progress of human history, has been practiced since at least 10000 BCE. The wheel was developed around 4000 BCE, and the first writing systems, cuneiform and hieroglyphics, developed about 500 years later. The earliest method for producing glass from the melting of sand and other quartz-based minerals, developed around 2500 BCE.

Around 500 CE, the Middle Ages began to take form. The introduction of paper to Europe (first developed in China around 200 CE) and invention of the printing press in 1450 were important technological developments in this period of time.

By the 1500s, cultures entered the Early Modern period, when trade and technology reached new levels of complexity. The Industrial Revolution began around 1760 and marked the introduction of a new period of scientific and technological breakthroughs, including the development of steam power, factory manufacturing and the use of iron and cement as structural materials.

More recent milestones include the development of synthetic plastics around 1900 and the identification of the first synthetic nanomaterial, the carbon fullerene, in 1985. As these new materials have been developed, they've made new products and technologies such as computers, spacecraft and robotics possible.

The growth of materials science and introduction of new materials in each age of history has made technological advances and new cultural practices possible.

Polymers in History

The Polymer Age is also called the age of plastics. "Plastic" (from the Greek "plastikos," meaning moldable) is the popular term for a variety of synthetic, or manmade, polymers.

Polymers are very large molecules—giants in the molecular world—comprised of smaller molecules called monomers ("poly" means many, while "mono" means one). Most polymers, but not all, consist of monomers that are similar to each other and joined together in a straight chain, like a long string of pearls.

Thousands of polymers exist in nature. The most plentiful natural polymer in the world is cellulose, the major structural material of trees and other plants. The proteins that make up our bodies are polymers too, including deoxyribonucleic acid (DNA), the material that carries the genetic codes for all living creatures.

Origins of polymer science

Chemists did not fully understand or identify polymers until the turn of the 19th century. But as early as 1861, the British chemist Thomas Graham had noted that when he dissolved organic compounds in solutions, some of them (cellulose, for instance) would leave sticky residues when passed through fine filter paper. These compounds could not be purified into a crystalline form. Graham thought such substances represented an entirely different class of matter. He called them "colloids," after "kolla," the Greek word for glue, another material that could not penetrate filters.

Many 19th century scientists modified colloids and natural polymers to form new materials. In 1870, the American inventor John Wesley Hyatt produced an astonishing new product called celluloid. Celluloid is a plastic made from natural cellulose, and it could be used for everything from movie film to billiard balls.

Celluloid and other early plastics were made from existing natural materials. The next step—the creation of completely synthetic plastics—was still to come.

Development of Bakelite

Around 1907, Belgian-born American chemist Leo H. Baekeland took two ordinary chemicals, phenol and formaldehyde, mixed them in a sealed vessel, and subjected them to heat and pressure. The sticky, amber-colored resin he produced was the first plastic ever to be created entirely from chemicals, and the first material to be made entirely by man.

Bakelite could be molded quickly into different shapes, an enormous advantage in mass production processes, and retained its shape even when heated or subjected to solvents.

Buttons made from Bakelite.
Courtesy Gregory Tobias/Chemical Heritage Foundation.

Bakelite was particularly suitable for the emerging electrical and automobile industries because of its extraordinarily high resistance—not only to electricity, but to heat and chemical action. It was soon used for all non-conducting parts of radios and other electrical devices, such as light bulb sockets, distributor caps and other insulators. Bakelite found a place in almost every area of modern life. From novelty jewelry to radios and telephones, Bakelite was everywhere.

Ultimately, Bakelite was replaced by other plastics that had greater qualities of strength, flexibility and appearance. However Baekeland's new material opened the door to the Age of Plastics and seeded the growth of worldwide production of synthetic plastics that are just as familiar to us as wood or metal.

Most of the plastics we know today are made from petroleum. Like Bakelite, these plastics are extremely resistant to natural decomposition. Recycling is a process that breaks down and reuses some types of plastics and other materials to make new products. The numbers found on the underside of many plastic products are used to sort them for recycling. The numbers correspond to the composition of different plastics—for example polyethylene and styrene.

In the current era of sustainability, scientists hearken back to the earliest man-made polymers by developing new plastics based on natural, renewable materials like vegetable oil or corn starch. Material scientists hope these plastics will have equivalent properties to petroleum-based plastics, but with environmental benefits.

Student Name: ____ Date: _______________ Period: ______

Recognizing Polymers: Classifying Everyday Materials

1. In the table below, choose whether you think each material is a polymer or a non-polymer. Mark “P” for materials you believe are polymers or “NP” for materials you believe are not polymers. If you are unsure, write “U”.

My Choice	
_______	Salt
_______	Hair
_______	Sugar
_______	Nylon
_______	Baking soda
_______	Rayon
_______	Glass
_______	Wood

My Choice	
_______	Styrofoam
_______	Fingernails
_______	Paper
_______	Vinegar
_______	Silk
_______	Wool
_______	Silly Putty
_______	Gold

My Choice	
_______	Polyethylene
_______	DNA
_______	Muscle
_______	Cellulose
_______	Silver
_______	Iron
_______	Plastic milk jug
_______	Neon

2. Once everyone had made their choices your teacher will lead a class discussion about each of the types of materials. Record the reasons for the type of classification of each substance.

Class Consensus		Reasoning
_______	Salt	
_______	Hair	
_______	Sugar	
_______	Nylon	
_______	Baking soda	
_______	Rayon	
_______	Glass	
_______	Wood	
_______	Polyethylene	
_______	DNA	
_______	Muscle	
_______	Styrofoam	
_______	Fingernails	
_______	Paper	

________	Vinegar	
________	Silk	
________	Wool	
________	Silly Putty	
________	Gold	
________	Silver	
________	Iron	
________	Plastic milk jug	
________	Cellulose	
________	Neon	

Student Name: ____ Date: ________________ Period: ______

Technologies of the Ages: A Timeline of Development

There are many ways to describe the history of mankind. One way is by tracking the major developments in technology. History is shaped by the materials we use and by the technology we have to create them.

Directions: Use the handout provided to place the following events on the history timeline.

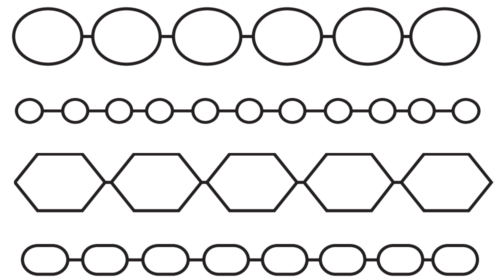
Events		
Stone Age	Age of Plastics	Glass production
Bronze Age	Industrial Revolution	Invention of wheel
Middle Ages	Writing	Agriculture
Modern Age	Copper smelting	Paper production
Iron Age	Printing press	Nanotechnology

History Timeline		
Ages of History	**Time**	**Technological Developments**
	15000 BCE	
	14000 BCE	
	13000 BCE	
	12000 BCE	
	11000 BCE	
	10000 BCE	
	9000 BCE	
	8000 BCE	
	7000 BCE	
	6000 BCE	
	5000 BCE	
	4000 BCE	
	3000 BCE	
	2000 BCE	
	1000 BCE	
	0 BCE	
	1000 CE	
	2000 CE	

Student Name: ______________________________________ Date: ______________ Period: ______

Building Polymers

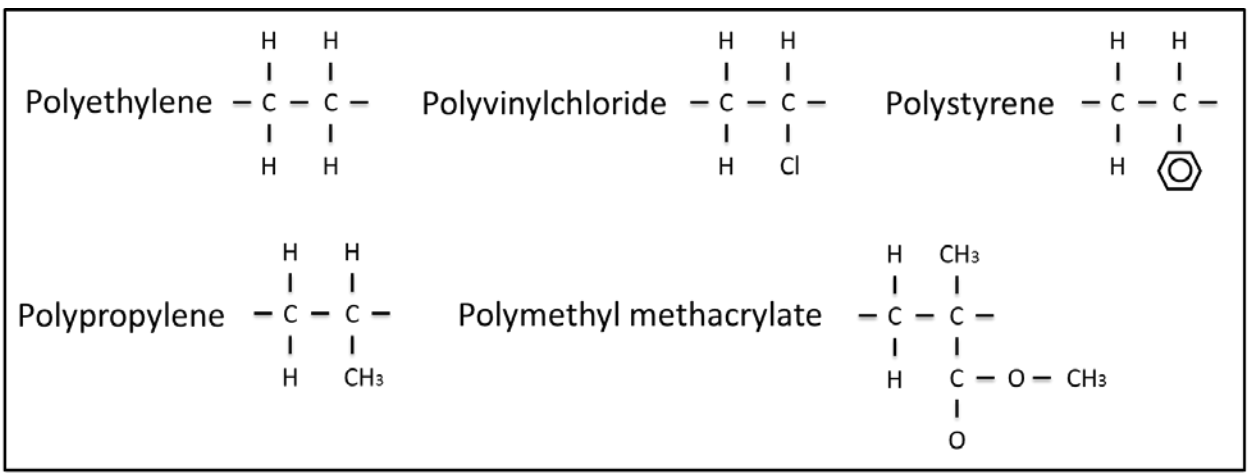
Polymers are chains of smaller molecules called monomers. The monomers fit together like toy pop beads. The physical and chemical properties of the polymer depends on the type of monomers that make it up.



There are many examples of natural polymers in nature. Proteins, for example, are chains of amino acid monomers. The type of protein (such as hair, or muscle) depends on the kind and number of amino acid monomers in the chain.

Most polymer chains are huge, and are classified as macromolecules. The long chains can have a molecular mass (the mass of all the atoms in a molecule in atomic mass units) in tens or hundreds of thousands or more, depending on the type of polymer and how it was formed.

Some typical monomers:



1. In the space below, draw a short section of at least three repeating units of the following polymers, based on the chart above.

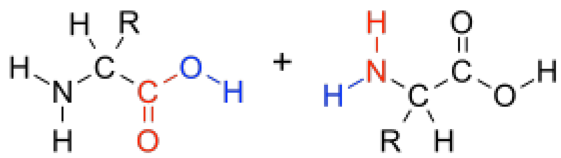
Polyvinyl chloride:

Polystyrene

Polymerization

In the exercise above we simply added the monomers together using the open 'bonds' on each end. But what kind of chemical reaction is involved in actually making bonds?

Consider joining the two glycine molecules below. They can bond when the OH (hydroxyl) group on the right side of the first molecule combines with one of the H atoms connected to the N atom of the second molecule. The H and the OH combine to form water. This type of reaction is called a 'condensation' reaction because two or more separate units come together to make something "dense". Because a molecule of water is "lost" in each bond, it is also called a dehydration reaction.



2. Write a balanced chemical equation that shows the two glycine molecules joined together by a condensation reaction. Make sure to include all reactants and end products.

Notice that one end of the chain has an open -OH group and the other end has a free $-NH_2$ group. We can use these open groups to add more glycine molecules to the chain.

3. Now draw a chain of at least two glycine molecules connected to each other below, with the appropriate number of water molecules resulting from the condensation reaction.

This is just one example of the kinds of chemical bonds that can join monomers together to make polymers.

Man and Materials Through History Answer Guide
Recognizing Polymers: Classifying Everyday Materials

1. In the table below, choose whether you think each material is made from polymers or not. Mark "P" for materials you believe are polymers or "NP" for materials you believe are not polymers. If you are unsure, write "U".

   Student answers may vary.

2. Once everyone had made their choices your teacher will lead a class discussion about each of the types of materials. Record the reasons for the type of classification of each substance.

   The idea of this lesson is to give students an appreciation for the many polymers that are all around us. There are many examples of synthetic polymers that are used in a wide variety of consumer products—plastics we are familiar with such as toys and soda bottles. But there are also many natural polymers, including things like wood, hair, skin, and silk.

Class Consensus		**Reasoning**
NP	Salt	Table salt is a simple molecule, sodium chloride.
P	Hair	A natural polymer made of amino acid monomers.
NP	Sugar	Table sugar (sucrose) is made of two molecules, glucose and fructose.
P	Nylon	A manmade polymer of two repeating subunits.
NP	Baking soda	A simple molecule, sodium hydrogen carbonate (also called sodium bicarbonate).
P	Rayon	A modified natural cellulose polymer.
NP	Glass	Glass is mostly silicon dioxide (SiO_2).
P	Wood	Mostly made of cellulose, a natural polymer.
P	Polyethylene	A manmade, synthetic polymer, and the most common plastic.
P	DNA	Genetic polymer made of repeating nucleic acids.
P	Muscle	Made of protein, a natural polymer of amino acids.
P	Styrofoam	Made from polystyrene, a synthetic polymer.
P	Fingernails	Made of protein, a natural polymer of amino acids.
P	Paper	Made mostly of cellulose, a natural polymer.
NP	Vinegar	A simple solution of water and acetic acid.
P	Silk	A natural polymer of amino acids.
P	Wool	A natural polymer of amino acids.
P	Silly Putty	A synthetic, silicone-based polymer.
NP	Gold	A pure chemical element, made of only one type of atom.
NP	Silver	A pure chemical element, made of only one type of atom.
NP	Iron	A pure chemical element, made of only one type of atom.
P	Plastic milk jug	Mostly made of high-density polyethylene, a synthetic polymer.
P	Cellulose	The most common natural polymer, made of glucose.
NP	Neon	A pure chemical element, made of only one type of atom.

Man and Materials Through History Answer Guide
Technologies of the Ages: A Timeline of Development

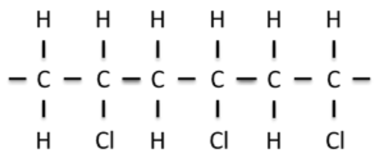
In this activity you will use the handout provided to place the following events one a history timeline. Place the following ages of history and technological developments on the timeline.

<table>
<tr><th colspan="3">History Timeline</th></tr>
<tr><th>Ages of History</th><th>Time</th><th>Technological Developments</th></tr>
<tr><td rowspan="9">Stone Age</td><td>15000 BCE</td><td></td></tr>
<tr><td>14000 BCE</td><td></td></tr>
<tr><td>13000 BCE</td><td></td></tr>
<tr><td>12000 BCE</td><td></td></tr>
<tr><td>11000 BCE</td><td></td></tr>
<tr><td>10000 BCE</td><td>Agriculture (10000 BCE)</td></tr>
<tr><td>9000 BCE</td><td></td></tr>
<tr><td>8000 BCE</td><td></td></tr>
<tr><td>7000 BCE</td><td></td></tr>
<tr><td rowspan="5">Bronze Age
(6000 BCE to 200 CE)</td><td>6000 BCE</td><td></td></tr>
<tr><td>5000 BCE</td><td></td></tr>
<tr><td>4000 BCE</td><td>Wheel (4000 BCE)
Writing (3500 BCE)</td></tr>
<tr><td>3000 BCE</td><td>Glass (2500 BCE)</td></tr>
<tr><td>2000 BCE</td><td></td></tr>
<tr><td rowspan="2">Iron Age (1200 BCE to 200 CE)</td><td>1000 BCE</td><td></td></tr>
<tr><td>0 BCE</td><td></td></tr>
<tr><td>Middle Ages (200 CE)</td><td>1000 CE</td><td>Paper (200 CE)</td></tr>
<tr><td>Modern (1500 CE)
Polymer Age (1900 CE)</td><td>2000 CE</td><td>Printing press (1450 CE)
Industrial Revolution (1760 CE)
Plastics (1907 CE)
Nanotechnology (1985 CE)</td></tr>
</table>

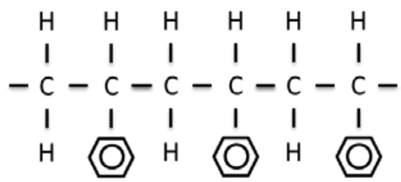
Man and Materials Through History Answer Guide
Building Polymers

1. In the space below, draw a short section of the following polymers, based on the chart above.

   Polyvinyl chloride:



   Polystyrene



2. Write a balanced chemical equation that shows the two glycine molecules joined together by a condensation reaction. Make sure to include all reactants and end products.

   $\mathbf{C_2H_5NO_2 + C_2H_5NO_2 = C_4H_8N_2O_3 + H_2O}$

3. Now draw a chain of at least two glycine molecules connected to each other below, with the appropriate number of water molecules resulting from the condensation reaction.