ACTIVITY

10 Adventures in Life Cycle Assessment

By performing a play or through group presentations, students investigate life cycle assessment (LCA) data for three types of outdoor dining furniture (plastic resin, cast aluminum, and pine) and make conclusions about the relative impact of the products on global climate change.

Subjects
Biology, Environmental Science, Language Arts, Mathematics, Social Studies

Skills
Analyzing, Communicating, Concluding, Determining Cause and Effect, Identifying Relationships and Patterns, Organizing Information, Predicting

Materials
Student pages, presentation, and answer key (see Activity Webpage link below); Optional: poster materials, props, and costumes

Time Considerations
Three Act Play: Three to four 50-minute class periods; One Act Play: Two to three 50-minute class periods
Student presentations: Two to three 50-minute class periods

Related Activities
Students should have an understanding of climate change (Activity 2) and externalities (Activity 9). This activity can be followed with exercises that apply this information to students' purchasing decisions (Activity 11) or climate change mitigation (Activity 12).

Research Connection
Economists are conducting life cycle assessment research comparing environmental impacts for different products that provide the same functions. A comprehensive life cycle assessment can help researchers quantify the pros and cons of different products and, in the case of this module, understand the role of forests and wood products in mitigating climate change. Databases containing information that researchers use to create LCAs can be found online (see Enrichment section of this activity).

Activity Webpage
Find online materials for this activity at https://sfcc.plt.org/section4/activity10

Objectives

By the end of this activity, students will be able to

- describe the stages of a product's life cycle and how greenhouse gas emissions may be generated during those processes, and
- compare life cycle data for two or more products to decide which product would reduce greenhouse gas emissions.

Assessment

- Ask students to draw a life cycle diagram, labeling each stage of the diagram and providing a brief description of each stage.
- Ask students to write a report summarizing the life cycle assessment of the outdoor dining furniture. The report should include an introduction to life cycle assessment, a description of the products analyzed, life cycle data for each product, and a discussion comparing each product's impact on global climate change.
- Ask students to decide which type of dining furniture the school should buy and to defend their choices by describing their personal values and the consequences of their choices using life cycle assessment information.

Background

To evaluate and compare the environmental impacts of products, scientists take a detailed look at the entire life cycle of a good or service—which means they conduct a ***life cycle assessment***. A ***product's life cycle*** begins with extracting and processing raw materials, continues through the manufacturing, includes how the product is used, and ends with disposal of the product (figure 1). At every step, resources and energy are used and ***greenhouse gas emissions*** and other byproducts are created. Life cycle assessments identify these resources and emissions and summarize their environmental effects. This information can be used by scientists, policymakers, manufacturers, and citizens to make decisions about which products to produce and purchase. In many life cycle assessments, transportation of items from stage to stage is another variable (shown as T in figure 1). In the assessments provided here, transportation has been included in each stage.

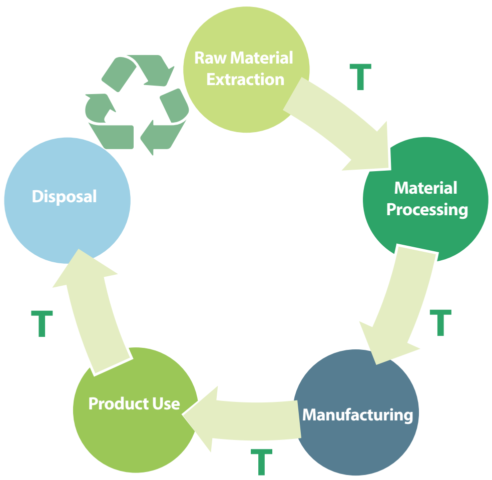


Figure 1. Steps in Life Cycle Assessment.

Additional background information can be found in the **Section 4 Overview** and in **Activity 9**.

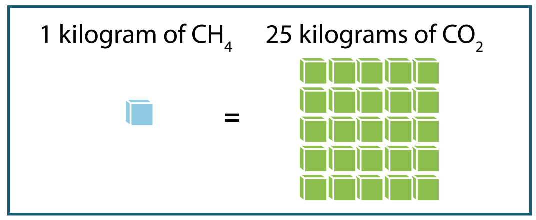
The National Renewable Energy Laboratory (NREL) U.S. Life-Cycle Inventory Database is a good resource to access data for life cycle assessments (http://www.nrel.gov/lci/). Data for utilities, transportation, and basic mining and forestry materials are included in this database. The life cycle data provided in this activity was calculated using the U.S. Life-Cycle Inventory Database, and a step-by-step tutorial for using this professional database to find information for other products is available on the Activity 10 webpage.

The life cycle data provided in this activity compares three types of outdoor dining furniture and focuses on greenhouse gas emissions resulting from the manufacturing, use, and disposal of the product. We focus on greenhouse gas emissions so that students can calculate the ***global warming potential*** of each of the three furniture sets.

Greenhouse gases trap heat in the Earth's ***atmosphere***. A certain amount of greenhouse gases are necessary to keep the Earth warm enough to sustain life. However, increasing amounts of greenhouse gases in the atmosphere create a gradual increase in the average global temperature, which is known as ***global warming.*** More information about global warming can be found in the **Section 1 Overview** and **Activity 2: Clearing the Air**. Greenhouse gases include the following:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulfur hexafluoride (SF_6)
- Water vapor (H_2O)

Of all the greenhouse gases, atmospheric carbon dioxide levels have increased the most in recent years. However, methane and nitrous oxide are important greenhouse gases to consider in the life cycle assessment as well. Not all greenhouse gases are equal. Some gases are able to capture more energy than others. For example 1 kilogram of methane in the atmosphere will trap about 25 times as much heat energy over a 100-year period as a kilogram of carbon dioxide. Therefore, methane is defined as having a global warming potential of 25. When scientists measure the impacts of greenhouse emissions, they often use the term ***carbon dioxide equivalents***. This is the basic unit for measuring the global warming potential of all emissions. Since 1 kilogram of methane traps as much heat as 25 kilograms of carbon dioxide, that 1 kilogram of methane has a global warming potential of 25 kilograms of carbon dioxide equivalents.



Carbon dioxide equivalents are a measure of global warming potential, expressed in the amount of carbon dioxide that would cause the same amount of warming. As seen here, 1 kilogram of methane (CH_4) is equivalent to 25 kilograms of carbon dioxide (CO_2).

Teaching This Content

This activity introduces the highly technical process of assessing a product's life cycle, and it is likely to involve more detail than students thought possible. After one or two examples, you might see if they can guess the steps in the process for the third. While our intuition about environmental impacts of products might be a reasonable guess, it is handy to have real numbers to lean on, especially for making recommendations that the school could use to reduce emissions! Also, if you have used **Activity 5: Managing Forests for Change**, please note the potential confusion between causal loop diagrams and life cycle diagrams explained in the Systems Thinking Connection box.

Learning about the environmental impacts of all the stuff we buy can be overwhelming

Systems Thinking Connection

IN THIS ACTIVITY, students explore diagrams of several different life cycles. Some students may confuse these diagrams with the ***causal loop diagrams*** from Activity 5. Instructors can explain that these are two different tools designed to emphasize different aspects of a ***system.*** In causal loop diagrams, the arrows represent cause-effect connections between different parts of the system. For example, "Atmospheric Carbon Dioxide → Heat Energy in the Atmosphere" in a causal loop diagram suggests that increasing the amount of carbon dioxide in the atmosphere will cause an increase in the amount of heat energy trapped in the atmosphere.

Conversely, the life cycle diagrams are designed to show material flowing through a system over time. Here, the arrows represent actual material flows over time. For example "Refined Oil → Plastic Pellets" suggests that the atoms in the refined oil are rearranged into molecules of plastic. Those pellets are then combined with other materials and rearranged into plastic furniture. The systems enrichment exercise is designed to give students practice seeing this important distinction.

and even depressing. Remind students that all products have some environmental impact. The focus is on weighing the costs and benefits associated with a product or service. Students may consider choosing to not buy anything because whichever product they select creates such a large impact on the environment. While companies are invested in encouraging us to buy more and replace out-of-fashion items frequently, students should consider the impact of their purchases. Maybe they don't need a new shirt just because it is attractive; maybe repairing a broken chair will extend its life span. Shopping at a thrift store is one way to give old products a new life. Suggest that students consider when it is appropriate to buy new things.

This activity integrates all aspects of STEM (science, technology, engineering, and math)! Students gain an understanding of the research behind the methods and technology that goes into how things are made, and they discover the intricate processes involved with manufacturing products. The life cycle analysis is typically done through engineering, the discipline that gives us technology and the ability to produce the outdoor furniture featured in this activity. In addition, students need to use mathematics to analyze the data to determine the "best" product. This activity provides a good opportunity to let students know that engineering and math are not always as complicated as building a rocket. Examples of STEM are all around us.

Getting Ready

The Activity 10 webpage provides **Teacher Tools** that you can use to become more familiar with this activity's background and procedure (https://sfcc.plt.org/section4/activity10).

If your students are not familiar with life cycle assessments, you may want to provide an overview of this topic using the LCA and Externalities presentation on the Activity 9 webpage.

Based on available time, number of students, student ability, and student interest**, you may choose to conduct this activity by performing a play or through student presentations**. The information for conducting life cycle assessments on three types of outdoor dining furniture is provided in both formats.

You may also mix and match the two delivery mechanisms by performing one or two of the acts, and providing the Life Cycle Information student pages for the remaining product(s).

Perform a Play

Students act out the play in class, and as the characters discover life cycle data for each product, the audience records this information using the Comparing Outdoor Furniture student page. The play is divided into three acts—one for each set of furniture. Each act has

TEACHERS SAY ...

My students are used to project-based instruction, so they tried out for parts after an oral reading during class time and the class voted on who would play each part. The class shared their play with the other section of the 8th grade class.

—Middle School Science Teacher, Arkansas

ANNIE OXARART, UNIVERSITY OF FLORIDA

Depending on time availability and student interest, you can choose whether to conduct this activity by performing a play or through student presentations.

ten or eleven actors and takes 30 to 35 minutes to perform. The acts can be performed on separate days or together if you have a long class period. There is also a one act version of the play with 11 scripted parts that includes a brief description of the life cycle of all three types of furniture and takes one or two class periods to complete. After the performance, students discuss and compare each product's impact on global ***climate change***.

- Download the LCA Play Script from the Activity 10 webpage and copy the number needed depending on the number of actors and acts performed.
- Download the LCA Play slide presentation from the Activity 10 webpage. This includes images for the stage backdrop and the notes on emissions.
- Make copies of the Comparing Outdoor Furniture student page for each student.
- You may wish to invite other students, teachers, or parents to enjoy the play. Try to make time for students to practice before inviting others to the performance. Encourage students to bring props!
- Note that each act of the play involves three review questions for the audience to answer during the play. Some of these come directly from the content of the play. Others concern key climate change concepts that are covered in Activity 2 of this module. If you elect to perform the play without working through other parts of the module, we recommend that you go through the background section for Activity 2. Alternatively, you can use these questions as a WebQuest or simply replace them with something that will review key concepts you have been covering in class.

Student Presentations

Using the Life Cycle Information student pages, student teams give a short presentation to explain their product's life cycle and report on the greenhouse gas emissions resulting from each stage. As each team presents, students in the audience complete the Comparing Outdoor Furniture student page. As a class, students discuss and compare each product's impact on global climate change.

- Divide the class into three teams: Plastic Resin, Cast Aluminum, and Pine. Make copies of the appropriate Life Cycle Information student pages, one for each student in each group. If there are enough students in each team, they could subdivide to each present a different stage of the life cycle.
- Make copies of the Comparing Outdoor Furniture student page, one for each student in class.

Doing the Activity

1. To introduce the topic of the life cycle assessment, ask students to select one item they have recently purchased. On a piece of paper, ask students to brainstorm ideas about the materials and processes it took to make that product; what resources are used to care for or maintain the product; and what happens to it when it is no longer useful. Ask a few students to share their ideas.

2. Explain that life cycle assessments are used to measure and calculate the environmental impact of a product. Draw the life cycle diagram on the board (see figure in Background section), and ask students if they can see where their ideas fit into the diagram and whether there are any circles that would require more information to complete.

3. Tell students to imagine that they have been charged with choosing new outdoor dining furniture for the school's cafeteria patio. Because your school is concerned with its environmental footprint, the students have to investigate the life cycles of three types of outdoor dining furniture before making a decision: a table and four chairs made from plastic, from aluminum, and from wood. Tell them that for these assessments, they will focus on greenhouse gas emissions. Remind students that carbon dioxide, methane, and nitrous oxide are the major greenhouse gases. Through either the play or presentations, students gather real data for greenhouse gas emissions for each step of each product's life cycle.

4. Ask students to predict which product they think will have the lowest greenhouse gas emissions. Which do they think will have the highest? Why?

5a. Stage the Play

- Based on the number of acts you plan to perform, and the number of students in your class, assign characters, or allow students to choose their own characters, and pass out copies of the script. Since most of the characters are on the stage for only a portion of the play, some students will be able to share scripts.
- For homework, ask students to read through the script and become familiar with their roles. They may wish to bring props or "dress" for the part on the day of the performance. You can encourage your students to personalize the script by making minor edits without removing any information. They may want to change some of the jokes or characters to make the play their own.
- The LCA Play slide presentation provides an instant "background set" for the play. Slides also provide the life cycle data for each stage, which students in the audience need to write down on the Comparing Outdoor Furniture student page. As the play progresses, allow some time for the student audience to record the data on student pages. You can advance the slides as noted in the script or assign a student to do this.

5b. Student Presentations

- Divide the class into three groups (plastic resin, cast aluminum, and pine). Pass out the appropriate Life Cycle Information student pages to each group member.
- Provide time for the students to read their Life Cycle Information student pages and to organize their presentations. Suggest that one or two people in each group cover each life cycle stage, so that all group members can participate in the presentation. During the presentation, students should describe what happens during that stage and provide life cycle data.
- Encourage students to make presentations interesting. If they give a slide presentation, they can include relevant photos or graphics. They can also use the board, flip chart paper, or any other visual presentation style. They should finish tasks not completed in class as homework and come to the next class prepared to give their presentations.
- While each group presents, the audience should record data on the Comparing Outdoor Furniture student page.

6. After the performance or presentations, give students a few minutes to complete the calculations for the greenhouse gas equivalents on the Comparing Outdoor Furniture student page. An answer key is available on the Activity 10 webpage. Then use the following wrap-up questions to guide a class discussion:

- What are carbon dioxide equivalents? How did this change the life cycle data? *Some gases have a larger effect per mass than others. For example, methane is more than twenty times stronger than carbon dioxide per unit. In order to combine the warming effects of different gases, scientists express the warming impact of methane and nitrous oxide emissions in the common unit of carbon dioxide equivalents.*

TEACHERS SAY ...

Students enjoyed the activity because it got them out of their seats. And they learned that they need to educate themselves about consumer choices and product selection.

— AP Environmental Science Teacher, Florida

TEACHERS SAY ...

All materials were at a perfect level for my students. I will do the activity again and will choose the presentation option again.

—AP Environmental Science Teacher, Kentucky

- What surprised you as you learned about the life cycles of outdoor dining furniture?
Answers will vary. Encourage students to compare different steps in the life cycles.

- What conclusions can you make about the relative impact of each product on global climate change?
The aluminum set has a much larger impact than the other two. The wood set has the lowest impact of the three.

- How could production change to reduce emissions?
Answers will vary. Have students identify the steps with the highest emissions. For example, the disposal stage represents most of the emissions associated with the wood set. Finding nontoxic ways to treat the wood would mean that it could be composted instead of taken to the landfill, significantly decreasing its climate change impact. Some wood is naturally more insect and fungus resistant than pine, which is why redwood and teak are often used for outdoor furniture. But that would involve additional product life cycle considerations!

- What factors do people usually consider when choosing between similar products?
Price and quality of the products are typically considered. This activity is designed to encourage students to think beyond these basic factors.

- Should life cycle information be available for more products? Why or why not?
Answers will vary. It is certainly useful information, but can be time consuming to obtain.

- Based on what you learned from the furniture comparisons, what types of general questions can you ask about a product prior to buying it? Using it? Disposing of it? Think of items that you tend to buy: what should you know about them to decide which is better for the environment?
Answers will vary. Encourage students to consider if a process involves high temperatures and large chemical inputs (such as aluminum). Does using the product result in significant greenhouse gas emissions? How long can you use the product before disposing of it? Can the product be reused or recycled?

- Draw a basic life cycle diagram for a tree or an animal (e.g., seed to sprout to sapling to adult tree to dead tree). Ask students where the "raw materials" come from during the various "production" steps. Ask them where the materials go during the "disposal" step.
Point out that all life cycles in nature are circular. Materials are reused over and over again. Many leaders in sustainable business suggest that this should be the model for industry as well. The aluminum furniture set is an example of a circular cycle that uses recycled materials even though some primary aluminum is still used in the process.

- Systems Reflection: In what way is LCA a tool for improving systems thinking?
One of the key insights that systems thinking can provide is a greater awareness of how we are connected to the world around us. LCA is a tool for doing just that. It increases the knowledge that consumers have about the social and environmental systems that are necessary to provide the products and services that we consume.

7. Summarize this activity by reviewing the steps of a life cycle assessment and the importance of quantifying impacts with a life cycle assessment when making recommendations for purchasing. You might suggest that students use this information when making their own purchasing decisions in the future. This process will be helpful for **Activity 11: Life Cycle Assessment Debate**, which is a good follow-up activity.

Types of Furniture

To shorten this activity, students can investigate one type of furniture to learn the life cycle steps and then discuss how these steps may differ for the other two types of furniture.

Modifications

If you are conducting either the three- or one-act play, you may want to ask for assistance from the drama club at your school or from parent volunteers. If you teach multiple classes of the same subject, you can divide the play or presentations into sections by class and come together for a group presentation.

Some of the content on product information sheets might include vocabulary that is new to your students. Edit the text to their reading level or have students look up new vocabulary words for homework or a separate assignment.

If limited by time, you can just investigate one type of furniture so students can learn the steps of the life cycle and then have a group discussion about how about these steps may differ by product type.

Enrichment

Use the Create Your Own LCA tutorial on the Activity 10 webpage to have students investigate and calculate greenhouse gas emission data for another product. Concrete is another material commonly used for sturdy outdoor picnic tables. Challenge students to conduct an LCA for this product and compare!

Systems Enrichment Exercises

YOU CAN HELP YOUR STUDENTS BETTER UNDERSTAND THE DIFFERENT WAYS WE CAN LOOK AT SYSTEMS by reinforcing that a causal loop diagram shows us the cause-effect connections between different parts of a system, and a life cycle diagram shows us one path that a set of matter (or atoms) follows through a system. The exercise, **The Impacts of Demand for Sustainable Wood**, was developed to help students see the difference between life cycle diagrams and causal loop diagrams—two different tools with two different functions. Additionally, this exercise uses a causal loop diagram to help students understand how demand for sustainable wood plays an important role in protecting forests. This exercise can be found on the Activity 10 webpage.

TEACHERS SAY ...

When using this activity, I incorporated the "Story of Stuff" from the resource section of The Real Cost to help introduce the concept of life cycle assessments.

—AP Environmental Science Teacher, Florida

Have students consider the durability of the materials and the frequency with which tables or chairs might need to be replaced. For example, the plastic chairs might easily break, or students might carve into the wood. While aluminum or concrete have more greenhouse gas emissions, they might be more durable in the long run.

Additional Resources

Consortium for Research on Renewable Industrial Materials (CORRIM)
www.corrim.org
This website provides many resources related to life cycle assessments, including several videos, presentations, and fact sheets.

Life Cycle Impacts of Forest Management and Wood Utilization on Carbon Mitigation: Knowns and Unknowns
Bruce Lippke et al., 2011
http ://www.corrim.org/pubs/articles/2011/FSG_Review_Carbon_Synthesis.pdf
This short article, published in *Carbon Management*, examines the complexities in accounting for carbon emissions in life cycle analyses and offers information on the many different ways that wood can be used.

The Life Cycle of Everyday Stuff
Mike Reeske and Shirley Watt Ireton, National Science Teachers Association, 2001
http://www.nsta.org/store/product_detail.aspx?id=10.2505/9780873551878
This supplemental curriculum guide uses central science concepts to explore the energy, raw materials, and waste issues that are associated with manufactured products.

U.S. Life Cycle Inventory Database
National Renewable Energy Laboratory
www.nrel.gov/lci
This database helps life cycle assessment practitioners answer questions about environmental impact. It provides accounting of the energy and material flows into and out of the environment that are associated with producing a material or component, or assembling products in the United States.

Which Do You A-Door? Comparing the Energy Needed to Make Wood and Steel Doors
Melissa Huff, Robert Ross, and Janet Stockhausen; U.S. Forest Service, 2009
www.naturalinquirer.org/Comparing-the-Energy-Needed-to-Make-Wood-and-Steel-Doors-a-82.html
This *Natural Inquirer* article, written for middle school students, describes research that compares portions of the life cycle for wood and steel doors.

References Cited

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Mulkey, S., Alavalapati, J., Hodges, A., Wilkie, A., & Grunwald, S. (2008). Opportunities for Greenhouse Gas Reduction through Forestry and Agriculture in Florida. School of Natural Resources and Environment, University of Florida. Gainesville, FL: University of Florida. Retrieved from http://snre.ufl.edu/research/greenhouse.htm

Life Cycle Information:

Plastic Resin Furniture (1 of 3)

The plastic resin set of furniture is made from polypropylene (pol-ee-proh-puh-leen) resin—a plastic polymer with a wide range of uses, including car parts, diapers, and, of course, outdoor furniture. It is made from by-products of processing natural gas and refining crude oil. Since each piece of the set is made from one mold, no fasteners are required. The total mass of the four chairs and table is approximately 30 kilograms (kg). All emissions reported here are based on this mass.

MUMUDESIGN.COM

A set of plastic furniture, such as the one shown here, is made from polypropylene resin.

Oil and Natural Gas Extraction

More than 300 million years ago, countless zooplankton, algae, and diatoms died and sank to the bottom of oceans all over the globe. After eons of pressure and geological processes, the planet has been left with billions of gallons of oil, also called "petroleum." Crude oil is generally located in cavities about a mile deep underground. Sometimes the oil is under pressure that is high enough that drilling a deep hole causes it to gush out of the earth—an event that has caused some oil prospectors to dance excitedly as their new oil wells shower them in a brown, gooey mess. Most of the time, however, it must be pumped to the surface. Oil from the ground usually contains water. This water is removed before sending the oil to a refinery. The natural gas is captured, but some leakage of gas always occurs when bringing petroleum to the surface. In addition, it takes energy to collect these substances and prepare them for refining and processing. The emissions that result from this step of the life cycle are reported in the following table.

Stage of Life Cycle	*Oil and Natural Gas Extraction*
CO_2 Emissions (kg/set)	4.20
CH_4 Emissions (kg/set)	0.164
N_2O Emissions (kg/set)	0.00000588

Refining Crude Oil and Processing Natural Gas

Most of the refineries in the United States are in Gulf Coast states. The majority of our oil (62 percent) is imported; 32 percent comes from the lower 48 states, and the remaining 6 percent comes from Alaska. The top three providers of foreign oil to the U.S. are Canada, Saudi Arabia, and Mexico. Scientists and economists use a weighted average of the emissions associated with transporting oil to U.S. refineries by pipeline or ship from these sources.

Once at a refinery, impurities are removed from the oil through a series of chemical processes. During this process, hydrocarbons such as methane and propane are removed from the oil. These hydrocarbons are used in many different products, including the production of polypropylene. The greenhouse gas emissions associated with the transportation of oil to U.S. refineries and

Life Cycle Information: Plastic Resin Furniture (2 of 3)

refining the oil and natural gas are reported in the following table.

Stage of Life Cycle	*Refining Oil/Processing Natural Gas*
CO_2 Emissions (kg/set)	6.87
CH_4 Emissions (kg/set)	0.0571
N_2O Emissions (kg/set)	0.0000350

Producing Polypropylene Resin

Propylene is made from a combination of chemicals derived from oil and natural gas, including hydrocarbons such as ethane and propane. These molecules are put through a process called "thermal cracking." The term "cracking" refers to a process in which heavy molecules are broken down into smaller ones. In this case, the hydrocarbons are combined with steam and the mixture is heated to around 1000 degrees Celsius (° C) or 1832 degrees Fahrenheit (° F). The combination of high temperature and pressure breaks the larger hydrocarbons into smaller molecules, including propylene. The propylene must then be separated from the other products that result or are leftover from this process.

The next step is to convert the propylene into polypropylene. The prefix "poly" means many. Polypropylene is a molecule made up of many propylene molecules connected together. The polymerization of propylene is accomplished through the use of catalysts at fairly moderate temperatures (80 to 90° C or 176 to 194° F) and high pressures (30 to 35 atmospheres). The greenhouse gas emissions listed in the following table represent emissions associated with the propylene portion of the thermal cracking stage as well as the polymerization of propylene into polypropylene.

Stage of Life Cycle	*Manufacturing Polypropylene*
CO_2 Emissions (kg/set)	32.4
CH_4 Emissions (kg/set)	0.427
N_2O Emissions (kg/set)	0.000280

Manufacturing the Furniture

Polypropylene in the form of small pellets (tiny beads) is shipped by rail to furniture manufacturing plants. Those pellets are melted and mixed with other substances that make each type of plastic a little different. The mixture is injected into a mold using a 1000-ton injection molding machine. After the resin hardens, the mold is opened, small amounts of resin are trimmed from the edges, and the piece is boxed for shipment. The greenhouse gas emissions reported

FRC INDUSTRIES, INC.

Small polypropylene pellets are packaged and shipped to manufacturing facilities that create plastic products.

Life Cycle Information: Plastic Resin Furniture (3 of 3)

here represent direct energy use necessary for melting, mixing, and injecting the polypropylene resin in to the molds.

Stage of Life Cycle	*Manufacturing Plastic Furniture*
CO_2 Emissions (kg/set)	15.6
CH_4 Emissions (kg/set)	0.0372
N_2O Emissions (kg/set)	0.0000622

Use/Maintenance

Maintenance and upkeep of the plastic resin patio furniture is minimal, consisting of washing with soap and water. Therefore, greenhouse gas emissions associated with this stage of the life cycle are assumed to be insignificant and not included in this assessment.

Stage of Life Cycle	*Use*
CO_2 Emissions (kg/set)	0.00
CH_4 Emissions (kg/set)	0.00
N_2O Emissions (kg/set)	0.00

Disposal

While many plastic resins can be recycled in curbside recycling programs, the mixture resulting from the manufacturing process of this patio furniture is not easily recyclable. Therefore, disposal consists of a trip to a community landfill. One of the criticisms of plastic resin is that it takes a very long time to decompose. Plastic can exist in a landfill for hundreds of years. In the context of greenhouse gases, this trait works in favor of plastics. Over a one hundred-year period, only 6 percent of the carbon in the plastic set will have decomposed and formed greenhouse gases—4 percent is carbon dioxide and 2 percent is methane. The greenhouse gas emissions reported here include these emissions as well as those associated with the collection and management of solid waste.

ROBERT GORDON, DEKALB COUNTY

Most plastic chairs are taken to a landfill after being thrown away.

Stage of Life Cycle	*Disposal*
CO_2 Emissions (kg/set)	12.8
CH_4 Emissions (kg/set)	0.292
N_2O Emissions (kg/set)	0.0000319

Life Cycle Information:
Cast Aluminum Furniture (1 of 3)

ANNIE OXARART, UNIVERSITY OF FLORIDA

An aluminum set of dining furniture is made of cast aluminum.

The aluminum set of dining furniture is made of cast aluminum. While manufacturers often use primary aluminum, we have based these calculations on a combination of primary and recycled aluminum often produced by aluminum plants in the United States. The energy requirements are decreased substantially by the inclusion of recycled aluminum. The mass of aluminum in the four chairs and table is approximately 60 kilograms (kg).

Extracting Aluminum

Aluminum manufacturing involves use of both primary aluminum from bauxite, an aluminum ore, and secondary aluminum, which is recycled from aluminum scrap.

Producing primary aluminum first requires mining bauxite from the ground. While aluminum is the third most plentiful element in the Earth's crust, it's usually found as part of a chemical compound with other elements. Trying to produce pure aluminum from most of these compounds is very expensive. It would cost more to produce the aluminum than the aluminum is worth. Bauxite, a type of rock that contains high amounts of aluminum is the exception, though even with bauxite, producing pure aluminum requires a lot of effort. First, the bauxite must be mined. In some cases, the bauxite is found in relatively soft rock that can be easily dug up, often in open-pit mines. In other cases more substantial drilling and the use of explosives are required. Mixing secondary aluminum with the primary aluminum decreases the amount of bauxite that must be mined. Here we assume that the outdoor furniture is made of 50 percent recycled aluminum since we want to consider furniture that will have the least impact on the climate.

Stage of Life Cycle	*Bauxite Mining (for ½ Primary Material)*
CO_2 Emissions (kg/set)	10.1
CH_4 Emissions (kg/set)	0.00203
N_2O Emissions (kg/set)	0.000221

Processing Aluminum

As previously mentioned, processed aluminum is a mixture of primary and secondary aluminum. Most of those emissions, however, are the result of the energy-intensive process of producing pure aluminum from bauxite. Once out of the ground, the bauxite is crushed into small pieces and sent to a processing plant. At the processing plant, the pieces are brought to a high temperature and pressure and mixed with sodium hydroxide in order to dissolve the ore and separate the aluminum from other materials found in the ore. Then the liquid containing the dissolved aluminum is pumped into tanks where it is cooled, allowing alumina hydrate crystals to form. Those crystals are filtered from the tank and dried in a kiln at approximately 400 degrees Celsius (° C) or 752 degrees Fahrenheit (° F) to produce aluminum oxide.

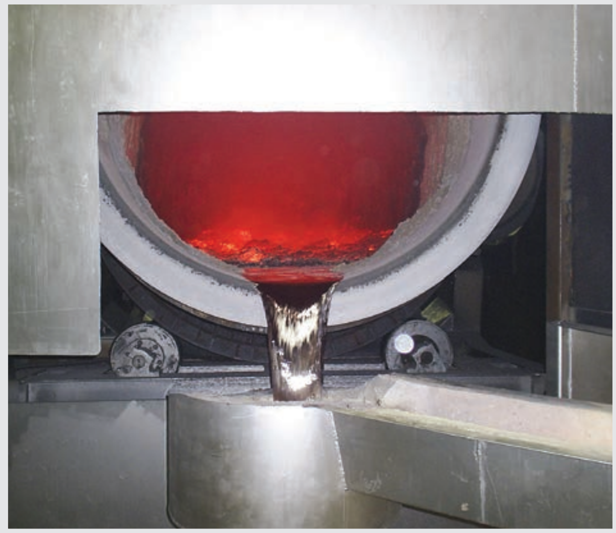
Producing aluminum from the aluminum oxide requires chemical reactions at temperatures of more than 1000° C (1832° F). The aluminum oxide is placed

Life Cycle Information: Cast Aluminum Furniture (2 of 3)

with a carbon rod into a cell where the combination of electricity and high temperatures causes a chemical reaction that produces carbon monoxide, carbon dioxide, and aluminum. The molten aluminum collects at the bottom of the cell where it can be separated from the other materials. Depending on the intended use of the aluminum, it will be mixed with small amounts of other metals to produce the desired characteristics. Such mixtures of metals are called alloys. The aluminum is made into an alloy while it is still in its molten form. The alloyed aluminum is then cast into ingots or billets (terms for rectangular and cylindrical pieces of aluminum alloy).

At this point the ingots of primary aluminum can be mixed with secondary aluminum. Recycling scrap aluminum is a way to avoid the most energy intensive (and costly) steps of aluminum production. Scrap aluminum has already been separated from the impurities in bauxite and converted from aluminum oxide. To process secondary aluminum, scrap aluminum must first be collected. Aluminum can be recycled without loss of quality. This makes scrap aluminum relatively valuable. As a result, collecting and recycling scrap aluminum has become its own sub-industry. Ideally, aluminum is collected in a closed-loop process based on the particular aluminum alloy. For example, soda cans are collected in order to be made into new soda cans. By including only one aluminum alloy in a batch of scrap, manufacturers can be confident that the final product will have the same desired characteristics for that particular use. In other cases, the various scrap aluminum alloys are mixed together.

Once the aluminum is collected, it is shaved into small pieces for processing. Often scrap aluminum has enamel, paint, or some other substance that can reduce the purity of the final product if it is not removed. The aluminum is heated close to the melting point of aluminum (660° C) to remove these substances. The aluminum is then melted down and cast into ingots or billets, similar to the process for primary aluminum, though the aluminum from the mixed scrap may require extra steps before that aluminum is again ready for use. As a result, the production of recycled aluminum results in a 90 percent reduction of greenhouse gas emissions when compared to the production of primary aluminum.



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Scrap aluminum is melted to remove impurities.

Stage of Life Cycle	*Processing Aluminum (½ Primary and ½ Secondary)*
CO_2 Emissions (kg/set)	187
CH_4 Emissions (kg/set)	0.302
N_2O Emissions (kg/set)	0.266

Manufacturing Furniture

To make cast aluminum, the ingots are melted and poured into molds of the desired shape. Unlike the plastic resin, each mold corresponds to just a part

Life Cycle Information: Cast Aluminum Furniture (3 of 3)

of the actual furniture piece. Once the pieces have been cooled and hardened, any excess aluminum can be removed and recycled. The pieces are then fitted together and welded. The cast aluminum dining set for this project has cushions made from plastic resin, but an alternate aluminum set might contain cotton cushions. Greenhouse gas emissions from the production of the plastic resin for these cushions are also included in the calculations for this step. Still, the bulk of the greenhouse gas emissions from this step result from the energy needed to melt the aluminum for casting.

Stage of Life Cycle	*Furniture Manufacturing*
CO_2 Emissions (kg/set)	108
CH_4 Emissions (kg/set)	0.437
N_2O Emissions (kg/set)	0.000113

Use/Maintenance

Like the plastic resin furniture set, the maintenance of cast aluminum furniture is minimal. Therefore, greenhouse gas emissions resulting from this stage are assumed to be negligible.

Stage of Life Cycle	*Use*
CO_2 Emissions (kg/set)	0.00
CH_4 Emissions (kg/set)	0.00
N_2O Emissions (kg/set)	0.00

Disposal

If processed correctly, aluminum can be recycled over and over again. Also, because of the relatively high value of scrap aluminum, rates of recycling are high. For this study, we assume that all of the aluminum in the furniture set is recycled. Greenhouse gas emissions associated with the collection and processing of recycled aluminum are included in the following table.

Stage of Life Cycle	*Disposal*
CO_2 Emissions (kg/set)	1.76
CH_4 Emissions (kg/set)	0.0000299
N_2O Emissions (kg/set)	0.0000440

Life Cycle Information:

Pine Furniture (1 of 3)

This set of pine furniture is made from slightly more wood than our calculations use because some wood is lost during cutting and sanding. The emissions provided in this section are based on 70 kg for the final product, with adjustments made to account for wood loss at each step. In addition to wood, the furniture has stainless steel bolts that hold it together.


FIFTHROOM.COM

This furniture is made from lumber harvested from pine trees that are grown in the Southeast United States.

Managing Forests and Harvesting Wood

When looking at the carbon dioxide (CO_2) emissions resulting from harvesting wood, it is important to distinguish between CO_2 produced from burning fossil fuels and CO_2 released from wood. The carbon trapped in trees is part of a relatively short biological cycle. Trees live for decades or perhaps centuries, storing CO_2 as they grow. When a tree dies, it decomposes, and the carbon stored in the tree is released to the soil and back to the atmosphere in the form of CO_2. Of course even as a tree dies, other trees are still growing and still absorbing CO_2 from the atmosphere. Therefore, if a forest is managed sustainably—meaning it is harvested no faster than its ability to grow new trees—then the CO_2 released by harvested trees is balanced over time by the CO_2 stored in new trees as they continue to grow. Because this carbon cycle is balanced in this short biological cycle, it is not typically included when calculating CO_2 emissions over time.

However, when we burn fossil fuels, we are taking carbon that has been trapped for hundreds of millions of years and converting that to CO_2. Since the Earth is not producing new fossil fuels at the rate that we are using them, this represents a flow of greenhouse gases into the atmosphere with no way for the carbon to be sequestered or stored at the same rate. Therefore, in this life cycle assessment, we will focus on the greenhouse gas emissions resulting from the use of fossil fuels since sustainably harvested wood is carbon neutral.

Most trees produced for lumber in the southeastern United States are grown on large plantations. In fact, with more than 32 million acres of pine plantations in the Southeast, this region has been called "the wood basket of the world" (Fox, Jokela, & Allen, 2004). Harvesting trees requires fuel for the tools that cut and trim the trees into logs. In addition, fuel is required to transport those logs to a mill. Sustainable management of a pine plantation, however, requires much more than harvesting trees. New seedlings must be produced and planted to replace harvested trees. Fostering the growth of these new trees may require the application of fertilizer and removal of weeds.

The intensity at which pine plantations are managed varies. Plantations are categorized as low, medium, or high intensity based on level of production. Currently, 37 percent of the pine plantations in the southeastern U.S. are managed at low intensity, 58 percent at medium intensity, and 5 percent at high intensity (Mulkey et al., 2008). The level of greenhouse gas emissions varies with the level of intensity. In order to calculate the greenhouse gas emissions that result in this step of the life cycle of our pine furniture set, a weighted average was calculated. The emissions resulting from the production of the amount of logged wood necessary to produce our furniture set are listed in the following table.

Life Cycle Information: Pine Furniture (2 of 3)

Stage of Life Cycle	*Sustainable Wood Production*
CO_2 Emissions (kg/set)	2.84
CH_4 Emissions (kg/set)	0.00245
N_2O Emissions (kg/set)	0.0000352

Lumber Manufacturing

The manufacturing process for lumber starts when logs are moved on to a conveyor belt that takes them into the mill where they are sorted, cut to a desired length, and debarked. The sawdust and bark made during these steps are typically collected and used to power the machinery at the mill. A large band saw cuts the logs into pieces roughly the same size and shape to be sold as lumber. The sawyer takes care to cut the logs so that he or she gets the maximum amount of lumber. These pieces are then trimmed in preparation for kiln drying. Sawdust is again collected for fuel.

At this point in the process, the wood pieces are called "green lumber" because they still have a lot of moisture. Most of this moisture is removed using a kiln, which is fueled largely by the bark and sawdust collected during the other steps of the process. Since the combustion of these wood products mimics the decomposition of wood in a forest, the carbon emitted from this combustion does not need to be included in this assessment.

BOONE VALLEY FOREST PRODUCTS, INC.

This lumber has been processed and is ready for sale.

Once the wood has been dried, it is planed. During this step, the surfaces of the lumber are smoothed and the wood is trimmed again if necessary. Finally, the lumber is sorted by size and quality and prepared for sale. The emissions reported in the following table include those related to energy from fossil fuels necessary for this step.

Stage of Life Cycle	*Wood Processing—Lumber Production*
CO_2 Emissions (kg/set)	5.96
CH_4 Emissions (kg/set)	0.0110
N_2O Emissions (kg/set)	0.0000134

Pressure-Treating Lumber

Lumber designated for outdoor use is typically pressure treated in order to extend the life of the lumber by protecting it from insects and moisture. In a typical pressure-treating process, the lumber is placed in a large horizontal cylinder that is then tightly sealed. Preservative chemicals are pumped into the cylinder. High pressure is used so that the chemicals penetrate the wood. The previous drying process allows the wood to absorb the preservatives more readily.

The emissions numbers provided for this step include direct emissions from the pressure-treatment process as well as emissions associated with the production of the preservative chemicals used during the process. These emissions are listed in the following table.

Life Cycle Information: Pine Furniture (3 of 3)

Stage of Life Cycle	*Pressure Treatment*
CO_2 Emissions (kg/set)	6.17
CH_4 Emissions (kg/set)	0.0143
N_2O Emissions (kg/set)	0.0000741

Manufacturing Furniture

Of the three sets of furniture, manufacturing of the wood set is perhaps the easiest to picture. The treated pieces of lumber are cut to the correct size and shape and sanded smooth. Those pieces are then fastened together with stainless steel nuts and bolts. The production of these fasteners must also be included when considering the emissions associated with this step of the life cycle.

Stainless steel is a combination of iron, chromium, and nickel. Scrap iron can be used. The rest of the ingredients must be mined from the ground and separated from their ores. The ingredients are melted and mixed in an arc furnace at temperatures of more than 1600 degrees Celsius (° C) or 2912 degrees Fahrenheit (° F). The molten steel is then transferred to a refining vessel, where impurities are removed. The steel is then cast and rolled out into flat sheets. The sheets are then cut into the desired dimensions for making screws, nuts, and washers. The combined weight of the screws and other steel pieces in our example furniture set is 1 kg. The combined emissions associated with the production of the stainless steel fasteners and the manufacturing of the wood furniture are provided in the following table.

Stage of Life Cycle	*Furniture Manufacturing*
CO_2 Emissions (kg/set)	5.24
CH_4 Emissions (kg/set)	0.00686
N_2O Emissions (kg/set)	0.0000410

Use/Maintenance

Wood sealer is typically applied to outdoor furniture in order to protect it from potentially damaging environmental conditions, such as sun and rain. For this study, it is assumed that two treatments of sealer are used over the 15-year life of the furniture set. The emissions listed for this section take into account the gases emitted during the production of the wood sealant.

Stage of Life Cycle	*Use*
CO_2 Emissions (kg/set)	4.25
CH_4 Emissions (kg/set)	0.00976
N_2O Emissions (kg/set)	0.0000432

Disposal

Treated wood must be disposed of in a landfill because of the potentially harmful preservative chemicals added to the wood during pressure treatment. Decomposition in a landfill is anaerobic, unlike decomposition of dead wood in a forest. Since no oxygen is present in an anaerobic environment, the chemical reactions taking place produce methane instead of carbon dioxide. This methane would not have been produced under normal forest conditions. Therefore, the methane emissions resulting from the anaerobic decomposition of wood in landfills are included in the emissions figures for this step of the life cycle. Other emissions result from fuels used in the collection of waste and the management of landfills.

Stage of Life Cycle	*Disposal*
CO_2 Emissions (kg/set)	24.6
CH_4 Emissions (kg/set)	1.63
N_2O Emissions (kg/set)	0.0000733

Comparing Outdoor Furniture

NAME GROUP MEMBERS

Instructions: As you listen to the play or to the student presentations, collect information about the following questions.

Plastic Resin Furniture Set

1. What are the basic raw material inputs necessary to produce polypropylene and other plastic resins?

Aluminum Furniture Set

2. When processing aluminum, most of the emissions are the result of which step?

3. How many times can aluminum be recycled?

Pine Furniture Set

4. When calculating emissions over time, why isn't the carbon dioxide emitted from wood burned for power during the manufacturing process included?

Summary

5. Which furniture type would be best for your school? Why?

6. If every school in your state purchased this type of outdoor furniture, what might the short and long-term impacts be?

Greenhouse Gas Emissions Tables

Use the tables below to keep track of the greenhouse gas emissions associated with each step of the life cycle.

Remember: CO_2 = Carbon dioxide CH_4 = Methane N_2O = Nitrous oxide kg = kilogram

Plastic Resin Set

Stage of Life Cycle	CO_2 Emissions (kg/set)	CH_4 Emissions (kg/set)	N_2O Emissions (kg/set)
Oil and Natural Gas Extraction			
Refining Oil/Processing Natural Gas			
Manufacturing Polypropylene			
Manufacturing Plastic Furniture			
Use			
Disposal			
TOTAL EMISSIONS			

Cast Aluminum Set

Stage of Life Cycle	CO_2 Emissions (kg/set)	CH_4 Emissions (kg/set)	N_2O Emissions (kg/set)
Bauxite Mining (for ½ Primary Material)			
Processing Aluminum (½ Primary and ½ Secondary)			
Furniture Manufacturing			
Use			
Disposal (Recycling Aluminum)			
TOTAL EMISSIONS			

Pine Set

Stage of Life Cycle	CO_2 Emissions (kg/set)	CH_4 Emissions (kg/set)	N_2O Emissions (kg/set)
Sustainable wood production			
Wood Processing/Lumber production			
Pressure Treatment			
Furniture Manufacturing			
Use			
Disposal			
TOTAL EMISSIONS			

Global Warming Contribution Calculation

After you have recorded the greenhouse gas emissions from each step and totaled the results, there's still one more step before you can decide which furniture set will have the highest impact on climate change. Not all greenhouse gases are equal. Some gases are able to capture more energy than others. For example, a kilogram of methane in the atmosphere will trap about 25 times more energy over a 100-year period than a kilogram of carbon dioxide. Therefore, it is said to have a global warming potential of 25. When scientists measure the impacts of greenhouse emissions, they often use the term "carbon dioxide equivalents." This is the basic unit for measuring the global warming potential of emissions. Since 1 kg of methane traps as much heat as 25 kilograms of carbon dioxide, that 1 kilogram of methane has a global warming potential of 25 kilograms of carbon dioxide equivalents. Now you can calculate the global warming potential of each of the three furniture sets. Use the following table to calculate the emissions for each dining set.

Calculating the Global Warming Contribution of Greenhouse Gas Emissions

Gas	**Emissions** (kg)	**Global Warming Potential** (100-year period)	**Carbon dioxide Equivalents** (kg CO_2-eq)
Plastic Resin Set			
Carbon dioxide		x 1	
Methane		x 25	
Nitrous oxide		x 300	
		TOTAL	
Aluminum Set			
Carbon dioxide		x 1	
Methane		x 25	
Nitrous oxide		x 300	
		TOTAL	
Pine Set			
Carbon dioxide		x 1	
Methane		x 25	
Nitrous oxide		x 300	
		TOTAL	