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Determining the Greenhouse Gas Index for Covered Products of Specific Manufacturers

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Acronyms and Abbreviations

- BA(s)—border adjustment(s)
- BTA(s)—border tax adjustment(s)
- CBAM—Carbon Border Adjustment Mechanism
- CO_2—carbon dioxide
- CO_2e—carbon dioxide equivalent
- EITE—energy-intensive, trade-exposed [sectors; industries; etc.]
- EPA—US Environmental Protection Agency
- ETS—emissions trading system
- GGI(s)—greenhouse gas index (indexes)
- GHG(s)—greenhouse gas(es)
- GHGP—Greenhouse Gas Protocol
- ISO—International Standards Organization
- LCAs—life-cycle analyses
- LDPE—low-density polyethylene
- LNG—liquefied natural gas
- MBtu—million BTU
- MWh—megawatt-hour
- NAICS—North American Industry Classification System
- PFCs—perfluorochemicals
- t—metric tonne
- UNFCCC—United Nations Framework Convention on Climate Change
- VATs—value-added taxes
- WBCSD—World Business Council for Sustainable Development
- WRI—World Resources Institute
- WTO—World Trade Organization

1. Introduction

In the context of a US upstream GHG tax, our **2020 Framework**[1] and related **Policy Guidance**[2] reports propose a Framework to create and implement border tax adjustments (BTAs)—export rebates and import charges for covered greenhouse gas (GHG) intensive products—consistent with US obligations under the World Trading Organization (WTO). They provide background and details on internationally recognized methodologies to determine GHG emissions from facilities and how they can be used to create WTO-compatible BTAs for GHG-intensive products eligible for and subject to BTAs.

The GHG index (GGI) is a central concept and administrative index proposed in the Framework that is used to determine BTAs for covered products. Given the GGI (with units of carbon dioxide-equivalent [CO_2e] per tonne of product) of a covered domestic product, the rate for its export rebate (US$ per tonne of product) is given by the GGI multiplied by the GHG tax rate (US$ per tonne CO_2). Similarly, for a covered imported product, the import charge is the US GHG tax rate multiplied by its GGI. GGI values for like products produced by different manufacturers in different ways (e.g., using different natural resources, technologies, processes, sources of thermal energy, and electricity) can have significantly varied GGI values. While like products will be taxed at the same US GHG rate, the amount of the import charge or export rebate will differ depending on the product's GGI. Section 3.6 of the Framework report details how GGI is determined in a manner analogous to value-added taxes (VATs), but here we apply it to propagation of the upstream sources of taxed emissions.

A companion report[3] describes procedures to determine indicative values of GGI for representative products in several sectors based on national and sectoral averages for key factors. Such approaches could be especially useful to determine initial import charges based on sectoral average values of GGI for products exported to the United States from nations that do not today require reporting of GHG emissions from industrial facilities. Those estimates aim to inform readers and regulators (i.e., "the Regulator"[4]) of indicative values for GGI (and therefore export rebates and import

1 Flannery, Brian P., et al. 2020. ***Framework Proposal for a US Upstream Greenhouse Gas Tax with WTO-Compliant Border Adjustments: 2020 Update***. Report 20-14. Washington, DC: Resources for the Future.

2 Flannery, Brian P., et al. 2020. ***Policy Guidance for US GHG Tax Legislation and Regulation: Border Tax Adjustments for Products of Energy-Intensive, Trade-Exposed and Other Industries***. Report 20-15. Washington, DC: Resources for the Future.

3 Flannery, Brian P., and Jan W. Mares. 2021. Export Rebates and Import Charges for Border Tax Adjustments under an Upstream US GHG Tax: Estimates and Methods. Report XX-XX. Washington, DC: Resources for the Future.

4 In Section 3.1 of the Policy Guidance report (mentioned in footnote 2), we recommend establishing lead and support agencies within the US government to administer the GHG legislation—i.e., the US Department of the Treasury, with support from the US Department of Commerce and the US Environmental Protection Agency (EPA), which we refer to collectively as "the Regulator."

charges for those products)—and to demonstrate that such estimates can be made based on available information for GHG emissions at national and sectoral levels. Using those methods, another related report[5] contains estimated GGI values for hundreds of products in modules for dozens of sectors.

This report describes procedures under the proposed Framework to determine the GHG tax and the GGIs for covered products of individual facilities and operations (e.g., a steel mill, chemical plant, or operation to produce fossil resources), as required for full implementation of the Framework in developed nations and, ultimately, in developing nations. Section 2 describes criteria for covered products, sectors, and manufacturers based on thresholds for products' GGIs. Section 3 describes the upstream GHG tax paid by a manufacturer based on the carbon content of produced fossil resources (coal, oil, and gas) and GHG process emissions, if any, from covered facilities and operations in all sectors. Section 4 explains how a manufacturer would evaluate GGIs for its products: under the Framework, evaluation of the GGI is simply a matter of accounting for information known by the manufacturer. Required information and procedures include: the GHG tax paid, amounts and GGI values of products (including electricity) purchased from suppliers, amounts and types of covered products created, and procedures to allocate total taxed sources of GHG emissions to covered products. Section 5 describes and illustrates how the flow of products created and utilized in these five sectors—producers of coal, oil, gas, electricity, and refined products—increases GGI values for their products beyond that associated solely with their carbon content. These interactions are especially important because all sectors of the economy, including consumers, utilize electricity and commercial fuels and therefore will be affected by the upstream GHG tax. Section 6 clarifies circumstances under which the Regulator would utilize firm-wide, sectoral, or national averages to determine export rebates and import charges. Section 7 highlights other circumstances where GGIs might provide useful information to compare the GHG emissions associated with products produced in different ways and in different nations. We also suggest that GGIs could provide a basis to develop a common international standard to compare emissions associated with GHG-intensive products, and, if legal and technical issues could be overcome, to use in connection with BAs not based on a tax. Section 8 presents a summary and conclusions. An Appendix provides examples of how hypothetical facilities would determine GGIs for products in several different sectors.

5 Mares, Jan W., and Brian P. Flannery. Forthcoming. *Modules with Estimates for Export Rebates and Import Charges Based on the Greenhouse Gas Index for Products in 36 Sectors*. Washington, DC: Resources for the Future. Anticipated in 2021.

2. Covered Products, Sectors, and Manufacturers

The 2020 update to our Framework report (see footnote 1) proposes criteria for BTAs of covered products based solely on GGI. The Framework refers to covered sectors as those that produce covered products; manufacturers in covered sectors are those that create covered products. As used here, the term "manufacturer" refers to the entity that manages the specific facility or operation producing covered products—and therefore will be responsible to determine and pay the GHG tax (if any) and evaluate GGI values for its products.

As described in the foreword to the 2020 update to the Framework, these criteria, based solely on GGI, differ from those used more than a decade ago in a widely cited interagency report.[6] That report identified 46 "energy-intensive, trade-exposed industries" (EITE) that would have been presumptively eligible for relief under the proposed Waxman-Markey[7] cap-and-trade bill (H.R. 2454). Waxman-Markey specified criteria for sectors (not products) based on three economy-wide economic criteria for GHG intensity, energy intensity, and trade exposure—and would have supplied relief to covered domestic facilities in such EITE sectors. It was silent on export rebates and import charges applied to products.

Under our Framework (see footnote 1), covered products, referred to as GHG-intensive products, are those in any sector with a GGI of at least 0.50 tonnes CO_2 equivalent (CO_2e)/tonne product and, for electricity, 0.25 tonnes CO_2e/megawatt-hour (MWh). With these thresholds, covered products occur in the 46 sectors identified and listed by their North American Industry Classification System (NAICS) code in the interagency report and most products in these sectors are GHG-intensive. Covered products also occur in NAICS code sectors for produced coal, oil, and gas, and for petroleum refining, electricity production, and several others—and, for various reasons, some products (e.g., liquefied natural gas [LNG]) occur in sectors not usually associated with GHG-intensive operations.[8]

6 **The Effects of H.R. 2454 on International Competitiveness and Emission Leakage in Energy-Intensive Trade-Exposed Industries. An Interagency Report Responding to a Request from Senators Bayh, Specter, Stabenow, McCaskill, and Brown.** December 2, 2009.

7 H.R. 2454 (Waxman-Markey cap-and-trade legislation) included provisions for relief to domestic firms in EITE sectors that would be disadvantaged in international trade by the proposal.

8 See Section 3.5 of the 2020 update to the Framework report (footnote 1).

3. The GHG Tax on Specific Facilities and Operations: Carbon Content of Produced Fossil Resources and GHG Process Emissions

The manufacturer would pay the upstream GHG tax on two sources of GHG emissions. Manufacturers that extract and initially process in-ground fossil resources (e.g., coal, oil, and gas) would pay the tax on CO_2 emissions latent in the carbon content of their products—$CO_2(CC)_{FR}$—under the assumption that 100 percent of the carbon will ultimately be emitted as CO_2. All manufacturers of GHG-intensive products would pay the tax on their GHG process emissions—$CO_2e(PE)$—if any, from operations (e.g., venting and flaring of produced natural gas and calcination of limestone to produce cement). The upstream tax paid by the manufacturer would be as follows:

$$\text{GHG tax} = (\text{US GHG tax rate}) \times [CO_2(CC)_{FR} + CO_2e(PE)] \quad (1)$$

Note that many covered manufacturers in sectors that do not produce fossil resources also have no GHG process emissions; consequently, they would pay no GHG tax.

Table 1. Factors to Determine the Carbon Content of Produced Fossil Resources Subject to the Upstream GHG Tax (over the period subject to the tax—e.g., a calendar year)

Symbol	Definition for a Specific Manufacturer of Fossil Resources
$CO_2(CC)_{FR}$	Total CO_2 emissions latent in the carbon content of produced fossil resources (tonnes CO_2)
M(CC)	Total mass of carbon in all products (tonnes carbon)
jp	Index *jp* denotes a specific GHG-intensive product of the manufacturer
M_{jp}	Mass of product *jp* (tonnes)
cc_{jp}	Fraction by weight of carbon in product *jp*, i.e., its carbon content

Table 2. Factors to Determine GHG Process Emissions Subject to the Upstream GHG Tax in Sectors That Produce GHG-Intensive Products (over the period subject to the tax—e.g., a calendar year)

Symbol	Definition for a Specific Manufacturer Producing GHG-Intensive Products
$CO_2e(PE)$	Total CO_2e GHG process emissions (tonnes CO_2e), if any
jg	Index *jg* denotes a specific emitted greenhouse gas
$M(PE)_{jg}$	Total emitted by weight (tonnes) of gas *jg*
GWP_{jg}	Global warming potential of gas *jg* (GHG emissions relative to CO_2 by weight)

Tables 1 and 2 define the factors used to evaluate $CO_2(CC)_{FR}$ for manufacturers that produce fossil resources as well as $CO_2e(PE)$ for manufacturers with GHG process emissions in any sector:

$$M(CC) = \Sigma_{products\ jp}(cc_{jp} \times M_{jp}) \quad (2)$$

$$CO_2(CC)_{FR} = (44/12)\ M(CC) \quad (3)$$

$$CO_2e(PE) = \Sigma_{emitted\ GHGs\ jg}\ M(PE)_{jg} \times GWP_{jg} \quad (4)$$

In equation (3) the factor (44/12) converts from carbon content embedded in products to CO_2 emissions by weight based on the molecular weight of CO_2 (44) relative to the atomic weight of carbon (12).

As proposed in our Framework report, taxed process emissions $CO_2(PE)$ from production of fossil resources would include venting, flaring, and leakage of associated gas. They would also include on-site CO_2 emissions, if any, from utilization of some of the produced, as-yet untaxed fossil resource to generate process heat, steam, or electricity. To avoid double taxation, they would not include CO_2 emitted from the combustion of commercial fuels, since the tax on them would have been paid earlier in the supply chain to produce fuels.

Manufacturers that create GHG-intensive products in sectors other than those that produce in-ground fossil resources would pay the tax on only their GHG process emissions $CO_2(PE)$, if any. For example, cement producers would pay the tax on process emissions from the conversion of limestone to lime, whereas electricity producers have no process emissions and would pay no tax at all.

Information required to determine $CO_2(CC)_{FR}$ and $CO_2e(PE)$ from manufacturing facilities and operations is already available in many nations. In the United States, industrial facilities and power plants that emit more than 25,000 tonnes CO_2e per year have for many years been required to report their GHG emissions (and other information, such as the carbon content of products) to the US Environmental Protection Agency (EPA) under its Greenhouse Gas Reporting Program[9]—and for power plants under the Emissions and Generation Resource Integrated Database, eGRID.[10] Similar regulatory reporting obligations exist in other developed nations but they are lacking in some developing nations. However, as described in Sections 3 and 3.1 of the Framework report, internationally recognized methodologies to determine GHG emissions from facilities and operations—many of them endorsed by international associations in EITE industries—have been available and used by multinational companies and others throughout the world for years to determine and report corporate GHG emissions. These include protocols developed by the International Standards Organization[11] and separately by the World Resources Institute in collaboration with the World Business Council for Sustainable Development,[12] and others.

9 **https://ghgdata.epa.gov/ghgp/main.do**

10 **https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid**

11 ISO 14064-1 2018 Greenhouse gases—Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals **https://www.iso.org/standard/66453.html**

12 Through the Greenhouse Gas Protocol (GHGP), World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) work with businesses to develop standards and tools that help companies measure, manage, report and reduce their carbon emissions. **http://www.ghgprotocol.org**

4. Determining the GHG Index (GGI) of Products from Specific Facilities

The procedures described below would allow a covered manufacturer to evaluate its total taxed sources of emissions and allocate them to its covered products to determine their GGI values. Under the Framework, doing so would simply be a matter of accounting for known information from the manufacturer's operations and products that it purchases from suppliers. These procedures apply generically to all covered manufacturers, ranging from those that produce only one or a few products with simple supply chains and few (if any) GHG emissions, to complex facilities and operations producing dozens of products utilizing materials, fuels, and electricity from multiple suppliers.

Procedures in Section 4.1 determine total taxed sources of GHG emissions. Although many manufacturers would have no taxed sources of GHG emissions, others would have taxed GHG process emissions, and producers of fossil resources would also be taxed on the carbon content of their products. GHG taxes must be determined by manufacturers based on their specific circumstances. In almost all cases, US manufacturers already report information on their GHG emissions that would be required to determine their tax—based on CO_2e(CC) and CO_2e(PE). Regarding evaluation of taxed emissions from the supply chain—CO_2e(SC)—the manufacturer will know the amounts of covered materials and electricity that they purchase from suppliers, and, under the Framework, suppliers would be required to communicate GGI values for products that they sell. In practice, the number of suppliers and purchased products may vary from a very few (e.g., fuel for a power plant) to many (e.g., a steel mill, or complex petrochemical plant).

Procedures in Section 4.2 describe allocation of total taxed sources of emissions—CO_2e(TOT)—to the entire slate of covered products that the manufacturer creates. The methodology covers situations where there are from 1 to 20 or, in some cases, many more products from a single manufacturing site for which to compute GGIs (e.g., an oil refinery, a petrochemical plant, an aluminum plant, a basic oxygen furnace, or electric arc furnace steel plant). The methodology also deals with factories that have several sources for electricity or natural gas, each with different GGIs. Finally, the methodology applies to GHG process emissions from facilities and operations that release more than a single GHG (e.g., from flaring methane (CH_4) and leakage or venting of CH_4 and CO_2 during oil and gas production, or from emission of perfluorocarbons during electrolysis of alumina ore).

Manufacturers of GHG-intensive products would be responsible to determine and report GGI values for them—they would report values both to the Regulator and to customers who purchase their covered products. Besides procedures to determine GHG emissions from facilities to pay the GHG tax, extending the analysis to products requires two separate additional procedures: first, to determine the total taxed sources of GHG emissions—CO_2e(TOT); second, to allocate taxed sources—CO_2e(TOT)—to the slate of GHG-intensive products that they create.

This section describes procedures for several approaches that we believe would be suitable for specific manufacturers in appropriate sectors. As proposed in the Policy Guidance report (footnote 2) the Regulator would be ultimately responsible for development and approval of authorized methods and procedures (as outlined here) for manufacturers to determine GGI values. In doing so, we recommend that the Regulator work closely with covered industries to develop effective and feasible methods and procedures reflecting differing circumstances in different sectors. For consistency with the WTO, procedures to determine GGI values should be justifiable based on taxed sources of GHG emissions. In addition, the approved procedure for a product must apply to both domestic and foreign manufacturers of the covered product.

The approaches proposed here to determine GGIs incorporate relevant provisions of related protocols developed by the ISO[13] and WRI/WBCSD[14] to determine the so-called carbon (or GHG) footprint of products based on life-cycle analyses (LCAs). Section 3 of the Framework report discusses in more detail the similarities and differences across those LCA-based protocols and procedures for GGIs. However, fundamentally, GGIs are not based on LCAs. Rather—to comply with WTO rules—GGI values are based on tracking cumulative sources of taxed emissions and content required to create GHG-intensive products. So, for example, LCA requirements typically would include aspects (e.g., treatment of land use change and leakage of natural gas during transport and distribution) that would be unlikely to be covered under a GHG tax. Also, many of the options allowed under the ISO and WRI/WBCSD protocols (e.g., boundaries of the analyses and criteria for verification) would be prescribed by legislation and regulation for a GHG tax with BTAs (see our Policy Guidance report; footnote 2). Like our proposal for GGIs, the ISO and WRI/WBCSD procedures cover 100 percent of emissions from fossil fuels and GHG process emissions that dominate contributions to GHG emissions allocated to products in most sectors. Consequently, results for GHG emissions from facilities and products in covered sectors would be very similar for all three procedures.

4.1. Sources Contributing to the GGI of Products

Three sources contribute to the GGI of products—$CO_2e(TOT)$—for a specific manufacturer:

- the carbon content of produced fossil resources $CO_2(CC)_{FR}$;
- GHG process emission from their own operations—$CO_2e(PE)$; and
- and taxed source of emissions from GHG-intensive products purchased from suppliers $CO_2e(SC)$.

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC) \quad (5)$$

13 ISO Greenhouse gases–Carbon Footprint of products–Requirements and guidelines for quantification, originally ISO/TS 14067:2013, superseded by ISO 14067:2018. **https://www.iso.org/standard/71206.html**

14 Bhatia, Pankaj, et al. 2011. *Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard*. WRI and WBCSD. **https://www.wri.org/publication/greenhouse-gas-protocol-product-life-cycle-accounting-and-reporting-standard**

The first two sources (see equations (3) and (4) above) are those on which the upstream GHG tax would be paid by the manufacturer. The third contribution arises from cumulative GHG taxes paid in the supply chain to create GHG-intensive products purchased and used by the manufacturer, as described in this section.

Table 3. Factors to Determine Taxed Sources of Supply Chain GHG Emissions in Sectors That Produce GHG-Intensive Products (over the period subject to the tax, e.g., a calendar year)

Symbol	Definition for a Specific Manufacturer Producing GHG-Intensive Products
$CO_2e(SC)$	Total taxed sources of GHG emissions from purchased products (tonnes CO_2e)
mp	Index *mp* denotes a specific GHG-intensive product purchased from a supplier
M_{mp}	Total by weight (tonnes) of product *mp*
GGI_{mp}	GGI of product *mp* (tonnes CO_2e per tonne of product)
me	Index *me* denotes electricity purchased from a specific supplier
EL_{me}	Total electricity (MWh) purchased from a specific supplier *me*
$GGI(EL)_{me}$	GGI of electricity from supplier *me* (tonnes CO_2e per MWh)

Table 3 defines the factors used to evaluate $CO_2e(SC)$:

$$CO_2e(SC) = \Sigma_{\textbf{products mp}} M_{mp} \times GGI_{mp} + \Sigma_{electricity\ suppliers\ me} EL_{me} \times GGI(EL)_{me} \qquad (6)$$

Supply chain contributions in equation (6) model the propagation of VATs from suppliers to the manufacturer. However, because the Framework utilizes an upstream GHG tax, it is not rebated and paid at each stage of transformation. Rather, the procedure to determine GGIs for covered products is simply one of accounting for the sources of GHG taxes paid to produce them and allocating them to the manufacturer's slate of covered products.

Under the proposed Framework, the manufacturer will have available all the information required to evaluate $CO_2e(TOT)$. The first two terms, $CO_2(CC)_{FR}$ and $CO_2e(PE)$, are those the manufacturer must evaluate to determine and pay the GHG tax. With regard to the third term, $CO_2e(SC)$, the manufacturer will know the amounts M_{mp} and EL_{me} of the products and electricity purchased from suppliers and suppliers would be required to communicate the GGI values of the products they sell to customers.

Not all manufacturers would experience contributions from all three sources in $CO_2e(TOT)$. $CO_2(CC)_{FR}$ contributes only for producers of fossil resources. Besides fossil resource producers, only a few sectors release GHG process emissions. Sectors such as electricity or oil refining that pay no upstream GHG tax would have contributions only from their supply chain, $CO_2e(SC)$. For most manufacturers, supply chain sources occur primarily from purchased electricity and commercial fuels that are used in all covered sectors, and from feedstocks and other GHG-intensive materials in sectors that use them (see examples in the Appendix and in the Modules report cited in footnote 5).

4.2. Procedures to Allocate Taxed Sources of Emissions to Covered Products

This section describes approaches to allocate taxed sources of GHG emissions—$CO_2e(TOT)$—from an entire facility or operation to its product slate. In particular, two approaches simplify the task of allocation while capturing fundamental behavior in many sectors that produce covered products. The first allocates total emissions based on the carbon content of products. Allocation by carbon content applies to products of fossil resource producers and some sectors that transform them into multiple products (e.g., refined products and olefins). The second—applicable to a variety of sectors that produce bulk commodity products such as cement, steel, and aluminum—allocates emissions to products by weight based on their content of what we refer to as the "core product" of the sector (see below). The two approaches are quite similar, since, by weight, carbon is the dominant component of hydrocarbon-based products.

These approaches to streamline allocation—without requiring a detailed engineering analysis of every step to manufacture each product (or the use of LCA-based approaches)—serve the environmental and administrative goals of reducing GHG emissions to limit risks from climate change while also limiting administrative costs and complexity. Allocation based on sources of taxed emissions also aligns with the VAT analog to develop WTO compatible BTAs by allocating all sources of taxed GHG emissions—those from operations and use of purchased covered products by the manufacturer—to create new GHG-intense products.

The following discussions also demonstrate that evaluation of supply chain emissions using GGIs requires only accounting for the GHG tax and flow of taxed sources of GHG emissions, plus information known by the manufacturer concerning covered products bought and sold (e.g., the amount and fraction by weight of raw steel in a fabricated steel product). It requires no additional analyses beyond those cited here, as, for example, would be required if evaluation of GGIs were based on LCA analyses. Evaluation of the contribution of supply chain emissions—$CO_2e(SC)$—to GGI values is simply a matter of accounting for flows of taxed sources of GHG emissions in a fashion similar to accounting for VATs.

4.2.1. Allocation Based on Carbon Content

Because CO_2 emissions of products based on fossil resources ultimately derive from the combustion (or disposal and decay) of carbon containing molecules, this approach allocates all sources that contribute to $CO_2e(TOT)$—not just those originating from embedded carbon in the products—to products in proportion to their carbon content by weight.

Table 4. Factors to Allocate Total Taxed Sources of GHG Emissions to Covered GHG-Intensive Products in Sectors Based on Carbon Content (over the period subject to the tax, e.g., a calendar year)

Symbol	Definition for a Specific Manufacturer of Products Allocated by Carbon Content
$CO_2e(TOT)$	Total taxed sources of GHG emissions (tonnes CO_2e) to be allocated to products
$<CO_2e/C>$	Average taxed sources (tonnes CO_2e per tonne of carbon) in all products
np	Index n*p* denotes a specific GHG-intensive product of the manufacturer
M_{np}	Mass of product *np* (tonnes)
M(CC)	Total mass of all products (tonnes product)
cf_{np}	Fraction by weight of the carbon (tonnes C per tonne product) in product *np*
GGI_{np}	GGI of product *np* (tonnes CO_2e per tonne of product)

Table 4 and equation (5) define the factors used in the following equations to determine GGI values based on the carbon content of products:

$$M(CC) = \Sigma_{products\ np} (cf_{np} \times M_{np}) \quad (7)$$

$$<CO_2e/C> = CO_2e(TOT) / M(CC) \quad (8)$$

$$GGI_{np} = cf_{np} \times <CO_2e/C> \quad (9)$$

Fossil Resource Producers: The GGIs for products of fossil resource producers will be dominated by their carbon content. The additional contributions from GHG process emissions and the supply chain can be allocated based on the carbon content of the product using ratios of $CO_2e(PE)$ and $CO_2e(SC)$ relative to $CO_2e(TOT)$ as follows.

Table 5. Factors to Allocate Total Taxed Sources of GHG Emissions to Covered GHG-Intensive Products of Fossil Resource Producers Based on Their Carbon Content (over the period subject to the tax, e.g., a calendar year)

Symbol	Definition for a Specific Manufacturer of Fossil Resources
R_{PE}	The ratio of total taxed process emissions to those from carbon content
R_{SC}	The ratio of total taxed emissions from the supply chain to those from carbon content

Table 5 and equations (2) through (6) and (8) define factors and relations in the following equations for the products—*np*—of fossil resource producers:

$$R_{PE} = CO_2e(PE)/CO_2(CC)_{FR}, \; R_{SC} = CO_2e(SC)/CO_2(CC)_{FR} \quad (10)$$

$$CO_2e(TOT) = CO_2(CC)_{FR} \times (1 + R_{PE} + R_{SC}) = (44/12)\, M(CC) \times (1 + R_{PE} + R_{SC}) \quad (11)$$

$$\langle CO_2e/C \rangle = (44/12) \times (1 + R_{PE} + R_{SC}) \quad (12)$$

$$GGI_{np} = cf_{np} \times (44/12) \times (1 + R_{PE} + R_{SC}) \quad (13)$$

Equation (12) contains the factor $(1 + R_{PE} + R_{SC})$, by which total taxed sources of GHG emissions in products exceeds the value (44/12) associated solely with their total carbon content. Typically, for producers of fossil resources the size of this factor ranges from a few to several percent. It varies depending on the geology and characteristics of the in-ground resource and production methods.

Refined Products: Manufacturers that transform produced fossil resources (e.g., coal, oil, and gas, as well as feedstocks and some derivative products) include contributions to $CO_2e(TOT)$ from GHG process emissions and their supply chain. Indeed, since most such manufacturers generate no GHG process emissions, contributions to $CO_2e(TOT)$ would occur solely through inputs from their supply chain.

$$CO_2e(TOT) = CO_2e(PE) + CO_2e(SC) \quad (14)$$

$$\langle CO_2e/C \rangle = [\, CO_2e(PE) + CO_2e(SC) \,] / M(CC) \quad (15)$$

$$GGI_{np} = cf_{np} \times [\, CO_2e(PE) + CO_2e(SC) \,] / M(CC) \quad (16)$$

GGI values for these products can be significantly greater than those determined solely by their carbon content. For example, based on a life-cycle analysis[15] and not an

15 *See*: Lattanzio, Richard K. 2014. *Canadian Oil Sands: Life-Cycle Assessments of Greenhouse Gas Emissions*. Washington, DC: Congressional Research Service. March 10. **https://fas.org/sgp/crs/misc/R42537.pdf**

evaluation of the GGI, on average in the United States, emissions (CO_2e) associated with production and refining of crude oil add another 20 percent (one third from production, two thirds from refining) to those from combustion of the carbon embedded in petroleum fuel. So, on average, the GGI for gasoline (or other finished products) made in the United States would be at least 20 percent higher than a value based solely on its carbon content. Production and refining of Canadian oil sands on average would add 30 percent to the GGI of refined petroleum products. GGI values for olefins and some other petrochemical products that require significant energy inputs can be far greater.

4.2.2. Allocation Based on Content of Core Product

The second generic approach in the Framework applies to sectors (such as steel, aluminum, glass, some chemicals, and cement) that use fossil energy to transform natural resources and other materials into GHG-intensive products. This approach allocates emissions to products based on their content by mass of what we refer to as the "core product" or "core products" of the sector. Creation of the core product (e.g., raw steel or unwrought aluminum) requires the vast majority of energy consumed by the manufacturer. Once produced, the core product provides the underlying material for other, more finished products that require comparatively little additional energy to fabricate.

Table 6. Factors to Determine and Allocate Total Taxed Sources of GHG Emissions to Covered GHG-Intensive Products Based on Their Content (by Weight) of the Sector's Core Product (over the period subject to the tax, e.g., a calendar year)

Symbol	Definition for a Specific Manufacturer
M(CP)	Total mass of the core product in all products (tonnes core product)
nc	Index *nc* denotes a specific GHG-intensive product of the manufacturer
M_{nc}	Mass of product *nc* (tonnes)
cp_{nc}	Fraction by weight of the core product present in product *nc*
$<CO_2e(TOT)/M(CP)>$	Average taxed sources (tonnes CO_2e per tonne of core product) in all products
GGI_{nc}	GGI of product *np* (tonnes CO_2e per tonne of product)

Table 6 and equations (4) and (6) define factors and relations that can be used in the following to determine GGI values of GHG-intensive products based on the core product in their sector:

$$M(CP) = \Sigma_{products\ np} (cp_{nc} \times M_{nc}) \quad (17)$$

$$<CO_2e(TOT)/M(CP)> = [\ CO_2e(PE) + CO_2e(SC)\ ] / M(CP) \quad (18)$$

$$GGI_{nc} = cp_{nc} \times <CO_2e(TOT)/M(CP)> \quad (19)$$

As with allocation by carbon content, this approach allocates total emissions from the entire facility, $CO_2e(TOT)$, to products in proportion to their fraction by weight (cp_{np}) of the core product. This approach does not neglect the taxed sources of emissions generated to create additional products based on the core product—it simply allocates them to products based on the amount of core product they contain. This is analogous to allocation per tonne of carbon as described above where carbon is a component of products rather than a "product" per se.

4.2.3. Allocation for the Electricity Sector

This section describes determination of GGIs for specific power plants and for providers utilizing a portfolio of generating plants. As described in the Framework, electricity producers have no GHG process emissions, so they would pay no GHG tax. Contributions to their taxed sources of supply chain emissions—$CO_2e(SC)$—occur from fuels they purchase. This results in the following simplifications in equations (1), (4), and (5) :

$$\text{GHG tax} = 0, \quad CO_2e(PE) = 0, \quad CO_2e(TOT) = CO_2e(SC) \quad (20)$$

Table 7. Factors to Determine and Allocate Total Taxed Sources of GHG Emissions from Fuels Supplied to a Manufacturer of Electricity (over the period subject to the tax, e.g., a calendar year)

Symbol	Definitions for a Power Plant Producing Electricity
$CO_2e(SC)$	Total taxed sources of GHG emissions from purchased fuels (tonnes CO_2e)
mf	Index *mf* denotes a specific GHG-intensive fuel from a supplier
M_{mf}	Total by weight (tonnes) of product *mf*
GGI_{mf}	GGI of product *mf* (tonnes CO_2e per tonne of product)
EL_{mf}	Total electricity (MWh) generated using fuel *mf*
EL(TOT)	Total electricity (MWh) generated using all fuels
<GGI(EL)>	Average GGI for the facility (tonnes CO_2e per MWh) generated using all fuels

Table 7 and equation (6) define factors and relations to determine GGI values of electricity from a specific power plant:

$$CO_2e(SC) = \Sigma_{fuels\ mf} M_{mf} \times GGI_{mf} \quad (21)$$

$$EL(TOT) = \Sigma_{fuels\ mf} EL_{mf} \quad (22)$$

$$< GGI\ (EL) > = CO_2e(SC) / EL(TOT) \quad (23)$$

Definitions in Table 7 and equation (23) account for the distinction that the GGI for electricity is measured in units (tonnes CO_2e per MWh).

These results allow for the possibility that a specific power plant may use more than one type of fuel or an electricity supplier may draw from a portfolio of generating units to determine and communicate to customers an average GGI for the electricity they purchase. The GGI value for purchased fuels will in all cases be larger than a value associated solely with its carbon content. For example, for produced coal and gas, it would be larger by the factor ($1 + R_{PE} + R_{SC}$) in equation (12) that accounts for contributions from process emissions and the supply chain to manufacture the fuel.

In Section 4.2 of the Framework report, we provide and discuss approaches to address other circumstances involving the production and use of electricity. In several sectors (e.g., petroleum refining, chemicals, and producers of pulp and paper), manufacturers may self-generate all or a portion of their electricity from on-site cogeneration of combined heat and power. In cases where a manufacturer operates under a contract to be supplied solely, or in part, with renewable electricity, they should assign GGI = 0 for electricity purchased under such contracts.

4.2.4. Other Approaches to Allocation

While the approaches described above apply to manufacturers in many sectors, circumstances may occur that require additional procedures. For example, a single facility (e.g., a petrochemical plant) may manufacture separate product lines based on different core products and with separate accounting for materials and energy supply. In such cases, the manufacturer should treat each family of products separately. As another example, based on a major energy-intensive transformation of one of the products in the family of the core product, a facility may develop another family of products that requires introducing a second core product as the basis to determine GGI values for them.

To illustrate the use of these procedures, the Appendix provides examples that evaluate GGI values for products in several hypothetical facilities using assumed, indicative inputs from supply chains and manufacturing processes to create covered products.

5. Tax and Supply Chain Interactions among Producers of Fossil Resources, Fuels, and Electricity

This section discusses interactions among producers of fossil resources (coal, oil, and gas) and producers of electricity and hydrocarbon-based commercial fuels and feedstocks (see Figure 1). In the United States, these five sectors consume as well as produce significant amounts of energy, would pay the dominant share of upstream GHG taxes, make an important (often predominant) contribution to supply chain emissions—CO_2e(SC)—in all covered sectors, and are major sources of both exports and imports.

Because it takes energy to create commercial energy from in-ground fossil resources, interactions and feedback among these sectors transfer and augment the economic impact of the upstream GHG tax paid only by producers of fossil resources. The tax directly affects the cost of resources purchased by manufacturers of commercial fuels and electricity that contribute significantly to taxed sources of supply chain emissions in all covered sectors—including producers of fossil resources. As a result, GGI values for produced fossil resources, commercial fuels, and feedstocks exceed values given solely by their carbon content, and GGI values for electricity are larger than they would be if determined based solely on CO_2 from combustion of fossil fuels. Typically, the increase ranges from a few to several percent or more (see Section 4.2 above).

Figure 1 schematically illustrates how the upstream GHG tax paid only by producers of fossil resources is transferred through flows of GHG-intensive products to and from each of the five sectors. Only producers of fossil resources pay the upstream GHG tax (Figure 1a). Although petroleum refineries and power plants pay no tax, they experience the economic impact of the tax in three main ways. First, they would pay higher prices for purchases of crude oil, coal, and natural gas (Figure 1b). Second, all sectors of the economy use electricity and commercial fuels (Figure 1c), including those sectors that produce fossil resources, thus affecting the GGI values of fossil resources and fuels used by refineries and power plants. Third, these interactions in turn affect the price of the products they sell. Figure 1d shows the flow of taxes and products among these sectors and to others.

As described in Section 3.3 of the Framework report, precisely determining the economic impact of the upstream GHG tax on the price that producers charge their customers may be an impossible task, since prices of commodity goods fluctuate from day to day for many reasons. However, it is straightforward— using GGI values— to track the propagation of taxed sources of GHG emissions through the supply chain and by the final manufacturer in a manner analogous to VATs. The procedure here follows the flow of taxed sources of emissions (carbon content of produced fuels and GHG process emissions), which are paid only once. Whereas Figure 1 depicts the flow of covered products among sectors with a single arrow from sector to sector, in the actual economy each of the five sectors (coal, oil, gas, electricity, and petroleum refining) contain hundreds to thousands of manufacturers, each producing from a few to many different products.

6. Use of Facility, Firm-Wide, Sectoral and National Averages to Determine BTAs

Ideally, GGI values for products should be evaluated using information from the manufacturer's specific operations and based on materials acquired from the manufacturer's suppliers, as described above. In some cases and for some purposes, the Framework recognizes that averages should be used for GGI values. This section discusses situations requiring the use of firm-wide, sectoral, or national averages to determine GGI values and BTAs. In particular, export rebates and import charges should be based on a firm-wide domestic average for products. Moreover, in many developing nations, national or sectoral averages likely will be required during the initial start-up of the border adjustment program.

6.1. Facility Accounting

The United States and most developed nations require GHG reporting on a facility-by-facility basis. Also, in states and nations with cap-and trade programs, caps are applied at the facility level. Similarly, the Framework proposes that manufacturers should determine GGI values for their specific facilities by determining supply chain emissions—$CO_2e(SC)$—based on GGI values from specific suppliers. For example, the GGI for purchased electricity should be based on the actual supplier of electricity to the facility (where possible), rather than some national or even regional average. Manufacturers that process raw materials (such as in-ground fossil resources or mineral ores) should determine GGI values for their products based on circumstances for the actual resource, rather than some average for the nation or sector. For example, GGI values for an oil refinery's products depend sensitively on the composition of crude oil that they process and regulatory requirements for fuels that they produce. As another example, GGI values for products from the same firm created in identical plants but using different raw materials and sources of electricity could have significantly different GGI values for otherwise like products. That is why the Framework requires manufacturers at each facility to determine GGI values for their product slate based on their specific operations and suppliers.

6.2. Export Rebates and Import Charges Based on Firm-Wide Averages

As described in Section 3.1 of the Framework, manufacturers would have an incentive to claim that products they export or import were sourced, respectively, from their most or least GHG-intensive manufacturing facilities to maximize export rebates and minimize import charges. For that reason, we recommend that both export rebates and import charges should be determined based on the average GGI value for the firm's entire domestic production of each product. In developing nations where such

information may be unavailable at the start of the program, the Regulator would determine import charges based on sectoral averages for products in that country.

6.3. Sectoral and National Averages

In developing nations, we recommend that facility and firm-wide reporting should be phased in over a period of two years for those that today do not have adequate reporting standards. In these cases, international protocols exist that could (and should) be used by firms exporting to the United States, given time to develop adequate capacity, to determine and report their GHG emissions reliably. During the start-up phase, the Regulator would determine GGI values for import charges on products exported to the United States from such nations using available United States or foreign national averages as discussed in the Estimates and Methods report (see footnote 3). Nonetheless, where they have adequate information, firms that export to the United States should be allowed to appeal such determinations if they can document lower GGI values for their products.

In Section 3 of the Estimates and Methods report, we describe a variety of sources available to the Regulator that could be used to determine import charges in the early years of the program. The Policy Guidance report (see footnote 2) also recommends that the program should provide for an appeals process that would allow appropriate entities (firms, business associations, and others) to challenge values used for import (or export) charges if they suspect that information is inaccurate, incomplete, or fraudulent. A robust appeals process will be essential to help identify such information and to promote continuous improvement in the system over the many decades that it would function to manage climate risks.

7. Uses of GGIs in Other Settings

We suggest that the GGI concept could be useful as the basis for international standards to compare GHG emissions associated with products in settings other than for BTAs. For example, GGI values allow one to compare the GHG emissions for similar products manufactured in different ways within a country or with those produced in other nations. As another example, GGI values could be used to compare impacts on products based on a hypothetical price, assumed for analysis as a GHG tax. Such comparisons could be made by assuming a common price in all nations, or by assigning different prices to each nation based on the portfolio of policies they employ or propose going forward. As described in Section 2 of the Framework report, pledges for national action under the Paris Agreement exhibit significant differences across nations, both in the stringency and types of policies that they use to limit GHG emissions. As described by Akimoto et al.[16] if nations met their pledges under the Paris

16 Akimoto, Keigo, Fuminori Sano, and Bianka Shoai Tehrani. 2017. "The analyses on the economic costs for achieving the nationally determined contributions and the expected global emission pathways." *Evolutionary and Institutional Economics Review* 14: 193–206. **https://doi.org/10.1007/s40844-016-0049-y**

Agreement solely through domestic action using a least-cost GHG tax, the required tax in 2030 would range from nearly $400 (per tonne CO_2) in some developed nations (Switzerland and Japan) to approximately $200 in the EU and $85 in the United States, to essentially zero in major rapidly growing developing nations (China and India). Such analyses could illuminate products and sectors in different nations that generate concerns and opportunities in international trade or global efforts to mitigate GHG emissions.

We began developing the Framework and GGI as the basis for WTO compliant BTAs several years ago in the context of an upstream US GHG tax as the policy to set the price for GHG emissions (US$ per tonne CO_2). Recently BA proposals have emerged in Europe and in the United States that would determine an "equivalent GHG price" based on regulatory policies rather than an explicit GHG tax. The EU's efforts to develop a Carbon Border Adjustment Mechanism[17] (CBAM) would set the price based on their Emissions Trading System (EU ETS)—a cap-and-trade system with a variable permit price that applies to GHG emissions from covered facilities not products. The Fair Transition and Competition Act[18] introduced in the US Congress would impose border adjustments based on the equivalent price of a portfolio of current and future regulations in the United States. Both these proposals provide only for import charges. We believe that such policies face major challenges both to satisfy WTO rules and to establish an objective methodology to determine the equivalent price of the regulatory policies.[19] Nonetheless, if it were possible to determine the equivalent price for GHG emissions, these proposals would also require a procedure to apply that price to the GHG emissions associated with covered products according to how they are produced. For example, GGI values for the product raw steel can differ by a factor of three or more depending on the technology—blast oxygen furnace or electric arc furnace—sources of electricity and thermal energy, and amounts of recycled steel used in the facility (see Table 1 in the Estimates and Methods report).

17 European Commission. 2021. Proposal for a Regulation of the European Parliament and of the Council—establishing a carbon border adjustment mechanism. Brussels. **https://ec.europa.eu/info/sites/default/files/carbon_border_adjustment_mechanism_0.pdf**

18 **https://www.govinfo.gov/content/pkg/BILLS-117s2378is/pdf/BILLS-117s2378is.pdf**

19 Flannery, Brian P., and Jan W. Mares. 2021. Comments to the European Union on Commission Issues Concerning a Possible Carbon Border Adjustment Mechanism (CBAM). **https://www.rff.org/publications/testimony-and-public-comments/comments-european-union-commission-carbon-border-adjustment-mechanism/**

8. Summary and Conclusions

This report describes how specific facilities and operations that manufacture covered products (those eligible for export rebates and subject to import charges) would determine GGI values for their products under our proposed Framework (see footnote 1). Determination requires information on their GHG emissions, products purchased from suppliers, and the slate of products that they create.

The United States and many other nations already require manufacturers to report information that could be used to determine their GHG taxes. US manufacturers in all covered sectors would pay the tax on GHG process emissions, if any, and producers of coal, oil, and gas would also pay the tax on CO_2 emissions latent in the carbon content of produced fossil resources.

Manufacturers would determine GGIs by allocating total taxed sources of GHG emissions (those from their operations and those from products purchased from suppliers) to their slate of covered products. Allocation requires information concerning both the manufacturer's products—essentially their amount and composition—and the amounts of and GGI values for products they purchase. This report describes how supply chain emissions and GGI values could be evaluated in a manner analogous to VATs—so that their use for border adjustments would be compatible with WTO rules. The Framework would require manufacturers of covered products to determine and communicate their GGI values to customers (and the Regulator). Consequently, a specific manufacturer would have the information required to determine total taxed sources of emissions (from both their operations and supply chain) to allocate to their product slate. Determining GGI values for their products becomes "simply" a matter of accounting for known or knowable information. The Appendix provides examples, based on illustrative hypothetical facilities, of the way that GGI values for products would be determined from known information.

The Framework proposed procedures appropriate for various types of manufacturers to allocate GHG emissions to products that they create. This report spells out in detail how they would be implemented by specific manufacturers. Procedures based on allocation by carbon content of products by weight would apply to sectors based on fossil resource production and use (e.g., for fuels, feedstocks, refined products, and olefins). Allocation by weight of what we refer to as a "core product" would apply to a number of sectors that produce bulk commodity products. For example, allocation to products in the steel and aluminum sectors would utilize their content by weight of raw steel and unwrought aluminum. The procedure would apply not only to the products created by the original manufacturer but also to downstream manufacturers that purchase them as a feedstock to fabricate more finished products. In these cases, carbon is not a major component of the product itself—contributions to the GGI occur primarily through the manufacturer's use of commercial fossil fuels and electricity and, in some cases (e.g., cement), GHG process emissions. We also describe allocation procedures for producers and distributors of electricity based on the GGIs of fuels that they utilize. Note that because of the nature of their product, GGIs for electricity are expressed as CO_2e emissions per MWh of electricity.

The procedures for GGI implement relevant aspects of internationally accepted protocols developed by the ISO and separately by WRI/WBCSD (see footnotes 12 and 13) as the basis to determine total taxed sources of GHG emissions from facilities and allocate them to their products. One of the early tasks of the Regulator under the proposed Framework would be to develop authorized procedures to be used by manufacturers for allocation. As in the development two decades ago of methods to measure GHG emissions from facilities (see the Section 3.1 of the Framework report), we recommend that the Regulator and the domestic manufacturers collaborate through public-private partnerships to develop effective and efficient procedures appropriate to the circumstances of individual sectors. Such interactions should help to clarify appropriate procedures to be used to allocate emissions from facilities to products. Collaboration would also be essential to identify and resolve circumstances that we have not yet considered, but that are likely to be discovered through more in-depth consideration of the range of manufacturing processes used to create covered products.

The summary above applies to implementation of the Framework in the United States where rigorous reporting standards for facilities already exist. In a companion report (see footnote 3) we describe procedures that could be used during a start-up phase by the US Regulator to determine initial import charges for products manufactured in countries that export covered products to the United States. These are largely based on publicly available sources of information that provide estimates of GHG emissions for raw materials for key products and national, sectoral averages for electricity and commercial fuels. We recommend that start-up approaches be phased out within two years and superseded by a requirement for determinations based on facilities and firms using internationally recognized procedures as the basis to determine GGI values for covered products. Such procedures exist and have been endorsed by international associations of many EITE industries (see Section 3.1 of the Framework report). The Framework also proposes that firms importing products to the Unites States should be allowed to appeal initial import charges determined by the Regulator if they have verifiable data at the facility and firm level on which to appeal for reduced import charges. Such information exists for some firms, even in nations that do not yet have rigorous GHG reporting standards.

We suggest that GGIs could provide the basis to develop a common international standard to assess the implications of GHG policies in different nations for products exchanged through international trade. For example, comparisons could be made based on a common hypothetical price or differing prices that reflect significant differences in ambitions and policies among nations. Finally, if legal and technical barriers to develop WTO-compliant BAs based on regulatory rather than tax policies could be overcome, the GGI concept could provide the basis to apply the equivalent price of those policies to specific covered products based on the GHG emissions required to create them.

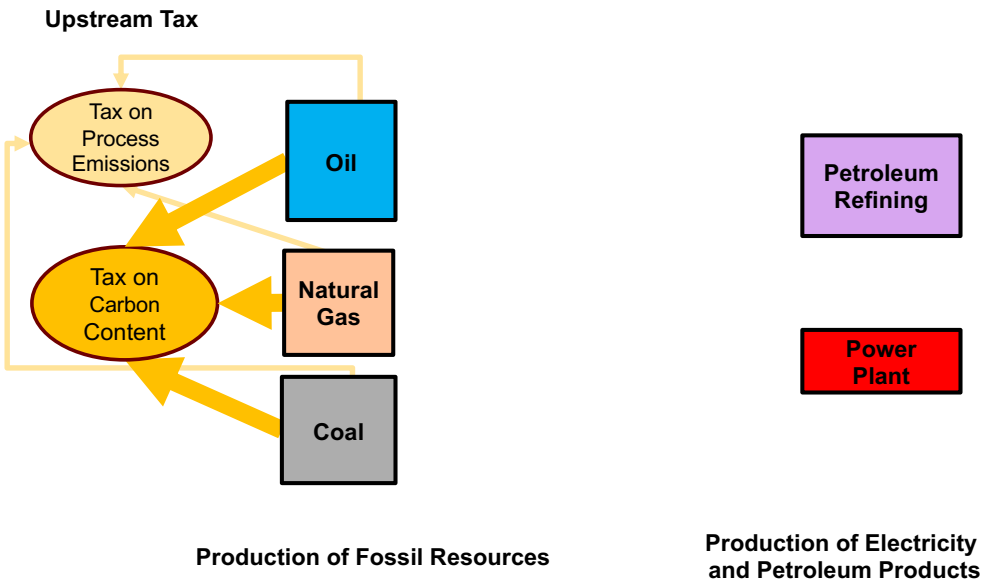
Based on the procedures described here and in the companion Estimates and Methods report (footnote 3), we believe that the administrative effort to implement the program would be significant but feasible. It would require ongoing efforts to account for many evolving factors. These would include ongoing changes in

regulations, products and processes, and the inclusion of additional countries and products over time. With these procedures, determining GGI values for products is simply a matter of accounting using information that would be known or available to the manufacturer.

Figures

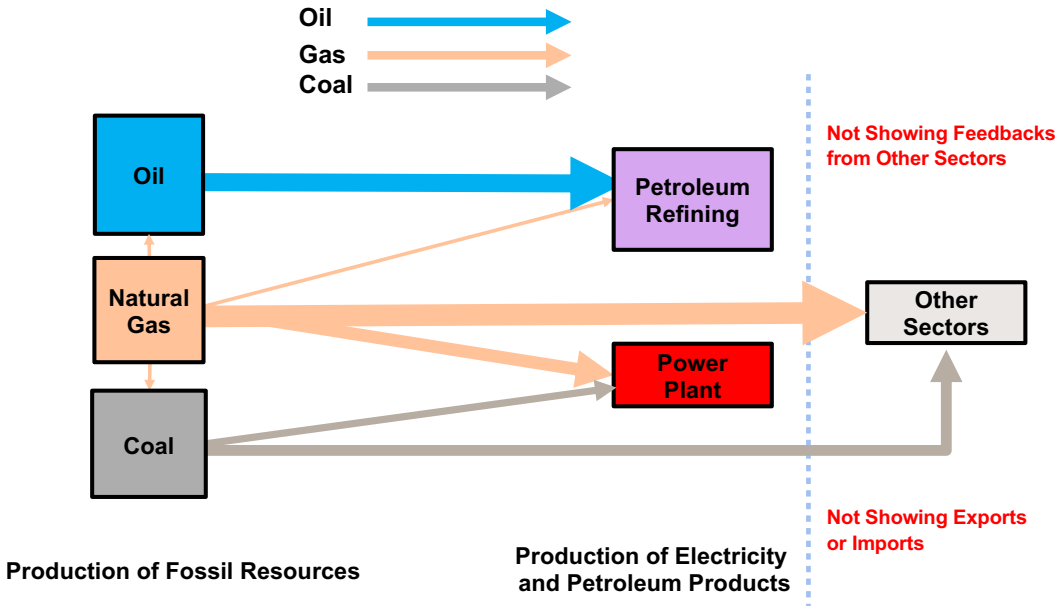
Figure 1. Upstream GHG Tax and Product Flows among Sectors That Produce Coal, Oil, Gas, Electricity, and Refined Petroleum

1a. Upstream Tax on GHG Process Emissions and Carbon Content of Produced Fossil Resources



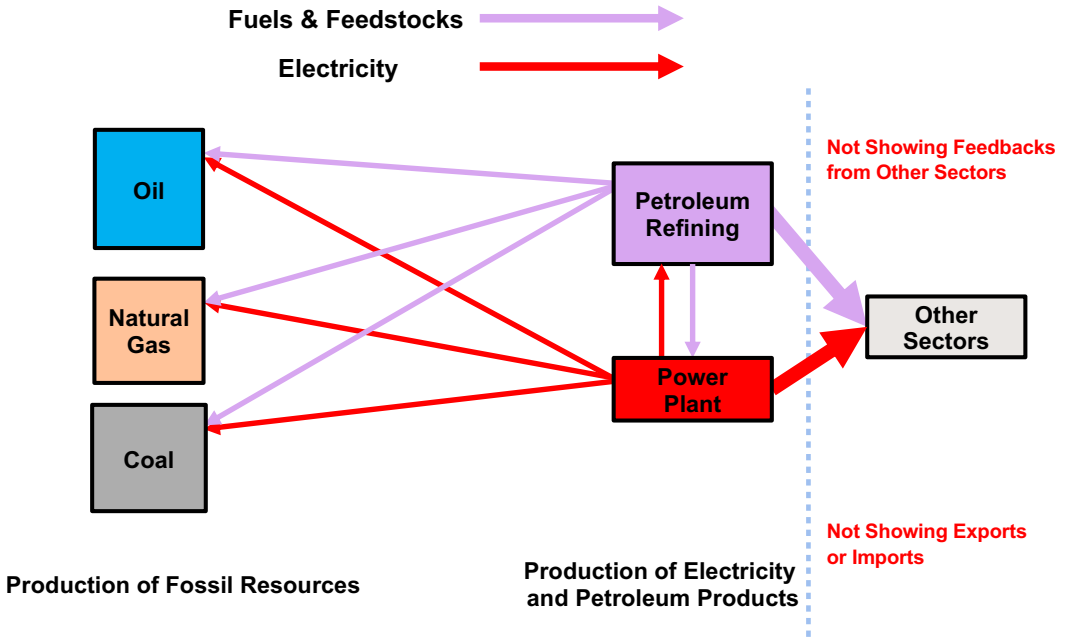
Note: Electricity and petroleum refining do not pay the GHG tax.

1b. Distribution of Produced Fossil Resources



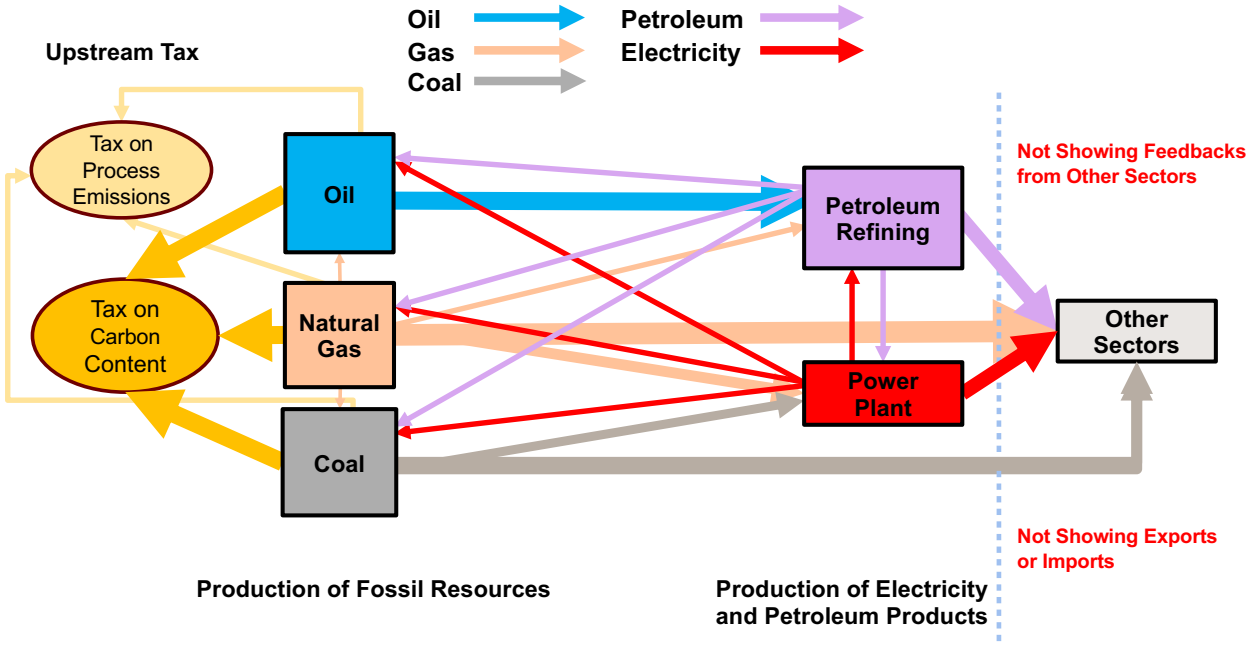
Note: For simplicity, the diagram includes only the dominant products produced—coal, natural gas, and crude oil. The schematic neglects co-produced associated gas and condensate liquids.

1c. Distribution of Electricity, Petroleum Fuels and Feedstocks



Note: All sectors of the economy, including those that produce fossil resources, utilize petroleum fuels and electricity.

1d. Upstream GHG Tax and Ensemble of Product Flows among All Five Sectors



Appendix. Determination of GGI Values for Covered Products in Several Hypothetical Manufacturing Facilities

For illustrative, hypothetical manufacturing plants in several sectors, this appendix presents examples of how the manufacturer (i.e., the entity that operates the facility) would determine GGIs for covered, GHG-intensive products that it creates. Under the proposed Framework, the manufacturer would know, or could readily obtain from suppliers, all the information required to determine GGIs. In that sense, as demonstrated in the examples, evaluation of GGI values is simply a matter of accounting for known information.

Facilities in the United States and many other nations already publicly report much of the information (e.g., GHG emissions) required to determine GGI in facilities. Other essential information (such as the amounts and properties of products produced and purchased) may not currently be publicly reported but would be known as a matter of normal business operations by the manufacturer. For example, the manufacturer would know the amounts and composition of the products that they purchase and sell, and, under the proposed Framework, suppliers would be required to provide GGI values for their products to business customers and the Regulator. However, because currently we do not have complete data for specific facilities and because we use shortened lists of products purchased and created, we refer to the examples as hypothetical plants.

The examples follow the procedures described in Section 4 above to allocate total taxed sources of GHG emissions—$CO_2e(TOT)$—to the slate of GHG-intensive products created by the facility using allocation procedures appropriate to the sector. Taxed sources of GHG emissions arise from: 1) the carbon content of produced fossil resources—coal, oil, and gas (these are not discussed in these examples but are covered in the forthcoming Modules report; see footnote 5); 2) GHG process emissions in facilities that produce them (e.g., cement in example VI); and 3) contributions from GHG-intensive products purchased in the supply chain. Typically, for manufacturers the most important supply chain sources include purchased electricity, commercial fuels used for thermal energy, and GHG-intensive feedstocks (e.g., naphtha in example plant IV and crude oil for petroleum refineries). The examples are simplified to consider only the most important sources contributing to the GGIs of covered products. Actual plants may have contributions from many more suppliers and sources, or from sources that vary in intensity throughout the year (e.g., a variety of electricity suppliers) and, in some cases, many more covered products.

The examples apply two approaches to allocate $CO_2e(TOT)$ for the facility to its covered GHG-intensive products, as described in Section 4.2. For sectors with products based on produced fossil resources (e.g., petroleum fuels and petrochemicals, allocation is based on the carbon content by weight of the product *cf* and the average CO_2e emissions per tonne of carbon for all products $<CO_2e/C>$, as defined in equations 7-10 above. For inorganic commodity products, e.g., steel or cement, allocation is based on the content by

weight of the core product *cp* and the average CO_2e emissions per tonne of core product for all products— $<CO_2e(TOT)/M(CP)>$—as defined in equations (17) through (19) above.

Values cited for amounts and GGI values of products in the supply chain are representative; however, they could be quite different in actual facilities. Table A1 lists GGI values assumed in the examples for use of fossil fuels to create thermal energy and electricity. These are based on average emissions in the United States that account only for combustion of fuels as reported by the US Energy Information Administration. As described in the forthcoming modules report (footnote 5), GGI values for fossil resources used to generate electricity and thermal energy should also account for taxed sources of GHG emissions required to extract and process the fossil resource (which could contribute anywhere from a few to several percent or more to the GGI). As well, for different plants, the required amounts of fuel and their GGI values vary considerably (by many tens of percent) depending on the properties of the resource and technologies used to generate electricity or heat, and to manufacture products. For purposes of the examples, the values in Table A1 are perfectly adequate. Note, also, that where natural gas is purchased as a source of thermal energy, we specify the amount used in units of 1,000 standard cubic feet (kscuf) and, as a representative value, that 44 kscuf would contain one tonne of natural gas. Where required for other purchased products, GGI values cited in the examples are based on determinations taken from the forthcoming modules report (footnote 5) that are representative of plausible values for US manufacturers.

GGI values determined in the examples should not be taken as definitive for products from these sectors. They can vary considerably depending on circumstances appropriate to individual facilities. The examples do illustrate that, under the Framework, manufacturers would be in possession of, or could readily obtain, all the information required to determine GGI values for covered products that they create. In practice, such determinations are simply a matter of accounting for known information concerning the products they utilize and create and taxed sources of GHG emissions from their operations.

Examples

Plant I. Based on Organic Chemicals

Plant II. Based on Steel

Plant III. Based on Concentrated Copper Ore

Plant IV. Based on Petrochemicals from Cracked Naphtha

Plant V. Based on High Impact Polystyrene

Plant VI. Based on Cement

Table A1. Reference GHG Emissions from Electricity and Thermal Energy for Fossil Fuels

Fuel	Electricity (tonne CO2e per MWh)	Thermal Energy (tonne CO_2e per MBtu)
Coal	1.00	0.0935
Oil	0.95	0.0733
Natural gas	0.42	0.0532

Source: US Energy Information Administration (US average values): **www.eia.gov/tools/faqs/faq.php?id=73&t=11** and **www.eia.gov/tools/faqs/faq.php?id=74&t=11.**

Plant I. Description and Product GGI Determination (based on two organic chemicals)

The plant manufactures two saleable products—X and Y—and a liquid waste that requires disposal. The plant utilizes three purchased raw materials—RM A, RM B, and RM C—that are reacted and then separated in a distillation unit into products X, Y, and the liquid waste (W). Pumps in the distillation unit are powered by purchased electricity. Products of the reactor are heated in the distillation process with steam derived from the combustion of natural gas.

Under the Framework, suppliers will communicate GGI values for their products to customers. So, the manufacturer will know GGI values for purchased materials and electricity.

During the covered period the manufacturer purchased and used the following:

- 100 tonnes of RM A, which had a GGI of 1.67 tonnes CO_2e/tonne RM A;
- 50 tonnes of RM B, which had a GGI of 2.13 tonnes CO_2e/tonne RM B;
- 10 tonnes of RM C, which had a GGI of 0.20 tonnes CO_2e/tonne RM C;
- 1,250 kscuf of natural gas (at 44 kscuf/t gas equals 28.4 tonne natural gas) for thermal energy; and
- 0.6 MWh of electricity, based on (40,40,10,10) percent: (renewables, natural gas, nuclear, coal).

The manufacturer produced:

- 100 tonnes of Product X, having carbon content 55 percent;
- 50 tonnes of Product Y, having carbon content 19.8 percent; and
- 10 tonnes of liquid waste, having carbon content 1 percent (which does not count as a covered product).

In this example, allocation of total taxed sources of GHG emissions will be based on the carbon content by weight—*cf*—of covered products X and Y, and the average tonnes of covered emissions per tonne of carbon—<CO_2e/C>—in all products (see equations (7) through (9)).

The GGI for covered products X and Y should be calculated as follows:

Determine the total taxed sources of GHG emissions—$CO_2e(TOT)$—to be allocated to products:

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC).$$

The plant does not produce fossil resources and has no GHG process emissions, so:

$$CO_2(CC)_{FR} = 0 \quad CO_2e(PE) = 0, \text{ so, } CO_2e(TOT) = CO_2e(SC).$$

Taxed sources of emissions from the supply chain—$CO_2e(SC)$—occur from purchased raw materials A, B, C, electricity, and natural gas for thermal energy:

Supply Chain—$CO_2e(SC)$

Purchased Electricity (600 MWh)

Source	GGI t CO_2e/MWh	%	MWh	Contribution t CO_2e
Renewable	0	40	240	0
Nuclear	0	10	60	0
Gas	0.42	40	240	100.8
Coal	1.00	10	60	60.0
		Total	**600**	**160.8**

Purchased Products

Products	GGI t CO_2e/t P	Amount t	Contribution t CO_2e
RM A	1.67	100	167.0
RM B	2.13	50	106.5
RM C	0.20	10	2.0
Natural gas	3.05	28.4	86.6
		Total	**362.1**

$CO_2e(SC)$ = (160.8 + 362.1) tonnes CO_2e =522.9 tonnes CO_2e

$CO_2e(TOT)$ = 523 tonnes CO_2e

Allocation of emissions—CO_2e(TOT)—to covered products based on carbon content: Determination of average emissions tonnes CO_2e / tonne Carbon: <CO_2e/C> in covered products X and Y.

Since it not a saleable product, W does not contribute to M(CC) the weight of covered products.

Product	Amount t	*cf*	t Carbon
X	100	0.550	55.0
Y	50	0.198	9.9
W	10	0.010	0.0

M(CC) = 64.9 tonnes Carbon
<CO_2e/C> = 8.06 tonnes CO_2e / tonne Carbon

With allocation by carbon content, GGI for product—*np*—is given by equations (7) through (9):

$GGI_{np} = cf_{np} \times$ <CO_2e/C>, where <Co_2e/C> = CO_2e(TOT)/M(CC).

Allocation by Carbon Content

Product	*cf*	GGI t CO_2e/t P	Amount t P	CO_2e t
X	0.550	4.43	100	443
Y	0.198	1.60	50	80
			Total	523

Plant II. Description and Product GGI Determination (based on steel)

The plant manufactures one saleable product, X, from three purchased raw materials and a solid waste that requires disposal. The plant utilizes raw materials—RM A, RM B, and RM C—that are mixed, reacted, rolled, and heated to dry before becoming the one saleable product (X) and the solid waste. The heaters and reactor are based on steam derived from the combustion of purchased natural gas. The machinery for mixing, pumping, and rolling are powered by purchased electricity. Raw materials B and C provide carbon and oxygen and react/combust with raw material A to convert it to product X and solid waste.

Under the Framework, suppliers will communicate GGI values for their products to customers. So, the manufacturer will know GGI values for purchased materials and electricity.

During the covered period the manufacturer purchased and used:

- 300 tonnes RM A, which had a GGI of 0.30 tonnes CO_2e/tonne RM A;
- 20 tonnes RM B, which had a GGI of 3.23 tonnes CO_2e/tonne RM B;
- 44.9 tonnes RM C, which had a GGI of 0.20 tonnes CO_2e/tonne RM C;
- 1,120 kscuf of natural gas (at 44 kscuf /tonne gas = 25.5 tonnes gas) for thermal energy; and
- 0.56 MWh of electricity, based on (40,40,10,10) percent: (renewables, natural gas, nuclear, coal).

The manufacturer produced:

- 280 tonnes of Product X; and
- 24 tonnes of solid waste (which does not count as a covered product).

In this example, allocation of total taxed sources of GHG emissions will be based on the weight of covered product X. With allocation by core product, GGI for product *np* is given by equations (17) through (19): $GGI_{np} = cp_{np} \times \langle CO_2e/CP \rangle$, where $\langle CO_2e/CP \rangle = CO_2e(TOT)/M(CP)$.

The GGI for covered product X should be calculated as follows:

Determine the total taxed sources of GHG emissions—$CO_2e(TOT)$—to be allocated to products:

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC).$$

The plant does not produce fossil resources and has no GHG process emissions, so:

$$CO_2(CC)_{FR} = 0 \quad CO_2e(PE) = 0, CO_2e(TOT) = CO_2e(SC).$$

Taxed sources of emissions from the supply chain—$CO_2e(SC)$—occur from use of raw materials A, B, C, electricity, and natural gas for thermal energy:

Purchased Electricity (560 MWh)

Source	GGI t CO_2e/t MWh	%	MWh	Contribution t CO_2e
Renewable	0	40	224	0
Nuclear	0	10	56	0
Gas	0.42	40	224	94
Coal	1.00	10	56	56
		Total	**560**	**150**

Purchased Products			
Products	GGI t CO_2e/t P	Amount t	Contribution t CO_2e
RM A	0.30	300	90
RM B	3.23	20	64.6
RM C	0.20	45	9.0
Natural Gas	3.05	25.5	77.6
		Total	**241**

CO_2e(SC) = (150 + 241) t CO_2e = 391 t CO_2e
CO_2e(TOT) = 391 tonnes CO_2e

Allocation of emissions—CO_2e(TOT)—to covered products based on weight:

Product X is the only product, so X is the core product with *cp* = 1:

Product	Weight t X	GGI t CO_2e/t X
X	280	1.40

Plant III. Description and GGI Determination (based on concentrated copper ore)

The company mines ore underground and then concentrates it at the surface from 0.007 percent to a concentration of 30 percent of metal A. Chemicals used to concentrate the metal are assumed to be small in amount and GGI value. Thus, we omit them from determination of CO_2e(TOT). The manufacturer purchased diesel fuel and electricity to operate its equipment.

Under the Framework, suppliers will communicate GGI values for their products to customers. So, the manufacturer will know GGI values for purchased materials and electricity.

During the covered period, the manufacturer purchased and used:

- 177,600 MWh of electricity based on coal with GGI = 1.0 tonnes CO_2e / MWh;
- 11,070 barrels of diesel fuel (@7.39 bbl / tonne diesel = 1497 tonnes diesel); with GGI = 3.66 tonnes CO2e / tonne diesel.

The company produced:

- 100,000 tons of concentrate containing 30 percent metal A.

In this example, allocation of total taxed sources of GHG emissions will be based on the weight of covered product A. With allocation by core product, GGI for product *np* is given by equations (17) through (19): $GGI_{np} = cp_{np} \times \langle CO_2e/CP \rangle$, where $\langle Co_2e/CP \rangle = CO_2e(TOT)/M(CP)$.

The GGI for covered product concentrate A should be calculated as follows:

Determine the total taxed sources of GHG emissions—$CO_2e(TOT)$—to be allocated to products:

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC).$$

The mine and processing plant do not produce fossil resources and have no GHG process emissions, so:

$$CO_2(CC)_{FR} = 0 \quad CO_2e(PE) = 0, CO_2e(TOT) = CO_2e(SC).$$

Taxed sources of emissions from the supply chain—$CO_2e(SC)$— from use of electricity and diesel oil:

Electricity

177,600 MWh of electricity are derived from coal with GGI = 1.00 tonnes CO_2e/MWh	
Electricity	177,600 tonnes CO_2e

Purchased Product

Product	t	GGI t CO2e/t Diesel	Contribution
Diesel	1,497	3.66	5,480 tonnes CO_2e

Total Supply Chain $CO_2e(SC)$ = 183,000 tonnes CO_2e
$CO_2e(TOT)$ = 183,000 tonnes CO_2e

Allocation of emissions—$CO_2e(TOT)$—to product A based on weight:

Since A is the only product, *cp* = 1. Determination of average emissions of t CO_2e per t Product A:

GGI (A) = $CO_2e(TOT)$ / Weight Product A = 1.83 (tonnes CO_2e / tonne A).

Plant IV. Description and GGI Determination (based on petrochemicals from cracked naphtha)

The steam cracker producing multiple petrochemicals exists within a factory that also produces other petrochemicals and some derivatives. The manufacturer converts feedstock material A into a variety of petrochemicals, using thermal energy derived from the feedstock and its products.

Under the Framework, suppliers will communicate GGI values for their products to customers. So, the manufacturer will know GGI values for purchased materials and electricity.

During the covered period the manufacturer purchased and used the following:

- 243,000 MWh of electricity based on natural gas with GGI = 0.42 tonnes CO_2e / MWh; and
- 1,000,000 tonnes of Raw Material A with GGI 3.66 tonnes CO_2e/tonne RM A.

The manufacturer produced the following:

- 324,000 tonnes of product S, with carbon content 85.7 percent;
- 168,000 tonnes of product T, with carbon content 85.7 percent;
- 50,000 tonnes of product U, with carbon content 88.9 percent;
- 104,000 tonnes of product V, with carbon content 91.3 percent;
- 62,000 tonnes of product W, with carbon content 82.8 percent;
- 40,000 tonnes of product X, with carbon content 83.7 percent;
- 12,000 tonnes of product Y, with carbon content 84.0 percent; and
- 86,000 tonnes of product Z, with carbon content 84.4 percent.

In this example, allocation of total taxed sources of GHG emissions will be based on the carbon content by weight—*cf*—of each of the covered products (S through Z) and average amount tonnes of covered emissions per tonne of carbon—$<CO_2e/C>$—in all products (see equations (7) through (9)).

The GGI for covered products S through Z should be calculated as follows:

Determine the total taxed sources of GHG emissions—$CO_2e(TOT)$—to be allocated to products:

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC).$$

The plant does not produce fossil resources and has no GHG process emissions, so:

$$CO_2(CC)_{FR} = 0 \quad CO_2e(PE) = 0, \text{ so, } CO_2e(TOT) = CO_2e(SC).$$

Taxed sources of emissions from the supply chain—$CO_2e(SC)$—occur from electricity and material A.

Electricity

243,000 MWh of electricity are derived from gas with GGI = 0.42 tonnes CO_2e/ MWh.	
Electricity	102,000 tonnes CO_2e

Raw Materials

Raw Material	t	GGI t CO2e/t A	Contribution
RM A	1,000,000	3.66	3,660,000 tonnes CO_2e

Total Supply Chain CO_2e(SC) = 3,762,000 tonnes CO_2e
CO_2e(TOT) = 3,762,000 tonnes CO_2e

Allocation of Emissions—CO_2e(TOT)—to Covered Products Based on Carbon Content

Determination of average emissions of CO_2e per tonne of carbon—<CO_2e/C>—in covered products (S through Z), where for each product *np*, $GGI_{np} = cf_{np} \times$ <CO_2e/C>, where *cf* is the fraction by weight of carbon in each product:

Product	Amount 10^6 tonne	*cf* fraction	Carbon Content 10^6 tonne
S	0.324	0.857	0.278
T	0.168	0.857	0.144
U	0.050	0.889	0.044
V	0.104	0.913	0.095
W	0.062	0.828	0.051
X	0.04	0.837	0.033
Y	0.012	0.840	0.010
Z	0.086	0.844	0.073
	Total	**0.846**	**0.729**

Total mass of carbon in products M(CC) = 0.729 million tonnes C
Average CO_2e(TOT) per tonne of carbon <CO_2e/C> = 5.164 tonnes CO_2e / tonne C

Product	GGI t CO_2e/ t Product
S	4.43
T	4.43
U	4.59
V	4.71
W	4.28
X	4.32
Y	4.34
Z	4.36

Note that the total mass of products is less than the mass of raw material A because some of the material and products were combusted for process energy.

Plant V. Description and Product GGI Determination (based on high impact polystyrene)

The plant polymerizes two raw materials (RM A and RM B) to produce plastic X. The manufacturer purchases natural gas for thermal energy and electricity to power the process steps.

Under the Framework, suppliers will communicate GGI values for their products to customers. So, the manufacturer will know GGI values for purchased materials and electricity.

During the covered period the manufacturer purchased and used the following:

- 9,640,000 tonnes of RM A, which had a GGI of 5.18 tonnes CO_2e/tonne RM A;
- 640,000 tonnes of RM B, which had a GGI of 4.90 tonnes CO_2e/tonne RM B;
- 0.870 kscuf of natural gas per tonne product X (at 44 kscuf/ tonne gas = 0.0198 tonnes gas); and
- 0.378 MWh of electricity generated from natural gas per tonne of product X.

The manufacturer produced the following:

- 9,970,000 tonnes of product X, with carbon content 91.4 percent.

In this example, allocation of total taxed sources of GHG emissions will be based on the carbon content by weight—*cf*—of covered product X and the average amount of covered emissions per tonne of carbon—<CO_2e/C>—in all products (see equations (7) through (9)).

The GGI for covered product X should be calculated as follows:

Determine the total taxed sources of GHG emissions—$CO_2e(TOT)$—to be allocated to products:

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC).$$

The plant does not produce fossil resources but has GHG process emissions, so:

$$CO_2(CC)_{FR} = 0 \quad CO_2e(PE) = 0.$$

Taxed sources of emissions from the supply chain—$CO_2e(SC)$—occur from use of electricity, raw materials, and natural gas.

Electricity

3,769,000 MWh of electricity are derived from gas with GGI = 0.42 tonnes CO_2e/MWh	
Electricity	1,583,000 tonnes CO_2e

Raw Materials

Raw Material	t	GGI t CO2e/t P	Contribution
A	9,640,000	5.18	49,900,000 tonnes CO_2e
B	640,000	4.90	3,100,000 tonnes CO_2e
Natural gas	197,000	3.05	600,000 tonnes CO_2e

Total Supply Chain—$CO_2e(SC)$—= 55,200,000 tonnes CO_2e
$CO_2e(TOT)$ = 55,200,000 tonnes CO_2e

Allocation of Emissions—$CO_2e(TOT)$—to Covered Products Based on Carbon Content

Determination of average emissions of CO_2e per tonne of carbon—$\langle CO_2e/C \rangle$—in product X:

Product	Amount 10^6 tonne	*cf* fraction	Carbon Content 10^6 tonne
X	9.97	0.914	9.11
Total	**9.97**		**9.11**

Total mass of carbon in products	M(CC) = 9.11 million tonnes C
Average $CO_2e(TOT)$ per tonne Carbon	$\langle CO_2e/C \rangle$ = 6.06 tonnes CO_2e / tonne C

Determination of GGI(X) = *cf* × $\langle CO_2e/C \rangle$ = 5.54 tonnes CO2e / tonne X

Plant VI. Description and Product GGI Determination (based on cement)

The plant produces one product (X), which contains no carbon and is made from assorted carbonates (raw material A) that, when heated, release CO_2 as a process emission. The carbonates are quarried and sold to the plant owner who processes them using purchased natural gas for heating and purchased electricity. Production of 1 tonne of product X requires: 1.01 tonnes RM A, 0.44 tonnes RM B (which has no GGI), 2.63 kscuf natural gas (at 44 kscuf / tonne natural gas = 0.060 tonnes gas), and emits 0.44 tones CO_2e / tonne RM A as GHG process emissions.

Under the Framework, suppliers will communicate GGI values for their products to customers. So, the manufacturer will know GGI values for purchased materials and electricity.

During the covered period, the manufacturer purchased and used the following:

- 101,000 tonnes of RM A, where heating RM A releases 44,440 tonnes CO_2e;
- 44,000 tonnes of RM B;
- 6,100 tonnes of natural gas; and
- 8,700 MWh of electricity generated using natural gas.

The manufacturer produced the following:

- 102,000 tonnes of product X.

In this example, allocation of total taxed sources of GHG emissions will be based on the weight of covered product X. With allocation by core product, GGI for product *np* is given by equations (17) through (19): $GGI_{np} = cp_{np} \times \langle CO_2e/CP \rangle$, where $\langle Co_2e/CP \rangle = CO_2e(TOT)/M(CP)$.

The GGI for covered product X should be calculated as follows:

Determine the total taxed sources of GHG emissions—$CO_2e(TOT)$—to be allocated to products:

$$CO_2e(TOT) = CO_2(CC)_{FR} + CO_2e(PE) + CO_2e(SC).$$

The plant does not produce fossil resources, so $CO_2(CC)_{FR} = 0$, and it does emit GHG process emissions: 0.44 tonnes CO_2e/ tonne RM A. So:

- $CO_2(CC)_{FR} = 0$, $CO_2e(PE) = 44{,}440$ tonnes CO_2e
- $CO_2e(TOT) = CO_2e(PE) + CO_2e(SC)$

Taxed sources of emissions from the supply chain—$CO_2e(SC)$—occur from use of electricity, and raw materials:

Electricity

8,700 MWh of electricity are derived from natural gas with GGI = 0.42 tonnes CO_2e/MWh.	
Electricity	3,650 tonnes CO_2e

Raw Materials

Raw Material	t	GGI	Contribution
Gas	6,100	3.05	18,600 tonnes CO2e

Total Supply Chain CO_2e(SC) **22,250 tonnes CO_2e**

Total taxed sources of emissions:

CO_2e(TOT) = 66,700 tonnes CO_2e

Allocation of emissions—CO_2e(TOT)—to covered products based on core product X:

Since X is the only product, *cp* = 1. Determination of average emissions of CO_2e per tonne of product X:

GGI (X) = CO_2e(TOT) / tonnes product X = 0.65 (tonnes CO_2e / tonne X)