Greenhouse Gas Index for Products in 39 Industrial Sectors: Plastic Material and Resin Manufacturing

NAICS CODE 325211

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For all products in this module, except PET and ABS (see Sections 7 and 8 below), we assumed and used natural gas as the fuel to provide electricity and thermal energy in our analyses.

An Important Note

This module is not a stand-alone document. Readers should refer to the introduction for a more detailed overview and discussion of the Framework and procedures to determine the GGI and, especially, to the ***Note on Common References, Default Values, Acronyms and Abbreviations used in the Modules***. Common information includes default values for CO_2 emissions from electricity and thermal energy derived from coal, oil and natural gas; a list of acronyms and abbreviations; guidance on using the sources cited for US exports, imports, and production by sector, and CO_2 emissions from electricity produced in nations that export to the United States.

Sharing Our Work

Contents

1. Introduction

The NAICS Code 325211 consists of more than 100 products.[1] During 2019, exports of products covered under this code were $32.5 billion and imports were $13.7 billion.[2] In 2018, total US production of these products was about $97.64 billion.[3] In this module, we determine greenhouse gas indices (GGIs)—which track taxed GHG process emissions and the contribution of the carbon content of products derived from fossil resources along the supply chain in a manner analogous to that used in value-added taxes—for plastic products. [4] When multiplied by the GHG tax, the result is the relevant export rebate or import charge. A minimum GGI of 0.50 tonnes CO_2e/tonne product is required for an export rebate or the imposition of an import charge.

The GGIs for products in this sector are determined by allocating total taxed sources of GHG emissions, $CO_2e(TOT)$, to the total slate of covered products based on the carbon content, *cf*, by weight of each product. As described in the introduction to the modules, allocation by carbon content is based on first determining the average CO_2e emissions per tonne of carbon C, $<CO_2e/C>$,[5] in all products, and then allocating GHG emissions to products based on *cf*. $<CO_2e/C> = <CO_2e(TOT)/M(C)>$, where M(C) is the mass of carbon in all covered products. The manufacturer will know the composition and amounts of covered products they produce. So, for each product in this sector, the GGI is determined as follows:

$$GGI = <CO_2e/C>\ cf.$$

Note that in the event that the manufacturer produces only a single covered product, P, as is often the case for products in this module, $GGI = CO_2e(TOT)/M(P)$, where M(P) is the weight of the covered product (tonnes P). Allocation only requires specific treatment on a product-by-product basis when the production process used by the manufacturer creates more than one covered product.

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[1] These consist primarily of polyethylene, polyvinyl chloride, polypropylene, polystyrene, polybutadiene, polyethylene terephthalate, and acrylonitrile-butadiene-styrene co-polymers.
[2] *See*: **USA Trade Online - Choose members (census.gov).**
[3] *See*: **https://data.census.gov/cedsci/table?q=AM1831BASIC&tid=ASMAREA2017.AM1831BASIC01** for the AM1831BASIC01 Annual Survey of Manufactures: Summary Statistics for Industry Groups and Industries in the US: 2018–2020.
[4] *See*: Flannery, Brian, Jennifer A. Hillman, Jan Mares, and Matthew C. Porterfield. 2020. Framework Proposal for a US Upstream GHG Tax with WTO-Compliant Border Adjustments: 2020 Update. Washington, DC: Resources for the Future. https://www.rff.org/publications/reports/framework-proposal-us-upstream-ghg-tax-wto-compliant-border-adjustments-2020-update/
[5] See the discussion in the introduction concerning the use of angle brackets “< >”to denote an average over the entire operation, e.g., a facility or entire sector, in this case to produce refined products.

The major contributors to the GGIs of these products are the GGIs of petrochemical feedstocks such as ethylene, propylene, butylene, butadiene, vinyl chloride, and styrene (which are created from ethane, propane, butane, naphtha, pyrolysis gasoline, and chlorine—which also are derived from natural gas liquids, natural gas, and petroleum—as well as electricity, which in turn is based on various energy sources with diverse GGIs). In addition, the thermal energy required for the various polymerization processes to make these products must be accounted for to determine their GGIs. The span of GGIs for the seven listed products (see footnote 1; including a total of five variations of two of them) ranges from 4.04 tonnes CO_2e/tonne polypropylene resin to 6.59 tonnes CO_2e/tonne acrylonitrile-butadiene-styrene resin.

This module provides a means for the Regulator to estimate, based on public information, initial export rebates for US exporters and import charges for imports to the United States of covered products—if there were an upstream GHG tax that provided for such rebates and import charges. This module uses such information to indicate what such export rebates and import charges for key countries would be if there were an upstream GHG tax of $20 per tonne of CO_2. This information would be useful to the Regulator in evaluating the information provided by exporters to indicate their requested export rebate.

The major US producers of plastics are already obligated to annually measure and report their facility GHG emissions to the US Environmental Protection Agency (EPA) if they are over 25,000 tonnes per year. They will also know the amounts and types of covered products they manufacture and, under our Framework (see footnote 4), in the United States suppliers would be obligated to inform customers (and the Regulator) of the GGI values of GHG-intensive products that they sell. Therefore, US manufacturers would have the information needed to determine the GGI values for GHG-intensive products that they create in specific facilities. More accurate and timely information to determine rebates and import charges could undoubtedly be obtained by the Regulator from either the industry association or firms (such as from S&P Global, which has a business of obtaining and marketing information about the GHG aspects of various products and corporate actions).

The overall average GHG emissions from fuels used to manufacture electricity in the relevant country should be used to determine the GHG emissions from electricity use associated with production of the imported plastic products unless more specific, verifiable information is provided to the Regulator. Such electricity information can be found in the International Energy Agency's World Energy Balances 2020.[6]

An important note: We emphasize that the estimates in this module are meant to provide only indicative, representative values for the GGIs of US plastics products. Some of the public data that the calculations rely on date back and probably are not representative of industry performance today. Actual values will depend on the

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[6] *See*: International Energy Agency. 2021. World Energy Balances; **https://www.iea.org/data-and-statistics/data-products?filter=balances%2Fstatistics**.

determination of a GGI for each specific product produced at a specific facility. Since companies, associations, and commercial firms that collect and market information about the energy and emissions profiles of various products can provide more accurate information than was used here, the Regulator should seek such information when determining potential import charges or evaluating requests for export rebates. The estimates here do not account for all chemicals or other raw materials that may have incurred the GHG tax directly or indirectly. Subject to the administrative costs to evaluate all such inputs and be consistent for both export rebates and import charges, the Regulators should strive to accept all verifiable raw material inputs to the GGI for specific products.

2. Polyethylene

There are three types of polyethylene that are made from ethylene:

- linear low-density polyethylene (LLDPE);
- high-density polyethylene (HDPE); and
- low-density polyethylene (LDPE).

LLDPE is produced by the addition of alpha-olefins (butene, hexene, or octene) during the polymerization of ethylene to give a resin with a similar density to LDPE but the linearity of HDPE. The additional olefins added to the ethylene in the LLDPE process are believed to be about 2–10 percent of the ethylene input and are described as low in comparison to ethylene. This analysis assumes 3 percent of raw materials are butylene and 97 percent are ethylene.

The conversion of ethylene to polyethylene is typically very high (95–98 percent); this analysis uses 97 percent conversion.[7]

2.1. Linear Low-Density Polyethylene (LLDPE)

Electricity and thermal energy contributions to LLDPE polymerization are 2.63 GJ/tonne LLDPE for electricity and 1.92 GJ/tonne LLDPE for thermal energy.[8] Thus, relevant contributions to the GGIs are as follows:

- Electricity: (2.63 GJ/tonne LLDPE) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.133 tonnes CO_2e/tonne LLDPE;
- Thermal energy: (1.92 GJ/tonne LLDPE) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.097 tonnes CO_2e/tonne LLDPE;
- Ethylene derived from ethane: 3.76 tonnes CO_2e/tonne ethylene, or
- ethylene derived from naphtha: 4.43 tonnes CO_2e/tonne ethylene;
- Butylene made from naphtha: 4.47 tonnes CO_2e/tonne butylene.

In this analysis, we use the average of the two GGIs for ethylene and one for butylene. Thus, the GGI contributions from ethylene and butylene for LLDPE are (1 tonne ethylene/0.98 tonnes LLDPE) (0.97) (4.10 tonnes CO_2e/tonne ethylene) + (1 tonne

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[7] The data used in this module on electricity and thermal energy used to make polyethylene is derived from the following: Franklin Associates. 2010. *Cradle-To-Gate Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors*. Final report. Prepared for: The Plastics Division of the American Chemistry Council; **https://www.americanchemistry.com/better-policy-regulation/plastics/resources/cradle-to-gate-life-cycle-inventory-of-nine-plastic-resins-and-four-polyurethane-precursors**. For data re components of LLDPE see **http://www.inference.org.uk/sustainable/LCA/elcd/external_docs/lldpe_311147f5-fabd-11da-974d-0800200c9a66.pdf**.

[8] *See:* Table D-2 in Appendix D of Franklin Associates (2010; see footnote 7).

butylene/0.98 tonnes LLDPE) (0.03) (4.47 tonnes CO_2e/tonne butylene) = (4.06 + 0.133) tonnes CO_2e/tonne LLDPE = 4.19 tonnes CO_2e/tonne LLDPE. So, the GGI for LLDPE is as follows:

GGI = CO_2e(TOT)/tonne LLDPE;
= (0.133 + 0.097 + 4.19) tonnes CO_2e/tonne LLDPE
= 4.42 tonnes CO_2e/tonne LLDPE.

2.2. High-Density Polyethylene (HDPE)

Electricity and thermal energy contributions to HDPE polymerization are 3.73 GJ/tonne HDPE for electricity and 1.48 GJ/tonne for thermal energy.[9] Thus, relevant contributions to GGIs are as follows:

- Electricity: (3.73 GJ/tonne HDPE) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.188 tonnes CO_2e/tonne HDPE;
- Thermal energy: (1.48 GJ/tonne HDPE) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.075 tonnes CO_2e/tonne HDPE;
- Ethylene derived from ethane: 3.76 tonnes CO_2e/tonne ethylene, or ethylene derived from naphtha: 4.43 tonnes CO_2e/tonne ethylene.

For 1 tonne HDPE, 1/0.97 tonnes ethylene is required (i.e., 1.031 tonnes of ethylene).

Thus, for HDPE, CO_2e(TOT) per tonne HDPE = 0.188 tonnes CO_2e/tonne HDPE + 0.075 tonnes CO_2e/tonne HDPE + 1.031 tonnes ethylene/tonne HDPE (3.76 or 4.43 tonnes CO_2e/tonne ethylene) = 4.15 or 4.83 tonnes CO_2e/tonne HDPE. So, depending, respectively, on whether ethylene is derived from ethane or naphtha, the GGI is as follows:

GGI = CO_2e(TOT)/tonne HDPE;
= (4.15 or 4.83) tonnes CO_2e/tonne HDPE.

2.3. Low-Density Polyethylene (LDPE)

Electricity and thermal energy contributions to LDPE polymerization are 7.78 GJ/tonne LDPE for electricity and 2.50 GJ/tonne LDPE for thermal energy.[10] Thus, relevant contributions to GGIs are as follows:

- Electricity: (7.78 GJ/tonne LDPE) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.392 tonnes CO_2e/tonne LDPE;
- Thermal energy: (2.6092 GJ/tonne LDPE) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.126 tonnes CO_2e/tonne LDPE;
- Ethylene derived from ethane: 3.76 tonnes CO_2e/tonne ethylene, or

[9] *See:* Table B-7 in Appendix B of Franklin Associates (2010; see footnote 7).
[10] *See:* Table C-2 in Appendix B of Franklin Associates (2010; see footnote 7).

ethylene derived from naphtha: 4.43 tonnes CO_2e/tonne ethylene.

For 1 tonne LDPE, 1/0.97 tonnes ethylene is required (i.e., 1.031 tonnes of ethylene). Thus, for LDPE, $CO_2e(TOT)$ = (0.392 + 0.126) tonnes CO_2e/tonne LDPE + (1.031 tonnes ethylene/tonne LDPE) (3.76 or 4.43) tonnes CO_2e/tonne ethylene = (4.40 or 5.09) tonnes CO_2e/tonne LDPE. So, depending on whether ethylene is derived from ethane or naphtha, respectively, the GGI is as follows:

GGI = $CO_2e(TOT)$/tonne LDPE;
= (4.40 or 5.09) tonnes CO_2e/tonne LDPE.

2.4. Export Rebates

If there were an upstream GHG tax of $20 per tonne of CO_2, the potential export rebates for the various types of polyethylene with different sources of ethylene would be as follows:

Table 1. Export rebates

Product	Ethylene Source	GGI (tonnes CO_2e/tonne product)	Rebate ($/tonne)
LLDPE	Avg. of ethane/naphtha	4.42	88.40
HDPE	Ethane	4.15	83.00
	Naphtha	4.83	96.60
LDPE	Ethane	4.40	88.00
	Naphtha	5.09	101.80

2.5. Import Charges

Although the data used to estimate the GGIs for the three polyethylenes in the United States and their potential rebates were derived from processes in the United States, the data are from 2003. The Regulator should use that same data for all imports of polyethylenes until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of $20 per tonne of CO_2, the import charges for the three polyethylenes would be as follows:

Table 2. Import charges

Product	Ethylene Source	GGI (tonnes CO_2e/tonne)	Import Charge ($/tonne)
LLDPE	Avg. of ethane/naphtha	4.42	88.40
HDPE	Ethane	4.15	83.00
	Naphtha	4.83	96.60
LDPE	Ethane	4.40	88.00
	Naphtha	5.09	101.80

3. Polyvinylchloride (PVC)

The main raw material for polyvinylchloride (PVC) is vinyl chloride monomer (VCM), which is polymerized in an exothermic reaction. There are two main polymerization processes: suspension and emulsion. Conversions are in the range of 85–95 percent; our analysis uses 90 percent.

We assume the energy usages below:[11]

Table 3. Energy usages for PVC

	Suspension	Emulsion
Thermal energy	2–3 GJ/tonne PVC	6–9 GJ/tonne PVC
Electricity	194–305 kWh/tonne PVC	389–611 kWh/tonne PVC

We use the midpoint for each energy usage in this analysis.

For suspension polymerization:

- Electricity: (251 kWh/tonne PVC) (0.42 tonnes CO_2e/1,000 kWh) = 0.105 tonnes CO_2e/tonne PVC
- Thermal energy: (2.5 GJ/tonne PVC) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.126 tonnes CO_2e/tonne PVC

For emulsion polymerization:

- Electricity: (500 kWh/tonne PVC) (0.42 tonnes CO2e/1,000 kWh) = 0.21 tonnes CO2e/tonnes PVC
- Thermal energy: (7.5 GJ/tonne PVC) (0.947 MBtu/GJ) (0.0532 tonnes CO2e/MBtu) = 0.378 tonnes CO2e/tonne PVC

As noted in our module on basic organic chemicals, the GGI for VCM is 4.34 tonnes CO_2e/tonne VCM.

[11] Based on data from Section 5.12.2 of Boulamanti, A., and J.A. Moya Rivera. 2017. *Energy Efficiency and GHG Emissions: Prospective Scenarios for the Chemical and Petrochemical Industry*. EUR 28471 EN, doi:10.2760/20486. **https://publications.jrc.ec.europa.eu/repository/handle/JRC105767.** For conversion % see p. 12 in **https://pvc4pipes.com/wp-content/uploads/2018/02/PlasticsEurope_Eco-profile_VCM_PVC_2015-05.pdf**

So, for suspension polymerization the GGI is as follows:

$$
\begin{aligned}
\text{GGI} &= CO_2e(\text{TOT})/\text{tonne PVC;} \\
&= (0.105 + 0.126) \text{ tonnes } CO_2e/\text{tonne PVC} \\
&\quad + (1 \text{ tonne VCM}/0.9 \text{ tonnes PVC}) \; 4.34 \text{ tonnes } CO_2e/\text{tonne VCM;} \\
&= (0.105 + 0.126 + 4.82) \text{ tonnes } CO_2e/\text{tonne PVC} \\
&= 5.05 \text{ tonnes } CO_2e/\text{tonne PVC.}
\end{aligned}
$$

For emulsion polymerization, the GGI is as follows:

$$
\begin{aligned}
\text{GGI} &= CO_2e(\text{TOT})/\text{tonne PVC;} \\
&= (0.210 + 0.378) \text{ tonnes } CO_2e/\text{tonne PVC} \\
&\quad + (1 \text{ tonne VCM}/0.9 \text{ tonnes PVC}) \; 4.34 \text{ tonnes } CO_2e/\text{tonne VCM} \\
&= (0.210 + 0.378 + 4.82) \text{ tonnes } CO_2e/\text{tonne PVC} \\
&= 5.41 \text{ tonnes } CO_2e/\text{tonne PVC.}
\end{aligned}
$$

3.1. Export Rebates

If there were an upstream GHG tax of $20 per tonne of CO_2, the export rebate for PVC would be as follows:

Table 4. Export rebates

PVC from Different Processes	GGI CO_2e/tonne PVC	Export Rebate ($/tonne PVC)
Suspension polymerization	5.05	101.00
Emulsion polymerization	5.41	108.20

3.2. Import Charges

Since the data used to estimate the GGIs for PVC in the United States were derived from processes in Europe, the Regulator should use that same data for all imports of PVC until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of $20 per tonne of CO_2, the import charges for PVC (assuming an averaging of the GGIs for ethylene and chorine from its sources) would be as follows:

Table 5. Import charges

PVC from Different Processes	**GGI** CO_2e/tonne PVC	**Import Charge** ($/tonne PVC)
Suspension polymerization	5.05	101.00
Emulsion polymerization	5.41	108.20

4. Polypropylene (PP)

The electricity and thermal energy contributions to polypropylene (PP) polymerization are 2.95 GJ/tonne PP for electricity and 1.02 GJ/tonne PP for thermal energy.[12] Thus, relevant contributions to the GGIs are as follows:

- Electricity: (2.95 GJ/tonne PP) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.149 tonnes CO_2e/tonne PP;
- Thermal energy: (1.02 GJ/tonne PP) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.052 tonnes CO_2e/tonne PP.

Our module on petrochemicals provides the GGI for propylene derived from propane dehydration—3.72 tonnes CO_2e/tonne propylene; that derived from naphtha is 4.43 tonnes CO_2e/tonne propylene; and that derived from propane cracking is 4.40 tonnes CO_2e/tonne propylene.

For 1 tonne PP, 1/0.97 tonnes propylene is required (i.e., 1.031 tonnes of propylene).

So, depending on the above sources for propylene, the CO_2e(TOT) per tonne PP is (0.149 + 0.052) tonnes CO_2e/tonne PP + (1 tonne propylene/0.97 tonnes PP) (3.72 or 4.43 or 4.40) tonnes CO_2e/tonne propylene = (4.04 or 4.77 or 4.74) tonnes CO_2e/tonne PP. So, the GGI is as follows:

$$\begin{aligned} \text{GGI} &= CO_2\text{e(TOT)/tonne PP;} \\ &= \text{(4.04, 4.77, or 4.74) tonnes } CO_2\text{e/tonne PP.} \end{aligned}$$

4.1. Export Rebates

If there were an upstream GHG tax of $20 per tonne of CO_2, the potential export rebates for PP made with different propylene sources would be as follows:

Table 6. Export rebates

Product	Propylene Source	GGI CO_2e/tonne PVC	Rebate ($/tonne PVC)
PP	Propane dehydration	4.04	80.80
PP	Naphtha	4.77	95.40
PP	Propane cracking	4.74	94.80

[12] *See:* Table E-3 in Appendix E of Franklin Associates (2010; see footnote 7).

4.2. Import Charges

Although the data used to estimate the GGIs for PP in the United States and their potential rebates were derived from processes in the United States, the data are from 2003. The Regulator should use that same data for all imports of EDC until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of $20 per tonne CO_2, the import charges for PP would be as follows, depending on the source of propylene used:

Table 7. Import charges

Product	Propylene Source	GGI CO_2e/tonne PVC	Import Charge ($/tonne PVC)
PP	Propane dehydration	4.04	80.80
PP	Naphtha	4.77	95.40
PP	Propane cracking	4.74	94.80

5. Polystyrene

5.1. General Purpose Polystyrene Resin (GPPS)

The electricity and thermal contributions to general purpose polystyrene resin (GPPS) polymerization are 1.25 GJ/tonne GPPS for electricity and 0.842 GJ/tonne for thermal energy.[13] Thus, relevant contributions to the GGIs are as follows:

- Electricity: (1.25 GJ/tonne GPPS) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.0630 tonnes CO_2e/tonne GPPS;
- Thermal energy: (0.842 GJ/tonne GPPS) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.042 tonnes CO_2e/tonne GPPS.

The assumed efficiency for the polymerization is 97 percent. Thus, the contribution of the styrene raw material to the GGI of GPPS is (1/.97) (6.07 tonnes CO_2e/tonne GPPS) = 6.26 tonnes CO_2e/tonne GPPS for styrene. The GGI for GPPS is determined as follows:

$$
\begin{aligned}
\text{GGI} &= \text{CO}_2\text{e(TOT)/tonne GPPS;} \\
&= (0.063 + 0.042 + 6.26) \text{ tonnes CO}_2\text{e/tonne GPPS} \\
&= 6.37 \text{ tonnes CO}_2\text{e/tonne GPPS.}
\end{aligned}
$$

5.2. High Impact Polystyrene (HIPS)

High impact polystyrene is made from styrene (93.6 percent) and polybutadiene (6.4 percent). As described in the section above on GPPS, we use 6.07 tonne CO_2e/tonne styrene with an assumed 97 percent efficiency for polymerization. As provided in the section below on polybutadiene (PB), the GGI for PB is 5.04 tonnes CO_2e/tonne PB.

A 2010 report by Franklin Associates[14] provides the following information on production of HIPS: electricity and thermal energy contributions to HIPS polymerization are 1.36 GJ/tonne HIPS for electricity and 0.92 GJ/tonne HIPS for thermal energy, and 936 kg of styrene and 64 kg of polybutadiene are required per tonne of HIPS. Thus, relevant contributions to the GGIs are as follows:

- Electricity: (1.36 GJ/tonne HIPS) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.069 tonnes CO_2e/tonne HIPS;
- Thermal energy: (0.92 GJ/tonne HIPS) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.046 tonnes CO_2e/tonne HIPS.

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[13] *See:* Table G-6 in Appendix G of Franklin Associates (2010; see footnote 7).
[14] *See:* Table H-4 in Appendix H of Franklin Associates (2010; see footnote 7).

So, for HIPS, the GGI is calculated as follows:

$$
\begin{aligned}
\text{GGI} &= \text{CO}_2\text{e(TOT)/tonne HIPS;} \\
&= (1/0.97)\ \{(0.936 \text{ tonnes styrene/tonne HIPS})\ (6.07 \text{ tonnes CO}_2\text{e/tonne styrene}) \\
&\quad + (0.064 \text{ tonnes PB/tonne HIPS})\ (5.04 \text{ tonnes CO}_2\text{e/tonne PB})\} \\
&\quad + (0.069 + 0.046) \text{ tonnes CO}_2\text{e/tonne HIPS} \\
&= 6.31 \text{ tonnes CO}_2\text{e/tonne HIPS.}
\end{aligned}
$$

5.3. Export Rebates

If there were an upstream GHG tax of $20 per tonne of CO_2, the potential export rebates for polystyrene would be as follows (depending on the source of the raw material for the benzene used to make the styrene raw material):

Table 8. Export rebates

Product	GGI CO_2e/tonne product	Rebate ($/tonne product)
HIPS	6.31	126.20
GPPS	6.37	127.40

5.4. Import Charges

Although the data used to estimate the GGIs for polystyrene in the United States and their potential rebates were derived from processes in the United States, the data are from 2003. The Regulator should use that same data for all imports of polystyrene until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of $20 per tonne of CO_2, the import charges for polystyrene would be as follows (depending on the source of raw material for the benzene used to make the styrene raw material):

Table 9. Import charges

Product	GGI CO_2e/tonne product	Import Charge ($/tonne product)
HIPS	6.31	126.20
GPPS	6.37	127.40

6. Polybutadiene (PB)

Polybutadiene (PB) is made from the polymerization of butadiene. We assume that the efficiency is 97 percent. As noted in the module on petrochemicals, the GGI for butadiene varies depending on its raw material source. For production from naphtha, butadiene's GGI is 4.59 tonne CO_2e/tonne butadiene. The butadiene contribution to PB is (1 tonne butadiene/0.97 tonnes PB) (4.59 tonnes CO_2e/tonne butadiene) = 4.73 tonnes CO_2e/tonne PB.

The electricity and thermal energy contributions to butadiene polymerization are 6.08 GJ/tonne PB.[15] Thus, the relevant contributions to GGI are as follows:

Electricity and thermal energy: (6.08 GJ/tonne PB) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.306 tonnes CO_2e/tonne PB.

So, for PB, the GGI is as follows:

GGI	=	CO_2e(TOT)/tonne PB;
	=	(0.306 + 4.73) tonnes CO_2e/tonne PB
	=	5.04 tonnes CO2e/tonne PB.

6.1. Export Rebates

If there were an upstream GHG tax of \$20 per tonne of CO_2, the export rebate would be (\$20 per tonne CO_2) (5.04 per tonne CO_2e/tonne PB) = \$100.80 per tonne PB.

6.2. Import Charges

The Regulator should use the US GGI for all imports of PB until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of \$20 per tonne of CO_2, the import charges would be (\$20 per tonne CO_2) (5.04 per tonne CO_2e/tonne PB) = \$100.80 per tonne PB.

[15] *See:* Table H-3 in Appendix H of Franklin Associates (2010; see footnote 7).

7. Polyethylene Terephthalate (PET) Resin

Polyethylene terephthalate (PET) resin is derived from methanol, acetic acid, ethylene glycol, and paraxylene. We again use 2003 data from Franklin Associates (2010; see footnote 7) for the production of PET resin (which includes energy required to produce its raw materials: terephthalic acid, dimethyl terephthalate, and crude terephthalic acid). Material inputs per tonne of PET include paraxylene (0.521 tonnes); ethylene glycol (0.322 tonnes); acetic acid (0.0372 tonnes); and methanol (0.0352 tonnes). Contributors to the GGI from energy include electricity (6.67 GJ/tonne PET); natural gas (4.1 GJ/tonne PET); coal (0.49 GJ/tonne PET); distillate oil (0.57 GJ/tonne PET); residual oil (1.28 GJ/tonne PET); and recovered energy (0.14 GJ/tonne PET).

The GGIs for the key raw materials are determined in our modules on petrochemicals and basic organic chemicals and are as follows:

- individual xylenes: 5.82 tonnes CO_2e/tonne xylene derived from catalytic reformer, and 6.07 tonnes CO_2e/tonne paraxylene derived from pyrolysis gasoline;
- ethylene glycol: 3.42 tonnes CO_2e/tonne EG, based on the average of GGIs based on ethane and naphtha;
- acetic acid: 2.84 tonnes CO_2e/tonne acetic acid; and
- methanol: 2.16 tonnes CO_2e/tonne methanol.

The contributions of electricity and thermal energy to the GGI are as follows:

- Electricity: (6.67 GJ/tonne PET) (0.2777 MWh/GJ) (0.42 tonnes CO2e/MWh) = 0.778 tonnes CO2e/tonne PET;
- Thermal energy:
  - Natural gas: (4.1 GJ/tonne PET) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.2066 tonnes CO2e/tonne PET;
  - Coal: (0.49 GJ/tonne PET) (0.947 MBtu/GJ) (0.0935 tonnes CO_2e/MBtu) = 0.0434 tonnes CO_2e/tonne PET;
  - Distillate oil: (0.57 GJ/tonne PET) (0.947 MBtu/GJ) (0.0733 tonnes CO_2e/MBtu) = 0.0396 tonnes CO_2e/tonne PET;
  - Residual oil: (1.28 GJ/tonne PET) (0.947 MBtu/GJ) (0.0733 tonnes CO_2e/MBtu) = 0.0889 tonnes CO_2e/tonne PET;
  - Recovered heat: (0.14 GJ/tonne PET) (0.947 MBtu/GJ) (0.0 tonnes CO_2e/MBtu) = 0.0 tonnes CO_2e/tonne PET;
  - Total: 0.378 tonnes CO_2e/tonne PET.

The GGI for PET is determined as follows:

$$
\begin{aligned}
\text{GGI} &= CO_2e(\text{TOT})/\text{tonne PET;} \\
&= (0.778 + 0.378) \text{ tonnes } CO_2e/\text{tonne PET} \\
&\quad + (0.322 \text{ tonnes EG/tonne PET}) (3.42 \text{ tonnes } CO_2e/\text{tonne EG}) \\
&\quad + (0.521 \text{ tonnes pxylene/tonne PET}) (5.95 \text{ tonnes } CO_2e/\text{tonne pxylene}) \\
&\quad + (0.0352 \text{ tonnes methanol/tonne PET}) (2.16 \text{ tonnes } CO_2e/\text{tonne methanol}) \\
&\quad + (0.0372 \text{ tonnes acetic acid/tonne PET}) (2.84 \text{ tonnes } CO_2e/\text{tonne acetic acid}) \\
&= 5.54 \text{ tonnes } CO_2e/\text{tonne PET.}
\end{aligned}
$$

7.1. Export Rebates

If there were an upstream GHG tax of $20 per tonne of CO_2, the export rebate for PET would be $110.80 per tonne PET.

7.2. Import Charges

The Regulator should use the US GGI for all imports of PET until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of $20 per tonne of CO_2, the import charges for PET would be = $110.80 per tonne PET.

8. Acrylonitrile Butadiene Styrene (ABS) Resin

Acrylonitrile butadiene styrene (ABS) resin is a **terpolymer** made by polymerizing **styrene** and **acrylonitrile** (AN) in the presence of **polybutadiene**. The proportions can vary from 15–35 percent AN, 5–30 percent **butadiene**, and 40–60 percent styrene. We assume that there is a 1 percent efficiency loss and that the proportions are 26.5 percent AN, 18.5 percent butadiene, and 55 percent styrene. Data for the production of ABS resin (which includes energy required to produce it) are derived from Franklin Associates (2010; see footnote 7).[16] The energy required per tonne of ABS is as follows: electricity (7.41 GJ); natural gas (1.96 GJ); coal (1.79 GJ); and residual oil and recovered energy (0.49 GJ).

The GGIs for polybutadiene, styrene, and AN are in this module and the modules on petrochemicals and basic organic chemicals. The GGI for polybutadiene is 5.04 tonnes CO_2e/tonne PB. Styrene's average GGI is 6.07 tonnes CO_2e per tonne. The average GGI of AN is 5.73 tonnes CO_2e per tonne if the CO_2 produced during ammonia manufacture is captured and 6.31 tonnes CO_2e per tonne if the CO_2 produced is not captured—and the difference between being based on propane or naphtha is averaged as it was for styrene.

The contributions to the GGI from electricity and thermal energy are as follows:

- Electricity: (7.41 GJ/tonnes ABS) (0.2777 MWh/GJ) (0.42 tonnes CO_2e/MWh) = 0.865 CO_2e/tonne ABS;
- Thermal energy:

  Natural gas: (1.96 GJ/tonne ABS) (0.947 MBtu/GJ) (0.0532 tonnes CO_2e/MBtu) = 0.0987 tonnes CO_2e/tonne ABS;

  Coal: (1.79 GJ/tonne ABS) (0.947 MBtu/GJ) (0.0935 tonnes CO_2e/MBtu) = 0.1585 tonnes CO_2e/tonne ABS;

  Residual oil: (0.49 GJ/tonne ABS) (0.947 MBtu/GJ) (0.0733 tonnes CO_2e/MBtu) = 0.0340 tonnes CO_2e/tonne ABS;

  Total: 0.291 tonnes CO_2e/tonne ABS.

[16] *See:* Table J-3 in the revised final appendices of Franklin Associates (2010; based on 2003 data). For components of ABS see: **https://en.wikipedia.org/wiki/Acrylonitrile_butadiene_styrene**; and **https://polysource.net/plastic-resin-families-and-applications/**.

- Depending on the options for CO_2 capture and the source of benzene, the GGI for ABS is determined as follows:

$$
\begin{aligned}
\text{GGI} &= CO_2e(TOT)/\text{tonne ABS;} \\
&= (0.865 + 0.291) \text{ tonnes CO2e/tonne ABS} \\
&\quad + (1.01)(0.265 \text{ tonnes AN/tonne ABS}) (5.73 \text{ or } 6.31) \text{ tonnes } CO_2e/\text{tonne AN} \\
&\quad + (1.01)(0.185 \text{ tonnes PB/tonne ABS}) (5.04 \text{ tonnes } CO_2e/\text{tonne PB}) \\
&\quad + (1.01)(0.55 \text{ tonnes styrene/tonne ABS}) (6.07 \text{ tonnes } CO_2e/\text{tonne styrene}) \\
&= 7.00 \text{ or } 7.16 \text{ tonnes } CO_2e/\text{tonne ABS.}
\end{aligned}
$$

The lower value applies if the CO_2 in ammonia processing is captured and benzene is derived from catalytic reforming. The larger value applies if CO_2 in ammonia processing is not captured and benzene used in styrene is derived from pyrolysis gasoline.

8.1. Export Rebates

If there were an upstream GHG tax of $20 per tonne of CO_2, the export rebate for ABS would be ($20/tonne CO_2) (7.00 tonnes CO2e/tonne ABS) = $140.00 per tonne ABS (based on acrylonitrile where its ammonia had its CO_2 captured); and ($20/tonne CO_2) (7.16 tonnes CO_2e/tonne ABS) = $143.20 per tonne ABS (based on acrylonitrile where the CO_2 co-produced with ammonia was not captured).

8.2. Import Charges

The Regulator should use the US GGI for all imports of ABS until the importer provides the Regulator with company- and country-specific data. Pending that, if there were an upstream GHG tax of $20 per tonne of CO_2, the import charges for ABS would be ($20/tonne CO_2) (7.00 tonnes CO_2e/tonne ABS) = $140.00 per tonne of ABS (based on acrylonitrile where its ammonia had its CO_2 captured); and ($20/tonne CO_2) (7.16 tonnes CO_2e/tonne ABS) = $143.20 per tonne ABS (based on acrylonitrile where the CO_2 co-produced with ammonia was not captured).

9. Other Plastics Products

9.1. Export Rebates

There are many other products covered under NAICS Code 325211 that will have GGIs of 0.50 tonnes CO_2e/tonne product or more. US producers of such products will be able to provide the Regulator with verifiable information indicating the GGIs for their exported products and thereby be entitled to export rebates. Until the exporter can provide such information to the Regulator, no rebates would be provided.

9.2. Import Charges

Until the exporter to the United States and/or the US importer provide verifiable information to the Regulator of the GGI for the imported products or the Regulator determines a GGI for such products, an initial import charge should be established. That initial GGI would be the arithmetic average of the GGIs provided above for the various products: 5.31 tonnes CO_2e/tonne product.