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

ED MANSELL/OWNER, MANSELL AND ASSOCIATES

Scrap aluminum is melted to remove impurities.

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.

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