# A DECREASING FOOTPRINT

## A Review of Resin Life Cycle Assessments

Reporting Improvements on the Carbon Footprint (GHG Emissions) and Total Energy Consumption from 2010 to 2020

Resin LCA Series for HIPS, GPPS, and ABS

American Chemistry Council® | Plastics Division

# EXECUTIVE SUMMARY

Plastics are durable and versatile materials used in many essential industries including the packaging, medical, automotive, and aviation sectors. Producers, brand owners, consumers, and policymakers use the potential environmental footprint of plastics to help inform their decisions. The information also helps demonstrate improved sustainability and environmental performance of products and packaging. Plastics can provide many environmental benefits compared to common alternatives, and because they are lighter than most other materials, they allow us to use fewer resources to accomplish many of the same functions, which helps to reduce energy use, carbon footprints, and even the amount of waste we generate, both across the value chain and life cycle of a product.

This report, the second of three, evaluates key findings for four plastic resins from the 2010 and 2020 series of life cycle assessments (LCAs) analyzing the potential environmental footprint of plastic resins and resin precursors.[1] This report compares the $CO_2$ emissions and total energy consumption of High Impact Polystyrene (HIPS), General Purpose Polystyrene (GPPS), and Acrylonitrile Butadiene Styrene (ABS) from 2010 to 2020, which demonstrates a clear trend of decreases in both impact categories ranging from 4 to 22% in $CO_2$ and 7 to 16% in total energy consumption. The results highlighted in this report support the conclusion that the environmental footprint of manufacturing these plastics is being reduced where energy demand and greenhouse gas emissions (GHGs) are concerned.

The full reports developed by Franklin Associates, a division of ERG, estimate the potential environmental 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 potential environmental impact of their product. 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 potential environmental impact of the life cycle for many parameters and categories. This executive summary and report focus on two of these 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 estimate 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. 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. This executive summary and 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 81% of each of the three resin's global warming potential. The second key impact evaluated in this report is total energy consumption during production shown in gigajoules (GJ).

[1] Plastic resins are synthetic materials produced from polymers and molded into various shapes, whereas plastic resin precursors are a chemical product used to produce the plastic resins.

**Carbon Dioxide, Methane, and Nitrous Oxide Emissions of HIPS, GPPS, and ABS From 2010-2020 in kg $CO_2$ eq. per 1,000 Kg of Resin**

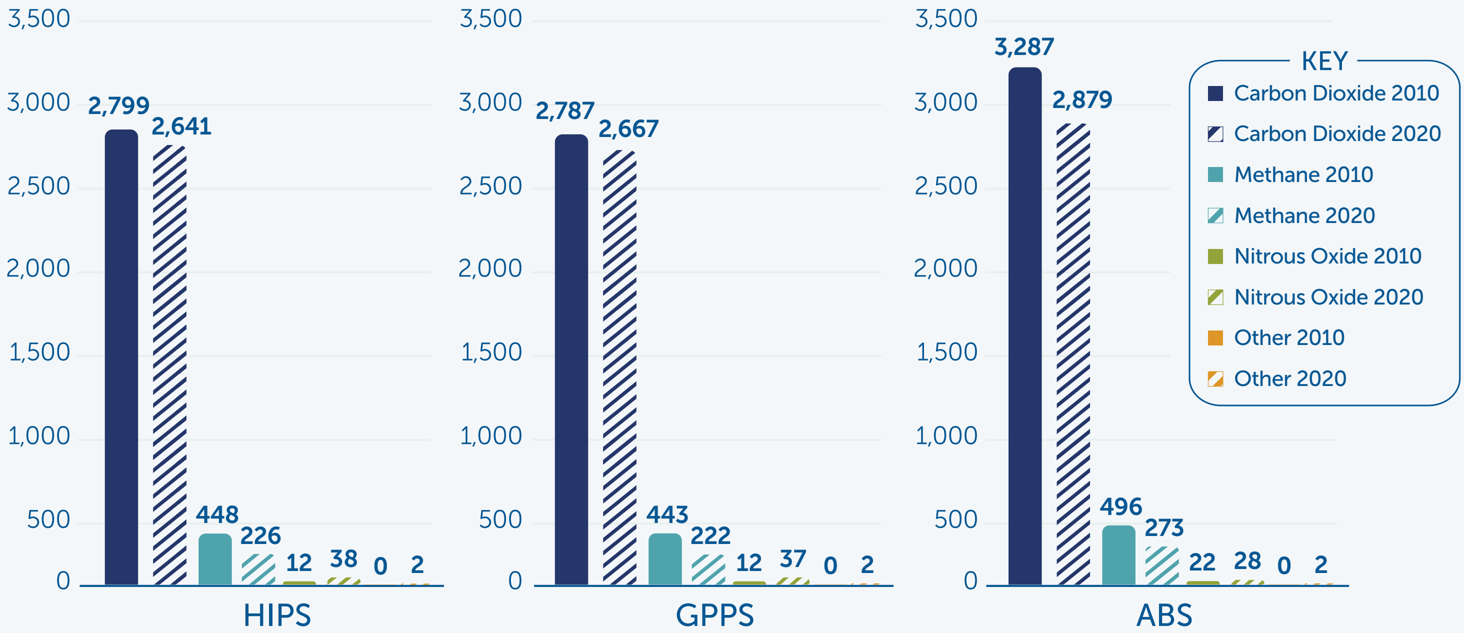


**FIGURE 1.** This figure shows the emissions of carbon dioxide, methane, and nitrous oxide in kg of $CO_2$ equivalent emissions per 1,000 kg of resin from the 2010 (solid color bars) report to 2020 (checked bars) for high impact polystyrene (HIPS), general purpose polystyrene (GPPS), and acrylonitrile butadiene styrene (ABS). Slight increases in Nitrous Oxide from the 2010 to 2020 series are a result of an increase in process emissions from the Olefins plant.

| Total GWP (kg $CO_{2\ eq}$) | HIPS | GPPS | ABS |
|---|---|---|---|
| 2010 | 3,259 | 3,242 | 3,805 |
| 2020 | 2,907 | 2,928 | 2,879 |

# INTRODUCTION

The life cycle of a product begins with the extraction of raw materials required to manufacture the product, on through manufacturing, product use, and end of life. A life cycle assessment (LCA) is the quantified analysis of the inventory and impact of a product through the various stages of that product's life and the findings can be used to compare the potential environmental footprint of a product to alternatives and identify opportunities for improvement. LCAs are important in decision-making processes, for example, helping to determine which material is the more sustainable option based on the data developed in the LCA report.

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. An LCA may look at all life cycle stages of a product, called a cradle-to-grave analysis, or may only analyze a portion of the life cycle stages from the raw material collection to the factory gate, called a cradle-to-gate analysis. This series of LCAs analyzes the potential environmental impact from cradle-to-gate to understand production-related impacts that may be incorporated into a full LCA, as well as pinpoint areas where changes may be most beneficial to reducing potential impacts within the production process. As seen in Figure 2, 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.

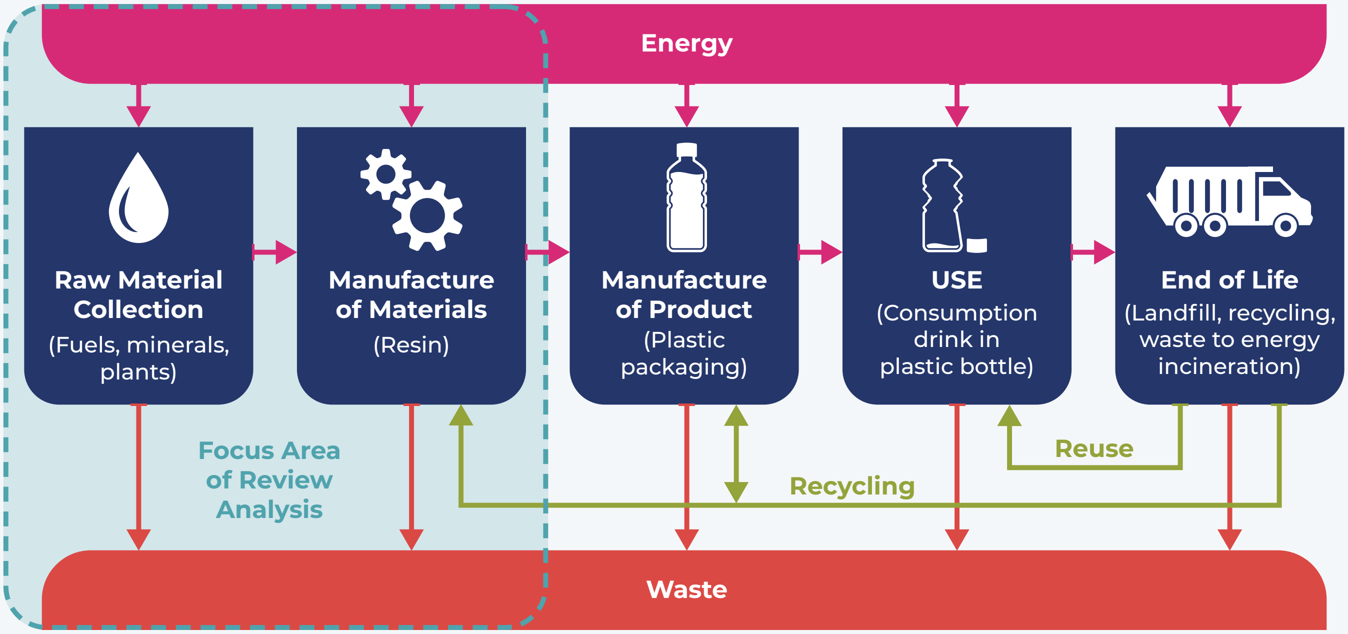


**FIGURE 2.** This figure outlines the life cycle stages, inputs, and outputs that may be included in an LCA. The dotted line denotes the system boundary for the life cycle stages included in this study, which are raw material collection, the manufacture of materials, energy inputs, and waste outputs.

The second stage of an LCA is the life cycle inventory (LCI) where data is collected and organized; an inventory analysis looks at resource use and emissions associated with each life cycle stage, such as the energy or carbon dioxide inputs and outputs. The third stage is the life cycle impact assessment (LCIA), which looks at categories such as 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 to assist in decision-making.

The first industry improvement report published in September 2022 showcased the results of four resins: Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), Linear Low Density Polyethylene (LLDPE), and Polypropylene (PP). This report is the second of three and displays the LCA results three more resin: HIPS, GPPS, and ABS. The third and final report will highlight the results of four polyurethane precursors: 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.

GPPS, HIPS, and ABS are examples of thermoplastics, which are a group of plastic polymers that become softer when heated and then can be processed using a variety of methods, including injection molding, blow molding, and thermoforming. Thermoplastics are widely used for their ability to be heated and cooled multiple times without significant degradation. HIPS and GPPS are types of polystyrene (PS); GPPS is typically used for protective packaging, bottles, and food containers. While similar to GPPS, HIPS is produced from a combination of PS and rubber and is commonly found in appliance parts and food packaging. ABS is highly durable and chemically resistant; it is commonly used in automotive components, kitchen appliances, protective headgear (helmets), and musical instruments such as plastic clarinets.

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 and findings in each report are measured per 1,000 kg of each resin.

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# RESULTS

Below are the results for $CO_2$ emissions and total energy consumption of HIPS, GPPS, and ABS comparing results of each individual resin from the initial LCA report in 2010 to the updated report in 2020. 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.

**3 Billion kg $CO_{2\,eq.}$ = GHG Emissions From More Than 440,000 Cars for One Year**

**Over the past decade, $CO_2$ emissions in the production of three common plastics have decreased by 3 billion kgs**

**That's like taking**

**440,000 CARS**


**off the road for an entire year**

**FIGURE 3** illustrates the $CO_{2\,eq.}$ emission reduction between 2010 to 2020 based on the total production of HIPS, GPPS, and ABS resins in 2010 and 2020, respectively. Through industry improvements, there was a total reduction of 3 billion kg $CO_{2\,eq.}$. As indicated above, the data for each series was collected in 2003 to 2005 and 2015 to 2017, respectively, during which time these three resins experienced a decline in production amount. While the overall production of these three resins decreased from 2010 to 2020, the $CO_{2\,eq.}$ emissions per kilogram of resin produced decreased by 13% underscoring the overall reduction in the carbon footprint of these three plastic resins. The 3 billion kg of $CO_{2\,eq.}$ reduction from 2010 to 2020 is equivalent to removing more than 440,000 cars from the road for an entire year and subsequently avoiding their GHG emissions.[2] This is equivalent to more than all of the automobile owners of Delaware not driving for an entire year.

[2] 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 $CO_{2\,eq}$ 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.

# HIPS

**Description:** HIPS is produced from the combination of rubber and polystyrene (PS); the presence of rubber in HIPS makes it slightly more impact resistant than GPPS. As a result of its durability and machinability, HIPS is found in a multitude of industries, including automotive, food packaging, and consumer products. Common applications include promotional signage, computer housing, toys, and gas tanks.

## HIPS Carbon Dioxide Emissions per 1,000 kg

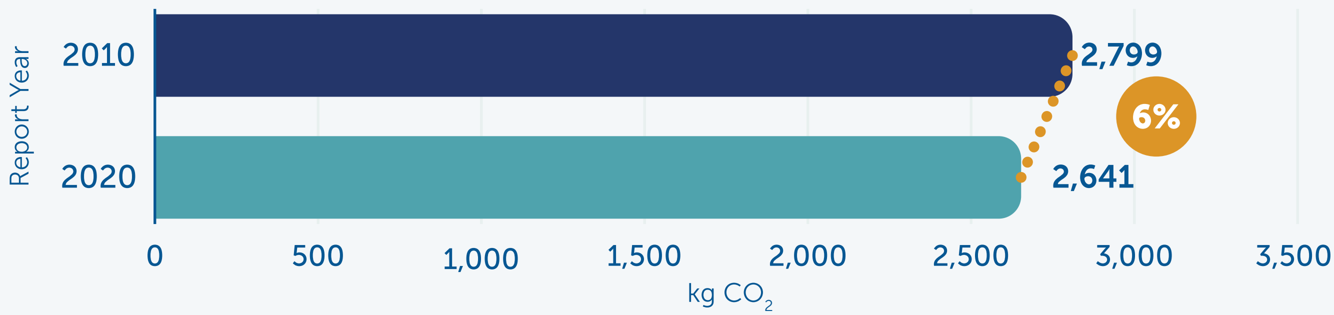


**FIGURE 6** displays the $CO_2$ emissions of HIPS from the cradle-to-gate LCA of 2010 as compared to that of 2022. The results, measured in kg $CO_2$ per 1,000 kg of HIPS, show a 6% decrease in $CO_2$ from 2,799 kg $CO_2$ to 2,641 kg $CO_2$. The decrease in $CO_2$ can be attributed to the shift in fuel composition used to produce HIPS resin from the 2010 to 2020 iteration. There was a 7% decrease in petroleum used in production and an 9% increase in natural gas, as well as a slight 2% decrease in the use of coal.

## HIPS Energy Consumption per 1,000 kg

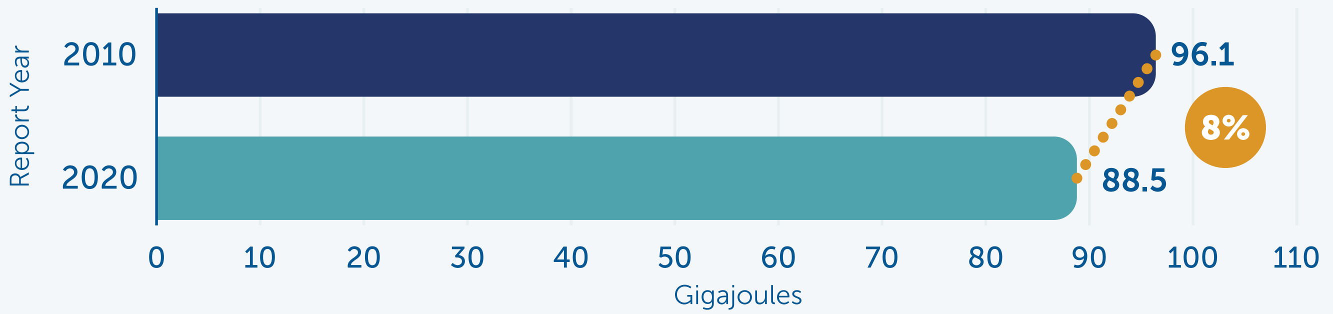


**FIGURE 7** shows the amount of energy consumed, measured in GJ, in the cradle-to-gate LCA of HIPS from 2010 compared to 2020. There was a 8% decrease in energy consumed from 96.1 GJ in 2010, to 88.5 GJ in 2020. The data suggests that the decrease reflects a decrease in energy consumed at the olefins plant, where some of the material inputs used to produce HIPS resin were produced. The energy decrease can also be attributed to improvements in the oil and natural gas extraction and refining processes.

# GPPS

**Description:** GPPS is a transparent polymer. GPPS is known for its glass-like clarity and ability to be easily molded into various shapes. GPPS is commonly used for food packaging, toothbrushes, pens, and children's toys.

### GPPS Carbon Dioxide Emissions per 1,000 kg

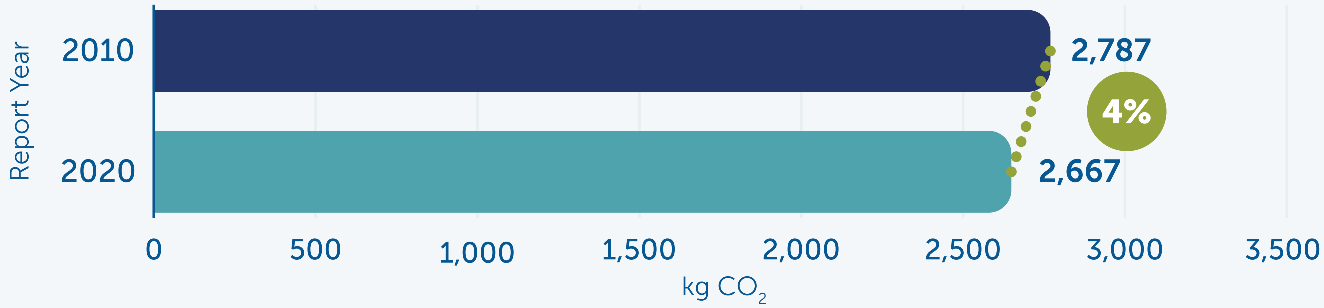


**FIGURE 4** displays the $CO_2$ emissions of GPPS from the cradle-to-gate LCA published in 2010 compared to the cradle-to-gate LCA published in 2022. The results, measured in kg $CO_2$ per 1,000 kg of GPPS, show a 4% decrease in $CO_2$ emissions from 2,787 kg $CO_2$ to 2,667 kg $CO_2$. The decrease in $CO_2$ emissions can be attributed to the shift in the composition of fuels used in the production of GPPS resin from the 2010 to 2020 iteration. There was a 7% decrease in petroleum used in production and an 8% increase in natural gas, as well as a 2% decrease in coal. The combustion of natural gas emits approximately 30% less carbon dioxide than the combustion of petroleum.

### GPPS Energy Consumption per 1,000 kg

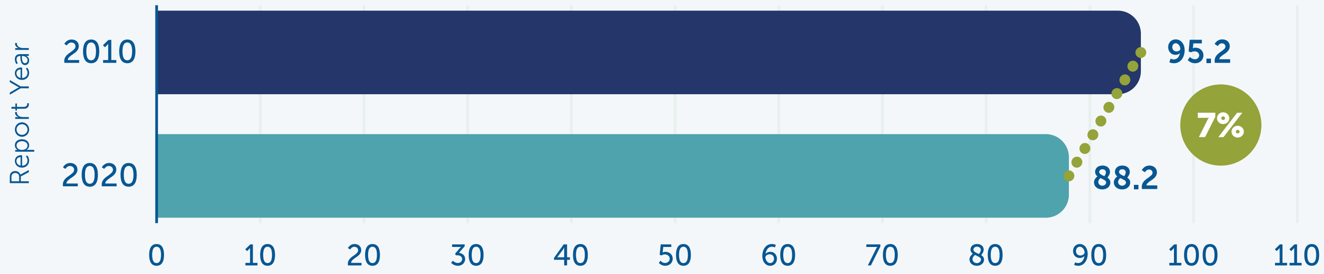


**FIGURE 5** shows the amount of energy consumed, measured in Gigajoules (GJ) throughout the cradle-to-gate LCA of GPPS from 2010 compared to 2020. There was a 7% decrease in energy consumed from 95.2 GJ in 2010, to 88.2 GJ in 2020. The report suggests the decrease in total energy consumption can be attributed to efficiency improvements within the production processes, as well as a decrease in energy required for the olefins production and natural gas refinement.

# ABS

**Description:** ABS is produced from the chemical combination of acrylonitrile, butadiene, and styrene, creating a material with high impact and chemical resistance. Due to its durability, common applications include building-block toys, protective headgear, and automotive parts.

## ABS Carbon Dioxide Emissions per 1,000 kg

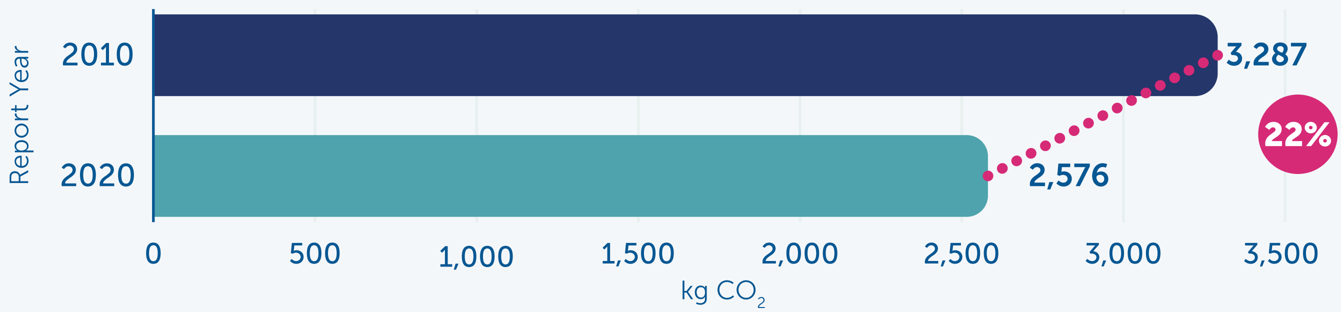


**FIGURE 8** displays the $CO_2$ emissions of ABS from the cradle-to-gate LCA of 2010 compared to 2022. The results, measured in kg $CO_2$ per 1,000 kg of ABS, show a 22% decrease in $CO_2$ from 3,287 kg $CO_2$ to 2,576 kg $CO_2$. The greater reduction in $CO_2$ emissions can be attributed to the shift in fuel composition, particularly a 5% decrease in coal and 11% increase in natural gas.

## ABS Energy Consumption per 1,000 kg

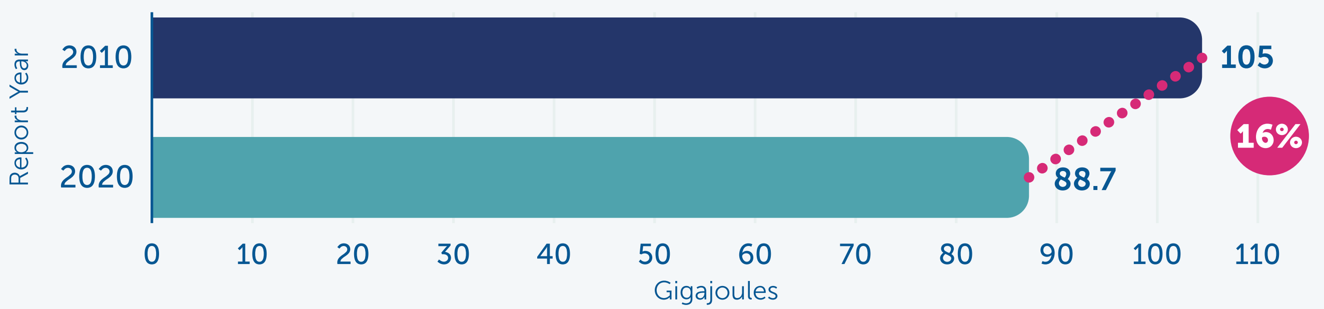


**FIGURE 9** shows the amount of energy consumed, measured in GJ, throughout the cradle-to-gate LCA of ABS from 2010 compared to 2022. There was a 16% decrease in energy consumed from 105 GJ in 2010, to 87.7 GJ in 2022. The notable decrease in energy consumption can be attributed to a decrease in the amount of styrene used to produce the ABS resin, as well as the decrease in energy required at the ABS resin plant. The decrease of styrene inputs to ABS by nearly 100kg per 1,000 kg of ABS produced is associated with potential technological improvements, as well as potential variations in the ABS recipes because of different companies participating in the latest update compared to the earlier report. It should be noted that the results shown are representative of the ABS production industry as a whole and are not specific to any product or ABS plant. Furthermore, some ABS products may require more flexibility, which would equate to more rubber and less styrene within the ABS resin.

# CONCLUSION

The executive summary and report highlight improvements made within the manufacturing processes of HIPS, GPPS, and ABS over the past 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 can offer 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 and policymakers assessing the contribution of plastics to a low-carbon economy when compared to alternative materials, such as paper, aluminum, or glass. Furthermore, this cradle-to-gate data can be used in combination with data from other parts of the full 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 life cycle.