Lesson Template – Ben Davis

Subject Area(s) **Environment, Science and Technology**

Associated Unit **N / A**

Lesson Title **How are plastic (PET) water bottles made?**

Header

Image 1

ADA Description: Supply chain for making polypropylene (PP) and polyethylene terephthalate (PET), showing the steps for turning crude oil into its constituents (light stuff, medium stuff, and heavy stuff).

Caption: Supply chain for plastic containers

Image file name: PETandPPSupplyChain.jpg

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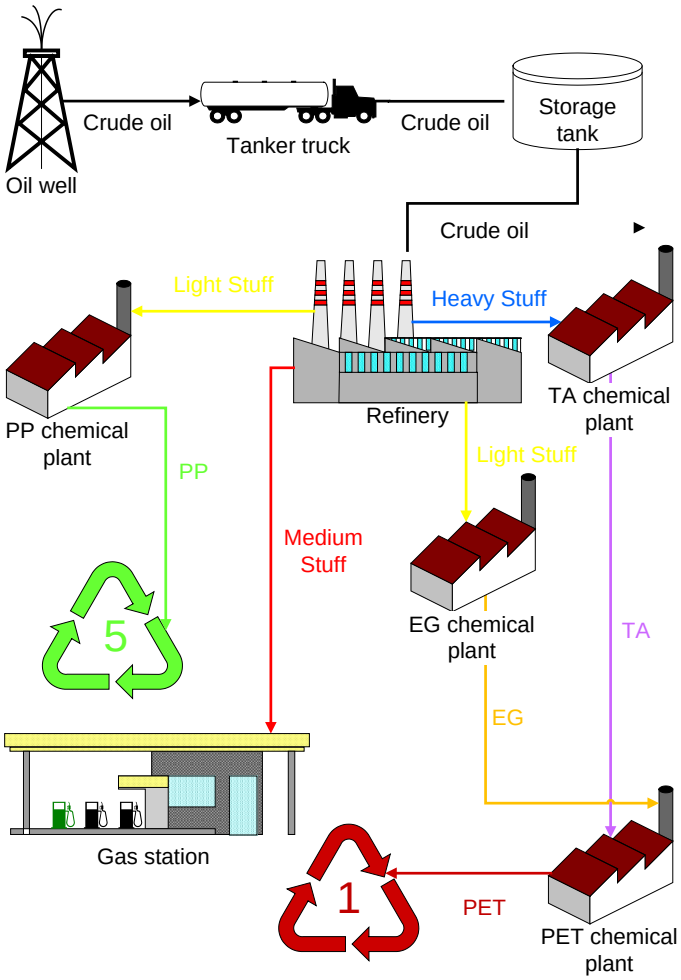


Grade Level 8 (8-12)

Lesson # 1 of 1

Lesson Dependency
NONE

Time Required
120 minutes

Summary

This lesson aims to teach students about plastics and how they are made. Students should learn what typical beverage containers they use are made of, what chemicals are required to make them, and what those chemicals are made from. In learning about plastics, the students should also learn about density, the difference between a physical and chemical change, data collection, and how a chemical reaction changes one substance into a completely different one. This lesson gives background to students so that they can do an activity where they collect data on the recyclable containers in their school and also make the supply chain for PET and PP.

Engineering Connection

Engineers are involved in all parts of the supply chain for plastics, from drilling for oil (petroleum engineers) to transporting and refining the oil (chemical engineers) to designing processes for creating containers from plastics (mechanical engineers and materials scientists) to disposing of and recycling the used containers (environmental engineers). This lesson can be focused on one aspect or another as the instructor sees fit in order to emphasize a particular career or a particular branch of engineering.

Engineering Category, if applicable

Provides engineering analysis or partial design

Level of Inquiry

1. Questions – Level 4: Learner poses a question / hypothesis before they begin
2. Evidence – Level 3: Learner directed to collect certain data
3. Explanations – Level 4: Learner formulates explanation after summarizing evidence
4. Evaluating explanations – Level 3: Learner directed towards areas and sources of scientific knowledge
5. Communication and justification – Level 2: Learner provided broad guidelines to sharpen communication

The lesson can be altered to incorporate more inquiry for more advanced or older students (less explanation of what data to collect, less leading in what their hypothesis should be, less information given on how much energy it takes to make different things, less information on what the component chemicals are made from, etc.) These levels were most appropriate for an average 8^{th} grade physical science student.

Keywords

Polymer, Plastic, Container, Petroleum, Recycling, Data collection, PET

Educational Standards

1) CA State Standards addressed:

Grade Eight – Science Content Standards

3. Structure of Matter – Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements. As a basis for understanding this concept:

b. Students know that compounds are formed by combining two or more different elements and that compounds have properties that are different from their constituent elements.

c. Students know atoms and molecules form solids by building up repeating patterns, such as the crystal structure of NaCl or long-chain polymers.

d. Students know the states of matter (solid, liquid, gas) depend on molecular motion.

e. Students know that in solids the atoms are closely locked in position and can only vibrate; in liquids the atoms and molecules are more loosely connected and can collide with and move past one another; and in gases the atoms and molecules are free to move independently, colliding frequently.

5. Reactions – Chemical reactions are processes in which atoms are rearranged into different combinations of molecules. As a basis for understanding this concept:

a. Students know reactant atoms and molecules interact to form products with different chemical properties.

d. Students know physical processes include freezing and boiling, in which a material changes form with no chemical reaction.

8. Density and Buoyancy – All objects experience a buoyant force when immersed in a fluid. As a basis for understanding this concept:

a. Students know density is mass per unit volume.

9. Investigation and Experimentation – Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations. Students will:

a. Plan and conduct a scientific investigation to test a hypothesis.

b. Evaluate the accuracy and reproducibility of data.

2) National Standards addressed:

Science and Technology in Society

Pre-Requisite Knowledge

Students should know basic elements (carbon, oxygen, hydrogen), compounds (water, methane), and mixtures (air, crude oil, gasoline).

Learning Objectives

After this lesson, students should be able to:

- **Identify the most commonly used recyclable materials in their school**
- **Explain how PET is made and from what raw materials**
- **Calculate how much energy it takes to make a beverage container**
- **Carefully collect data about containers in their school**

Introduction / Motivation

I have a problem for you guys; I want to know how much recycling we make at our school. What do we recycle here? [take suggestions]

Okay, what do you think we make the most of? [probably paper]

Second most? [try to get them to some sort of plastic – water bottles, soda bottles, etc.]

How would we figure it out? [take data!]

Well, that's what I want you guys to do today – I want you to take data and figure out how much plastic we make at the school. I'm going to split you up into groups and we're going to go around the school and try to figure out how much plastic we make here. Here's the data sheet we're going to use [show them data sheet – rows for each room / area they visit, columns for each different kind of recyclable material, areas for their names / group number]

Now, I want you and your group members to go to your areas and figure out how many of each container type are in the area as accurately as you can. Make sure you ask the teacher permission before doing anything in their room. We don't need the containers (we just want to count them) but you can take them back here if the teacher doesn't want them. Make sure you write down how many of each that you find, write "N / A" if you can't get any data, and write "0" if you don't find any. I want you all back in 20 minutes. [let them disperse and collect data]

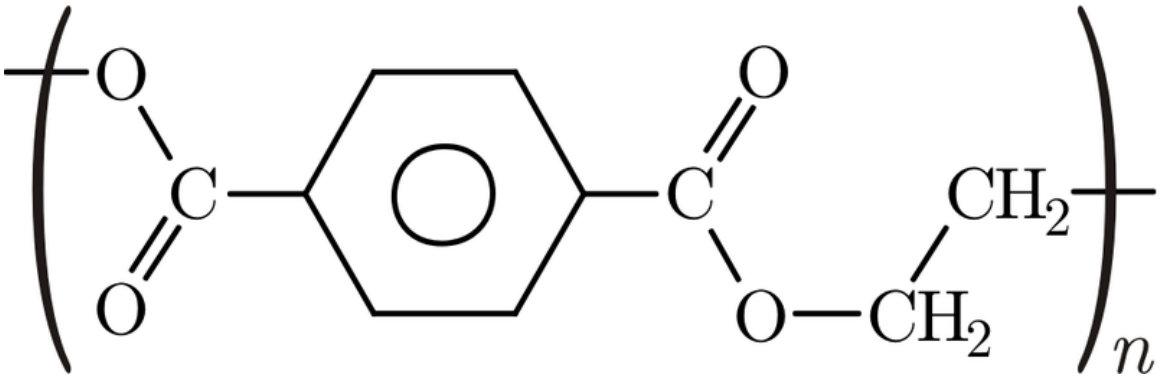
Okay, excellent work on that! Now, we took this data. What can we do with it? What can it tell us? [take suggestions]

Okay, we're in science class so lets make a hypothesis [lead them to make something like "the most energy can be saved by recycling #1 plastic" or "aluminum cans are the second most common recyclable material in our school" etc. It can be right or wrong, it doesn't

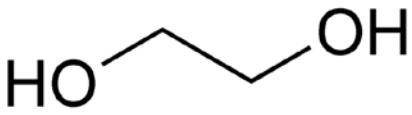
matter too much, but for the rest of the lesson it works better if it involves #1, #2, or #3 plastics.]

How do we test or prove this? [take suggestions]

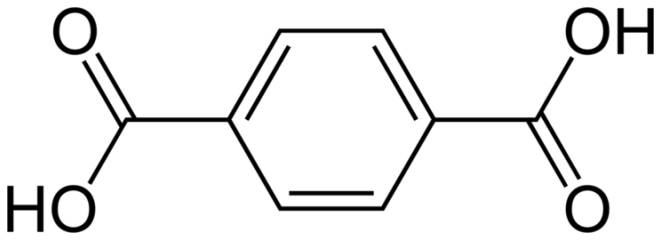
Well, before we can figure anything out, we need to know how to make these things. Plastic water and soda bottles are typically made of polyethylene terephthalate or PET. Don't worry too much about the chemical name, I'm just going to call it PET from now on. This is recycling symbol #1 plastic and it's the most commonly recycled plastic. PET is a polymer, meaning that its molecules are long chains made up of a repeating unit or monomer. The repeating unit in PET looks like this:



This monomer is made up by reacting two different chemical compounds together. The first one is ethylene glycol (EG). Again, don't worry too much about the long chemical name, I'm just going to call it EG. EG looks like this:



It's used in your car as antifreeze. The other chemical compound you need to make PET is Terephthalic Acid or TA. It looks like this:



Can you see how you might put these molecules together to make PET? [take answers / suggestions]

Don't worry too much about the chemical formulas or the names, just remember that you need to react EG and TA to make PET. Now how do you get EG and TA? Well, they both come from oil, air, and water. How do you think they do this? [chemical reactions, physical changes, etc.] Good.

Crude oil is drilled from the ground. It's black, goopy, nasty, smelly stuff. It's a mixture of a lot of different compounds which all have different densities. When it comes out of the ground out of an oil well [draw picture], it's put on a truck [draw picture] or pumped through a pipeline to a storage tank [draw picture]. A factory that chemical engineers call a refinery [draw picture] takes the oil from the storage tank and separates it into different stuff based on its density [emphasize this]. Basically, the refinery cooks the oil in big towers [try to get students to identify with a refinery that they've seen, if possible] and through a physical change [emphasize this], the different stuff in the crude oil is separated from each other (but not changed too much chemically). What comes out of the top of the tower is the "light stuff", which has low density and is mostly gas. The middle of the tower makes "medium stuff" which has medium density and is mostly liquid. The bottom of the tower makes "heavy stuff" and it's liquid or solid stuff. [draw picture]

We can use the light stuff to make EG [draw picture]. We can also use the propylene or the ethylene in the light stuff to make polypropylene (used to make UnderArmour and bottle caps) or polyethylene (used to make water bottles and lots of other stuff).

We can use the medium stuff to run our cars [draw picture]. Most of the medium stuff goes directly to the gas station or the airport to fuel our cars, trucks, and planes.

We can use the heavy stuff to make TA [draw picture]. We can also use it to make wax for candles, petroleum jelly (Vaseline), even asphalt for our roads.

Once we've made the EG and the TA, we can take them to a chemical plant [draw picture] to turn them into PET.

Okay, break time; that was a lot of information (I hope you took good notes!) Now, what I want you to do is to make me a picture of how you make PET and PP. This picture is something that engineers call a "supply chain".

So what I want you to do is to cut out these different things and put them together to make the whole supply chain for the PET in our water bottles. [show them pictures of refinery, chemical plants, truck, oil well, PET symbol, PP symbol, etc.]

Use different colors for each different chemical in the process (since they are all different things) and make a legend for your colors on the back. I'd also like you to label everything that you can. While you're doing that, I'm going to collect and tabulate our data that we collected about the recycling today. [put recycling data in the spreadsheet while they are doing the supply chain]

Okay, when you're done get out a new sheet of paper for me. I want to ask you a few questions about the recycling data. [write compiled data on the board]

My first question for you is: is this data reproducible? Why or why not? Answer this for me on your sheet of paper in one or two sentences. [after they answer, go over answers]

[at this point, if you had the students take data over multiple days, ask them to predict how many containers they collected today]

Now our second [third] question is, what types of containers should we recycle at our school based on the numbers we have? [have them answer the question on their sheet of paper and then go over the answers]

Okay, those are all good guesses. Now I'd like you to calculate how much energy we save by recycling each material. Here is some data on how much energy it takes to make different materials. I want you to tell me which materials we should recycle and why based on the data we collected, the energies I just gave you, and the weights of a container / water bottle that I've given you [let students work this out for themselves in small groups or by themselves].

Don't forget that bottlecaps can be recycled too!

So what are our conclusions? [follow up, review what they learned]

Lesson Background & Concepts for Teachers

My goal in writing this lesson was to explore how much recyclable materials are produced in the students' school, what those materials were made of, how each of them are made, and how the students could use concepts that they already know to calculate how much energy can be saved by recycling each one. Ideally this lesson would be done over many weeks, with students collecting data before class every week, to get a more accurate picture of the number of containers that are in the school. The more data they collect, the better their answers to questions about reproducibility, experimental techniques, etc.

TA is made by reacting another organic compound [para-xylene] with oxygen from the air. This organic compound comes from oil, specifically the heavy stuff in oil. EG is made from ethylene (C_2H_4), oxygen from the air, and water. Again, the organic compound (ethylene) comes from oil, this time from the light stuff in the oil.

Numbers for calculating energy savings:

$$E_{Al} \approx 1.44 \quad \frac{MJ}{can}$$

$$E_{PP/LDPE/HDPE} \approx 110 \quad \frac{MJ}{kg}$$

$$E_{PET} \approx 97 \quad \frac{MJ}{kg}$$

$$E_{oil} \approx 6.12 \quad \frac{GJ}{barrel}$$

$$1 \quad \text{PET water bottle} \approx 12.6 \quad grams$$

$$1 \quad \text{water bottlecap} \left(\text{could be PP or PE} \right) \approx 1.5 \quad grams$$

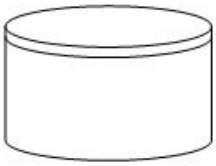
Where the first number is the energy it takes to make a new aluminum beverage can in megajoules (MJ) per can, the second number is the energy it takes to make polypropylene (PP) or polyethylene (LDPE or HDPE) in MJ per kilogram (kg), the third number is the energy it takes to make polyethylene terephthalate in MJ per kg, the fourth number is the energy content of a barrel of crude oil in gigajoules (GJ) per barrel, and the fifth and sixth numbers are approximate weights of PET water bottles and their caps, respectively. These numbers are approximate and were estimated by the author using numbers found in the references below.

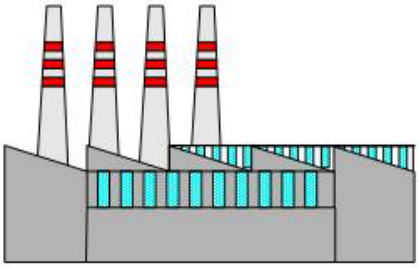
References

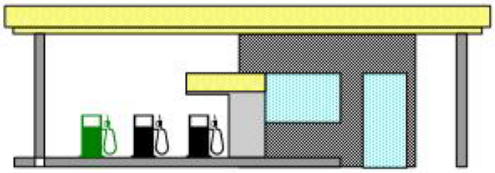
http://www.energybulletin.net/node/34403

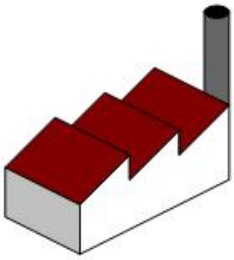
http://www.pacinst.org/topics/water_and_sustainability/bottled_water/bottled_water_and_energy.html

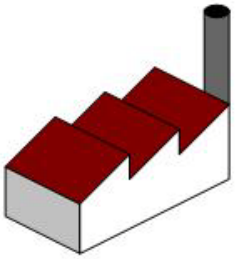
Images

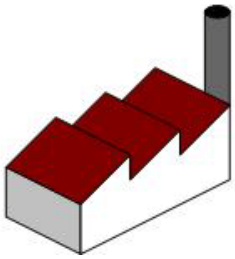












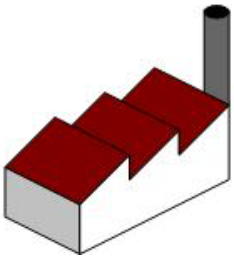


Figure #1

ADA Description: Pictures needed to make PET and PP supply chain. An oil well, a storage tank, a truck, a refinery, a gas station, four chemical plants, a symbol for PET plastic (#1), and a symbol for PP plastic (#5).

Caption: Pictures for supply chain

Image file name:
PicturesForMakingSupplyChain.jpg

Vocabulary / Definitions

Word	Definition
Polymer	(use the definition from the students' textbook)
Monomer	(use the definition from the students' textbook)
Refinery	A factory which separates crude oil (a mixture) into different products (light stuff, medium stuff, and heavy stuff)
Chemical reaction	A process where elements or compounds undergo a chemical change. In a reaction, atoms are rearranged into different combinations of molecules.
Density	(use the definition from the students' textbook)
Chemical plant	A factory where engineers and workers use chemical reactions to turn raw materials into useful products
Ethylene Glycol (EG)	Organic compound used in antifreeze in cars; also used to make PET
Terephthalic Acid (TA)	Organic compound used to make PET; very toxic to people
Polyethylene Terephthalate (PET)	Recyclable plastic #1 – an organic polymer very commonly used to make beverage containers
Polypropylene (PP)	Recyclable plastic #3 – an organic polymer used to make beverage container caps, clothing, and other products
Propylene	The monomer used to make polypropylene polymer
Polyethylene (LDPE or HDPE)	Recyclable plastic #2 – an organic polymer used to make beverage containers, water bottles, bottle caps, etc.
Ethylene	The monomer used to make polyethylene polymer
Oil well	Site where crude oil is pumped out of the ground
Supply chain	A diagram of the chain of events, buildings, materials, and products necessary to produce a good or service
Physical property	(use the definition from the students' textbook)
Chemical property	(use the definition from the students' textbook)

Associated Activities

The lesson can be broken into four parts:

1. Data collection and graphing
2. Data analysis and forming hypotheses
3. How PET and PP are made (with supply chain activity)
4. Calculating the energies saved by recycling different materials

Each part could be kept or removed as the instructor saw fit. When I implemented the lesson, it worked well to have them just collect data for a couple of sessions, then to do the PET / PP supply chain activity one day, then the energy calculations another day, then the data analysis a third day. This gives students time to collect many data points and makes the lesson a bit more realistic and meaningful.

Lesson Closure

So what did we learn today? We learned how PET is made and that it's a polymer. Its monomer (the unit which makes up the polymer) is made up of two different chemicals called EG and TA and that they are made by chemical reactions. We learned that crude oil can be divided into different components (based on their density) in a refinery. We learned what the most easily recycled things in our school are. We learned how to calculate the energy it takes to make different materials and what it means for recycling at our school. We learned how to collect data, to graph it, to use it to confirm or reject our hypotheses, and how to tell how reproducible the data is.

Assessment

Pre-lesson: Quiz students on vocabulary (polymer, monomer, plastic, density, etc.)

Post-lesson: Assessment is kind of included in the lesson (whether they did the supply chain right, their answers to the questions about the recycling data, the calculation of the energy). You could quiz or test them on the concepts they learned (density, chemical reaction, etc.)

Lesson Extension Activities

1. You can make a quiz or a homework assignment based on a correct supply chain for PET or PP.
2. For advanced students, you could have them make up their own supply chain for something else (HDPE or LDPE, polystyrene (PS), aluminum (Al), etc.)
3. You could have students continue to take recycling data or start a recycling program if there is not one already at your school. This would make an excellent science project.