A DECREASING FOOTPRINT

A Review of Resin Life Cycle Assessments

2010 to 2020

Analysis finds lower CO_2 emissions and total energy consumption from 2010 to 2020 for low density polyethylene (LDPE), high density polyethylene (HDPE), linear low-density polyethylene (LLDPE), and polypropylene (PP).

American Chemistry Council | Plastics Division

Plastics are durable and versatile materials used in most industries including the packaging, medical, automotive, and aviation sectors. To evaluate the sustainability and environmental performance of their products and packaging, producers, brand owners, consumers, and policymakers use the environmental footprint of plastics to help inform their decisions.

This report, the first of three, compares key findings for four plastic resins from the 2010 and 2020 series of Life Cycle Assessments (LCAs) analyzing the environmental impact of plastic resins and resin precursors produced in the United States. Plastic resins are synthetic materials produced from polymers and molded into various shapes, whereas plastic resin precursors are chemical products used to produce plastic resins. A product's environmental impact refers to the amount of resources, such as water and fossil fuels, the product consumes in different stages of its lifecycle. The full reports, developed by Franklin Associates, measure the footprint of each resin starting with the extraction of raw materials up to the resin or resin precursor leaving the manufacturing plant. This type of LCA is called cradle-to-gate and is used for environmental product declarations (EPDs), which are a way for producers to communicate the environmental impact of their product.

The resin reports demonstrate the minimal environmental footprint created in the production of each resin in comparison to alternative materials, particularly in the packaging industry. The inventory data from the full reports was submitted to the U.S. Life Cycle Inventory Database and is accessible to LCA professionals, academics, policymakers, and regulators to be used in future studies or comparative analyses.

The footprint of each resin is determined by calculating the environmental impact of the life cycle. This report focuses on two key categories: greenhouse gas emissions (GHGs) and total energy consumption. GHGs are gases that absorb and trap heat in the atmosphere; the most common GHGs include Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (NO_x). The full technical reports measure the GHGs through a metric called global warming potential (GWP). GWP is used to measure the impact of different gases on one shared scale, due to gases having different effects on global warming. The two main ways GHGs have varying effects on global warming are their abilities to absorb energy and the amount of time they stay in the atmosphere. Therefore, GWP measures the amount of energy one ton of a gas will absorb over a certain amount of time compared to the amount of energy one ton of CO_2 will absorb over the same amount of time. GWP is measured as kilograms (kg) of CO_2 equivalent and allows different GHGs to be compared on the same scale. Figure 1 shows a breakdown of the GWP for the four resins in this report comparing the three main GHGs per resin from 2010 to 2020. A full description of the figure can be found below, but there was a significant decrease in CO_2 and CH_4 from 2010 to 2020. The increase in NO_x from 2010 to 2020 can be attributed to emissions included in the 2020 studies that were not specified in the 2010 studies. This report focuses on the GHG emissions from CO_2, specifically because it is the most abundant GHG emitted through human activity and accounts for more than 77% of the resins in this report's global warming potential.

The second impact evaluated in this report is total energy consumption during production shown in gigajoules (GJ). Comparing CO_2 emissions and total energy consumption from 2010 to 2020, this report demonstrates a clear trend of decreases in both impact categories ranging from 6-18% in CO_2 and 2-7% in total energy consumption. The metrics in this report show that, despite higher production of plastic resins from 2010 to 2020, the environmental impact (as defined above) of manufacturing plastics is being reduced.

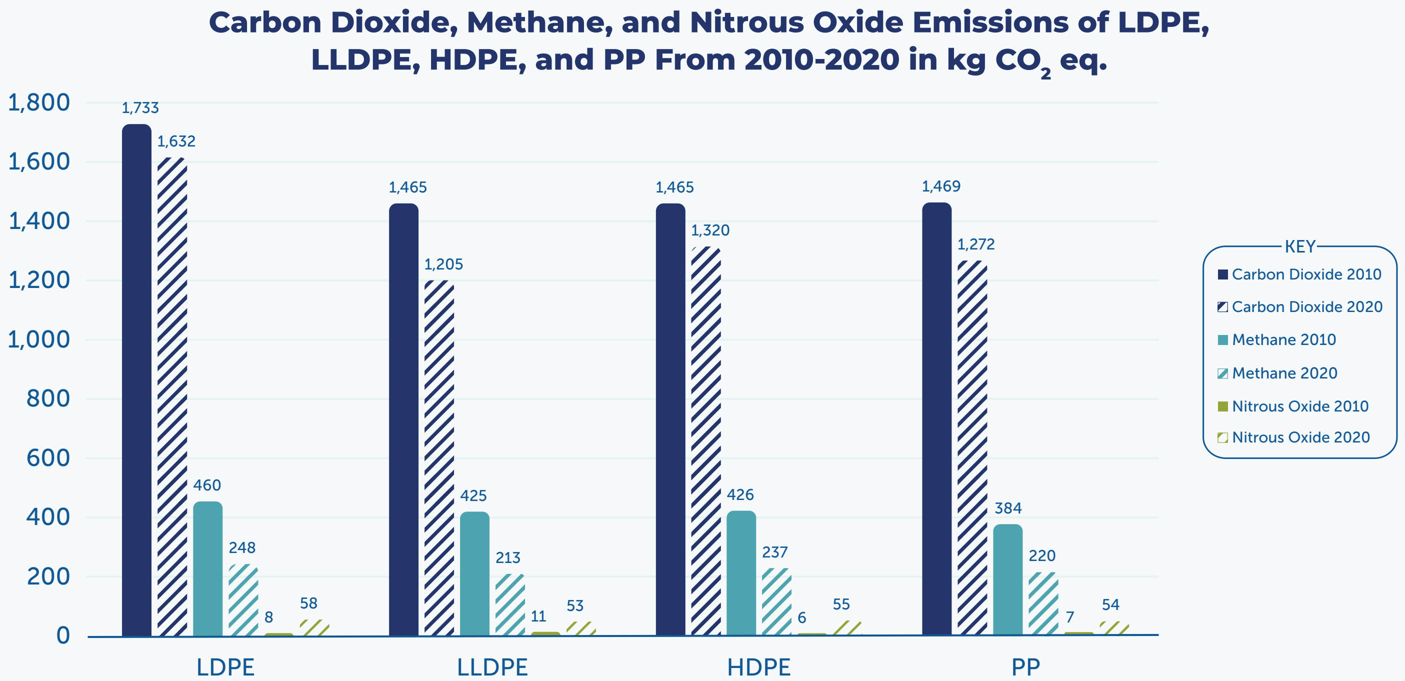

FIGURE 1. This figure shows the emissions of Carbon Dioxide, Methane, and Nitrous Oxide in kg of CO_2 equivalent emissions from the 2010 (solid color bars) report to 2020 (striped bars) for low density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high density polyethylene (HDPE), and polypropylene (PP).

Total GWP (kg $CO_{2\ eq}$)	LDPE	LLDPE	HDPE	PP
2010	2,201	1,901	1,897	1,860
2020	1,927	1,472	1,612	1,548

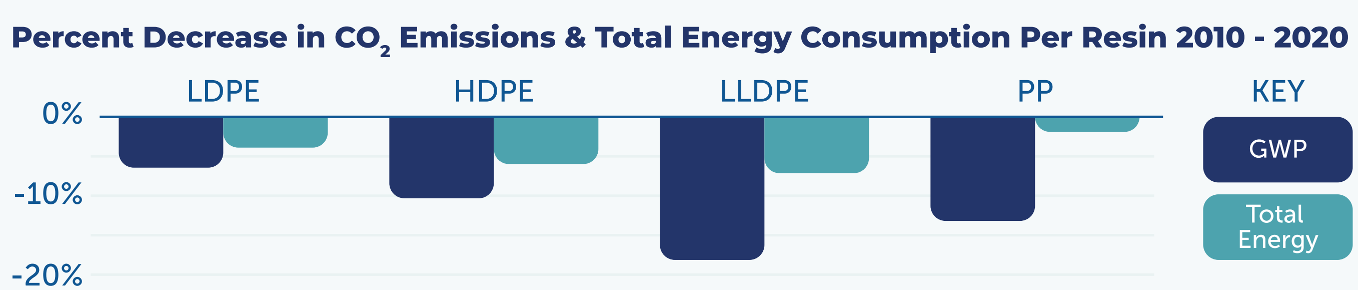

FIGURE 2. This figure shows the percent decrease of CO_2 emissions (navy) and total energy (teal) from the 2010 report to 2020 for low density polyethylene (LDPE), high density polyethylene (HDPE), linear low-density polyethylene (LLDPE), and polypropylene (PP).

INTRODUCTION

The life cycle of a product begins with the extraction of raw materials required to manufacture the product, followed by manufacturing, product use, and end of life. A Life Cycle Assessment (LCA) is the study of a product through the various stages of that product's life and can be used to compare the potential environmental footprint of a product to alternatives. LCAs are important in decision-making processes such as helping to determine which material is the more sustainable option.

An LCA consists of four stages: goal and scope, life cycle inventory, life cycle impact assessment, and interpretation of the results. The goal and scope outlines what a study intends to achieve and what parts of a product's life will be included in the study. As seen in Figure 2, this series of LCAs analyzes the potential environmental impact from cradle-to-gate; therefore, the scope, or boundary, is drawn around raw material collection (such as elements and minerals), and the manufacturing of the materials, which in this case is the production of resins. Also included in the scope are inputs, such as energy and recycled materials used in manufacturing, and outputs, such as wastes. Figure 2 displays the stages of a product's life cycle with a dotted boundary line drawn around the stages that are included in this study.

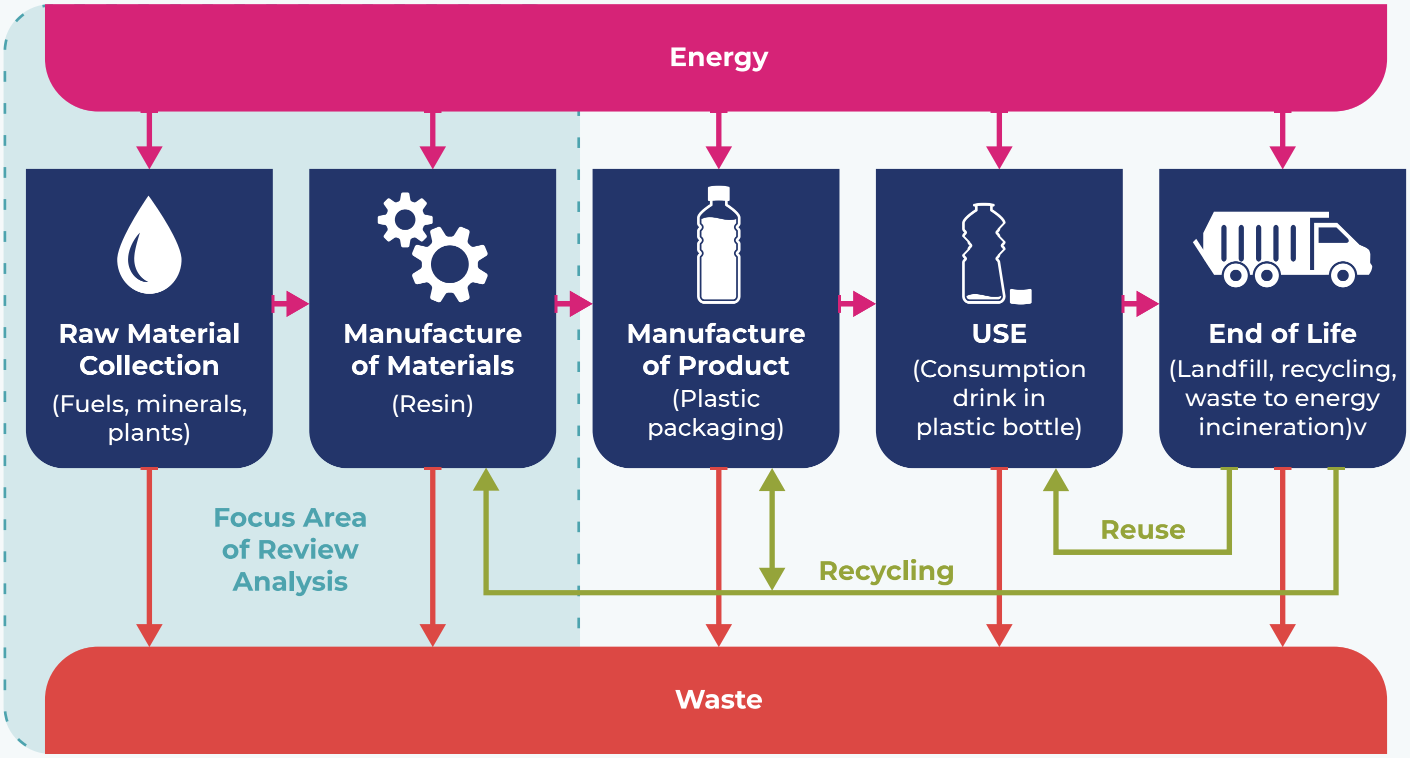

FIGURE 3. The second stage of an LCA is the life cycle inventory (LCI) where data is collected and organized, such as analyzing how much energy is consumed to produce each resin or the GHG emissions emitted during the production of a resin. The third stage is the life cycle impact assessment (LCIA), which looks at categories like water consumption, energy consumption, or acidification. The fourth and final stage of the LCA is an interpretation of the results that can be used for future studies or assist in decision-making.

These three reports will compare the LCA results of eight resins and four resin precursors: LDPE, HDPE, LLDPE, PP, general purpose polystyrene (GPPS), high impact polystyrene (HIPS), acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), toluene diisocyanate (TDI), methylene diphenyl diisocyanate (MDI), flexible polyether polyols, and rigid polyether polyols. Data used in the LCAs was collected from 2003-2005 for the 2010 series and 2015-2017 for the 2020 series.

LDPE, HDPE, and LLDPE are types of polyethylene, which is the most common plastic material in the world, due to its commercial applicability. LDPE is typically used for films and food packaging like bread bags; HDPE is commonly used for milk jugs, detergent and soap bottles, and pipes; LLDPE is typically used to produce wraps and flexible tubes. PP, polypropylene, is the fifth most distributed plastic for commercial use; it is used for various food packaging containers, appliance and automotive parts, as well as fibers used in carpets.

Each resin and resin precursor LCA was conducted by Franklin Associates, a Division of ERG, using U.S. data provided by resin manufacturers with U.S. facilities. The inventory data from the LCI can be found on the U.S. Life Cycle Inventory (USLCI) Database and an expert-reviewed version of each resin report can be found on the ACC website. Each resin LCA maintains the same boundary, as seen in Figure 2, and the metrics in each report are measured per 1,000 kg of each resin.

RESULTS

Below are the results for CO_2 emissions and total energy consumption of LDPE, HDPE, LLDPE, and PP comparing the 2010 and 2020 LCAs. The results show a decrease in both CO_2 emissions and total energy consumption for each resin when comparing the 2010 to 2020 LCAs (with the decreases ranging from very significant for CO_2 in most cases to marginal energy consumption decreases for some resins). The energy consumed by each resin includes the energy used for fuel combustion and the energy that is stored in the fuel (inherent), but not combusted. In these studies, the greatest amount of GHGs is released during the combustion of fuel, whereas no GHGs are released from the energy stored in the plastics. Out of these four resins, LLDPE required the lowest percent of energy for fuel combustion and had the greatest decrease in this energy when comparing the energy results from the 2010 to 2020 LCAs. For this reason, LLDPE had the largest decrease in CO_2 emissions from 2010 to 2020.

From 2010 to 2020 the total production of LDPE, HDPE, LLDPE and PP Resins

Increased by more than 4 BILLION POUNDS while **Decreasing CO_2 Emissions by 4.97 BILLION KG**

That's the same as taking more than 1 MILLION CARS

off the road for an entire year

FIGURE 4 illustrates the CO_2 eq. emission reduction between 2010 to 2020 based on the total production of LDPE, HDPE, LLDPE, and PP resins in 2010 and 2020 respectively. Through industry improvements, there was a total reduction of 4.97 billion kg CO_2 eq., despite the total combined production of LDPE, HDPE, LLDPE, and PP increasing from 2010 to 2020 by more than 4 billion pounds. The significant increase in plastic resin production is often attributed to the growing middle class. As consumers move into the middle class, they begin consuming more goods, such as appliances, vehicles, housing, and consumer electronics, a lot of which is made with plastic. Additionally, urban populations live further away from the sources of food and other consumable products, which means the items travel further in plastic packaging. The 4.97 billion kg of CO_2 eq. reduction from 2010 to 2020 is equivalent to removing more than one million cars from the road for an entire year and subsequently avoiding their GHG emissions[1]. This is equivalent to every resident of San Jose, California, not driving for an entire year.

[1] Total emissions were calculated using resin production data published in the Resin Review. Production data for 2010 and 2020 were represented by data from 2005 and 2017, respectively in correlation with the dates these studies were conducted. The difference in CO_2 emissions from 2005 to 2017 was calculated by taking the sum of the total emissions for each resin (production/resin multiplied by emissions/1,000kg) and subtracting 2017 from 2005 totals (2005 total minus 2017 total). The emission difference was plugged into the EPA's GHG Equivalencies Calculator and the amount of cars equivalent to the emissions reduction was provided.

LOW DENSITY POLYETHYLENE (LDPE)

Description: LDPE is a flexible, lightweight plastic. LDPE is known for its flexibility at low temperatures, durability, and corrosion-resistant properties. LDPE is commonly used for films in various applications, such as food packaging or newspapers, as well as cups used to hold hot and cold liquids. Additionally, LDPE is used to produce orthotics and prosthetics.

LDPE Carbon Dioxide Emissions per 1,000 kg

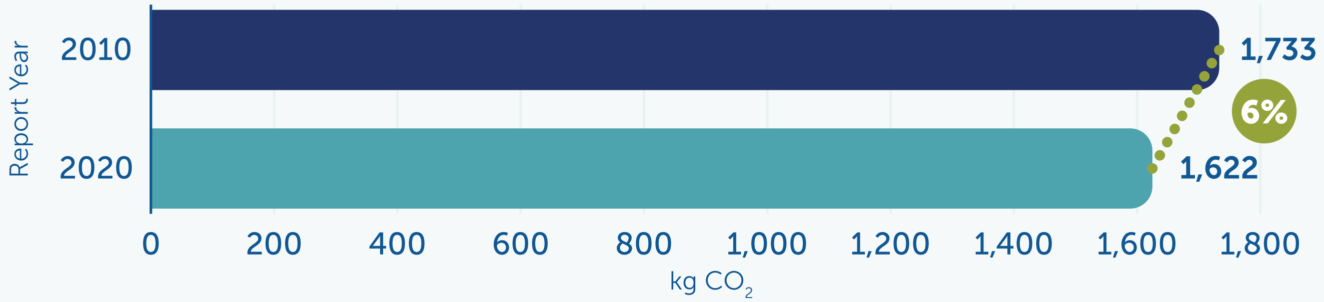

FIGURE 5 displays the CO_2 emissions of LDPE from the cradle-to-gate LCA published in 2010 compared to the cradle-to-gate LCA published in 2020. The results, measured in kg CO_2 per 1,000 kg of LDPE, show a 6% decrease in CO_2 emissions from 1,733 kg CO_2 to 1,622 kg CO_2. The decrease in CO_2 emissions can be attributed to the shift in the composition of fuels used in the production of LDPE resin from the 2010 to 2020 iteration. There was a decrease in petroleum used in production and an increase in natural gas. The combustion of natural gas emits approximately 30% less carbon dioxide than the combustion of petroleum. Notably, there was also an increase in renewable energy used in production that is expected to continue to increase in coming years.

LDPE Energy Consumption per 1,000 kg

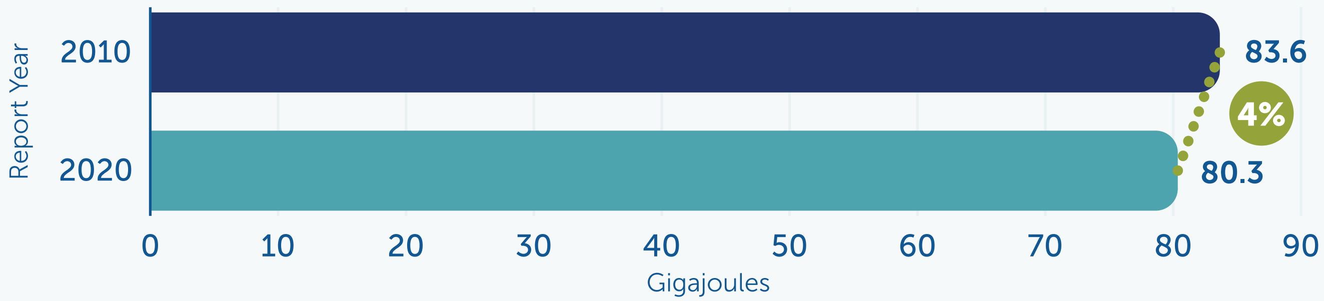

FIGURE 6 shows the amount of energy consumed, measured in Gigajoules, throughout the cradle-to-gate LCA of LDPE from 2010 compared to 2020. There was a 4% decrease in energy consumed from 83.6 GJ in 2010, to 80.3 GJ in 2020. Franklin Associates suggests the decrease in total energy consumption can be attributed to efficiency improvements within the production processes.

HIGH DENSITY POLYETHYLENE (HDPE)

Description: HDPE is produced from the same material as LDPE; despite this similarity, HDPE is stronger and stiffer than LDPE, which makes it well suited for applications in the food, chemical, and medical industries. Common uses include pipe, cutting boards, milk jugs, detergent and soap bottles, playgrounds, and outdoor furniture.

HDPE Carbon Dioxide Emissions per 1,000 kg

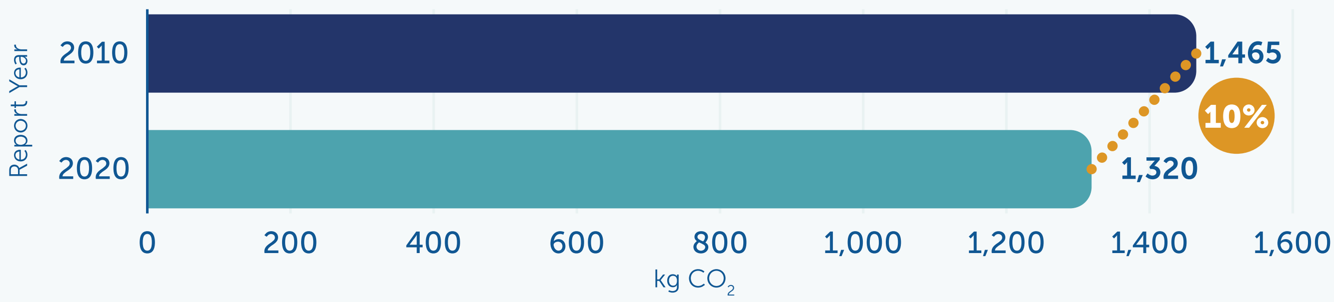

FIGURE 7 displays the CO_2 emissions of HDPE from the cradle-to-gate LCA of 2010 as compared to that of 2020. The results, measured in kg CO_2 per 1,000 kg of HDPE, show a 10% decrease in CO_2 from 1,465 kg CO_2 to 1,320 kg CO_2. The decrease in CO_2 can be attributed to the shift in fuel composition used to produce HDPE resin from the 2010 to 2020 iteration. There was a 6.6% decrease in petroleum used in production and a 7.7% increase in natural gas. Additionally, there was a 0.9% decrease in use of coal and 0.8% increase in renewable energy used in the production of HDPE resin, indicating a trend in energy substitutions where renewables are likely to continue to grow in relation to fossil energy sources.

HDPE Energy Consumption per 1,000 kg

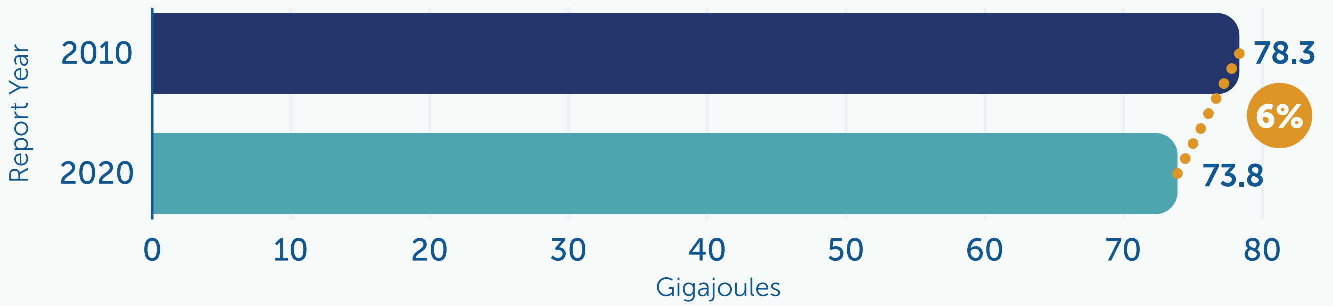

FIGURE 8 shows the amount of energy consumed, measured in GJ, in the cradle-to-gate LCA of HDPE from 2010 compared to 2020. There was a 6% decrease in energy consumed from 78.3 GJ in 2010, to 73.8 GJ in 2020. The data suggests that the decrease reflects a decrease in energy consumed to produce olefins, which is the main material inputs used to produce HDPE resin.

LINEAR LOW-DENSITY POLYETHYLENE (LLDPE)

Description: LLDPE is comparable to LDPE but is significantly more flexible and is more resistant to impact and stress than LDPE. Common applications include food packaging, agricultural film, and power cables.

LLDPE Carbon Dioxide Emissions per 1,000 kg

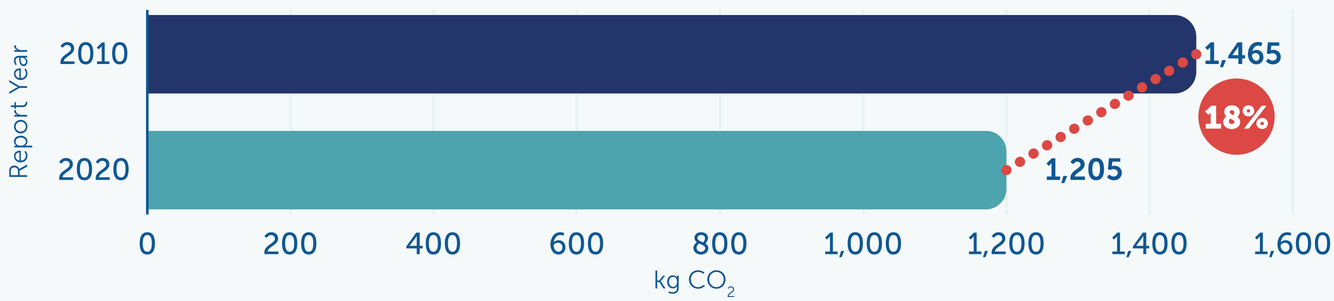

FIGURE 9 displays the CO_2 emissions of LLDPE from the cradle-to-gate LCA of 2010 compared to 2020. The results, measured in kg CO_2 per 1,000 kg of LLDPE, show an 18% decrease in CO_2 from 1,465 kg CO_2 to 1,205 kg CO_2. The greater reduction in CO_2 emissions can be attributed to the shift in fuel composition, particularly the decrease in coal consumption. The 2020 LLDPE report saw a 6.5% decrease in petroleum and an 8% increase in natural gas consumed in production, as well as the shift to renewable energy sources reported for other resin types.

LLDPE Energy Consumption per 1,000 kg

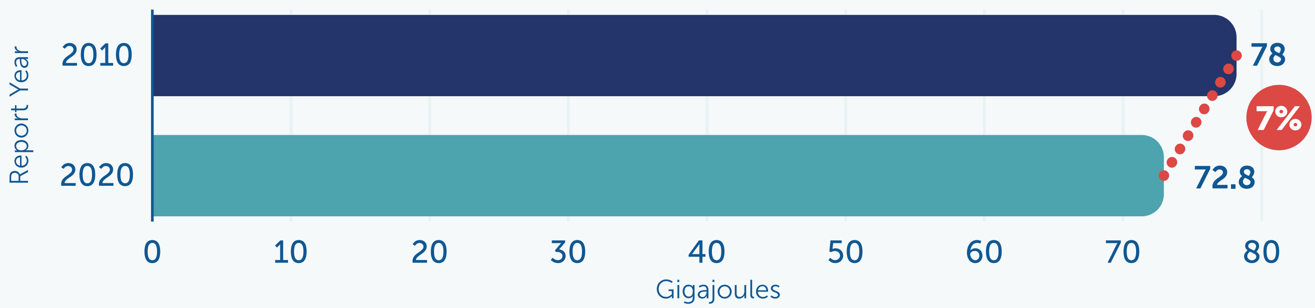

FIGURE 10 shows the amount of energy consumed, measured in GJ, throughout the cradle-to-gate LCA of LLDPE from 2010 compared to 2020. There was a 7% decrease in energy consumed from 78 GJ in 2010, to 72.8 GJ in 2020. Like the HDPE report, the decrease in energy consumption can be attributed to a decrease in energy consumed to produce olefins, which is the material input used to produce LLDPE resin.

POLYPROPYLENE (PP)

Description: PP is a chemically-resistant plastic made from propylene; it has a high melting point and is very durable. For these reasons, it is commonly used in food packaging, such as yogurt cups, and insulation in winter clothing.

LDPE Carbon Dioxide Emissions per 1,000 kg

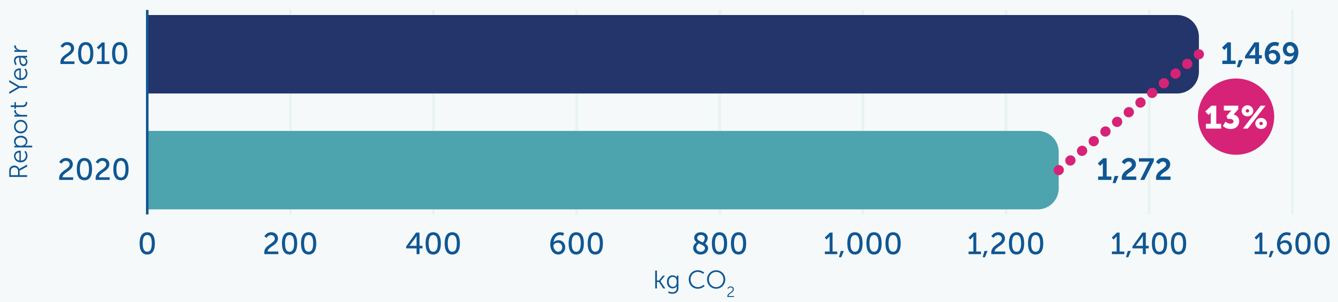

FIGURE 11 displays the CO_2 emissions of PP from the cradle-to-gate LCA of 2010 as compared to that of 2021. The results, measured in kg CO_2 per 1,000 kg of PP, show a 13% decrease in CO_2 emissions from 1,469 kg CO_2 to 1,272 kg CO_2. Similar to the CO_2 emissions for LDPE, the decrease in CO_2 can be attributed to the shift in fuel composition used to produce PP resin from the 2010 to 2021 iteration. The 2021 report saw a 19% decrease in petroleum consumption and a 21% increase in natural gas used in production with a notable 1.7% decrease in coal consumption, as part of the shift to lower carbon fuel sources.

LDPE Energy Consumption per 1,000 kg

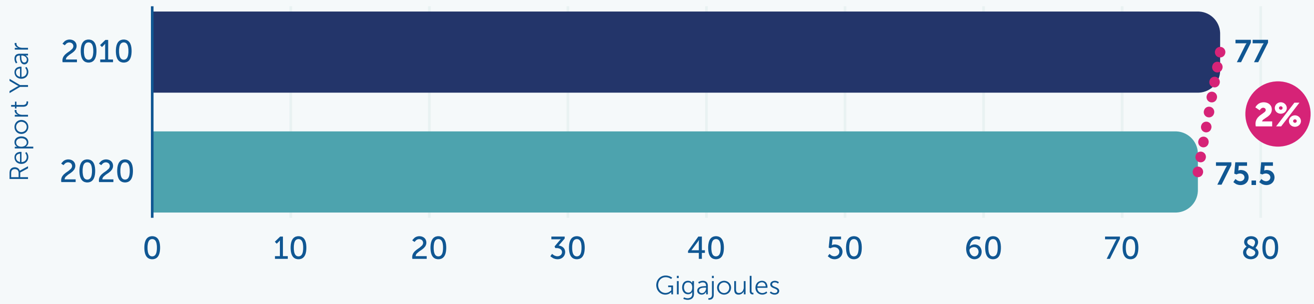

FIGURE 12 shows the amount of energy consumed, measured in GJ, in the cradle-to-gate LCA of PP from 2010 compared to 2021. There was a 2% decrease in energy consumed from 77 GJ in 2010, to 75.5 GJ in 2020. Like the HDPE report, the decrease in energy consumption can be attributed to a decrease in energy consumed to produce olefins, which is the material input used to produce PP resin.

CONCLUSION

This report highlights improvements made within the manufacturing processes of LDPE, HDPE, LLDPE, and PP over the last decade. These improvements resulted in reduced CO_2 emissions and energy consumed to produce the same amount of plastic resin. Additionally, after it is manufactured, plastic offers advantages compared to other materials with its lightweight nature, durability, and versatility. Improvements to the potential environmental footprint of plastics are expected to continue as production technology improves efficiency and the fuel mix continues its transitions to lower carbon sources. The full inventory data found in the USLCI Database can be used by decision-makers assessing the contribution of plastics to a low-carbon economy when compared to alternative materials, such as paper, aluminum, or glass. Furthermore, this data can be used in combination with data from other parts of the product life cycle, such as with use or end-of-life phases to better inform decisions related to the environmental footprint of products over their full lifecycle.