U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Environmentally Extended Input-Output for Industrial Decarbonization Analysis (EEIO-IDA)

Tool Documentation and User Guide: EEIO-IDA, Version 1.0

September 2023

DRAFT REPORT

Disclaimer

Preface

The Environmentally Extended Input-Output for Industrial Decarbonization Analysis (EEIO-IDA) tool is an Excel-based tool that allows users to conduct rapid "what-if" analysis for user-defined industrial decarbonization assumptions. EEIO-IDA can be used to explore how greenhouse gas emissions accrue in industrial supply chains, including detailed Scope 1, 2, and 3 emissions breakdowns for 25 individual industrial subsectors. User-adjustable model parameters in the tool include assumptions for the U.S. electric grid mix; industry-specific fuel mix and energy requirements; non-energy-related greenhouse gas emissions releases; carbon capture; and shifts in product demand.

EEIO-IDA is a top-down, economy-scale model that represents the U.S. economy with 71 unique subsectors (25 of which are industrial subsectors). Based on nomenclature from the U.S. Bureau of Economic Analysis (BEA), the resolution of this model is considered "summary level." Many well-known EEIO models for the United States, including the U.S. Environmental Protection Agency's (EPA's) USEEIO model (Ingwersen et al. 2022; Yang et al. 2017) and Carnegie Mellon's EIO-LCA model (Chen et al. 2016; Weber et al. 2009), are resolved at the "detail level" (405 unique subsectors), although some models, such as EPA's new subnational StateIO models, are resolved at the summary level (Li et al. 2023). Higher-resolution models allow for more in-depth analysis of environmental impacts for more granular commodities; however, a major limitation is model recency. BEA's most recent release of a 405-subsector benchmark IO (input-output) dataset was for the year 2012 (more than 10 years old as of this writing). Conversely, BEA releases IO datasets at the 71-subsector level of resolution annually. To maximize data recency while also achieving a manageable model size that is well suited for rapid and intuitive scenario development, the authors selected a 71-subsector resolution for the EEIO-IDA model and tool. Future work may include a new tool resolved at the 405-subsector level.

This documentation report is primarily intended as an informational resource and user guide for the EEIO-IDA tool and is not intended as a primer on input-output models in general. Background information on IO and EEIO methods can be found elsewhere (e.g., Hendrickson et al. 1998; Matthews et al. 2014; U.S. Bureau of Economic Analysis 2011).

EEIO-IDA tool, version 1.0, is available for download from the Industrial Efficiency and Decarbonization Office (IEDO) website. Along with this open-source tool and documentation package, the following web resources are being published:

- EEIO-IDA tool overview slide deck, which provides a high-level summary of EEIO techniques and how they are implemented in the EEIO-IDA tool. This slide deck also includes baseline emissions results for all industrial subsectors for the year 2018.
- A set of individual "Industry Fact Sheets" for each industrial subsector in the EEIO-IDA model. Each Fact Sheet displays a detailed visualization of Scope 1, 2, and 3 emissions information for that subsector, based on EEIO-IDA data for the base case (for the year 2018).

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List of Acronyms

AEO	Annual Energy Outlook (EIA)
AR5	Fifth Assessment Report (of the IPCC)
ASM	Annual Survey of Manufactures (U.S. Census)
BEA	U.S. Bureau of Economic Analysis
C_2F_6	Hexafluoroethane
C_3F_8	Perfluoropropane
C_4F_8	Perfluorocyclobutane
CBECS	Commercial Buildings Energy Consumption Survey (EIA)
CCUS	Carbon capture, utilization, and storage
CF_4	Tetrafluoromethane
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	CO2-equivalent
DOE	U.S. Department of Energy
EEIO	Environmentally extended input-output
EEIO-IDA	Environmentally Extended Input-Output for Industrial Decarbonization Analysis
EIA	U.S. Energy Information Administration
EIO-LCA	Economic Input-Output Life Cycle Assessment
EPA	U.S. Environmental Protection Agency
FTA	Federal Transit Administration (U.S. Department of Transportation)
GHG	Greenhouse gas
GWP	Global warming potential
HCFC-22	Difluoromonochloromethane
HFC-134a	Tetrafluoroethane
HFC-23	Trifluoromethane
IEA	International Energy Agency
IEDO	Industrial Efficiency and Decarbonization Office (DOE)
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
MECS	Manufacturing Energy Consumption Survey (EIA)

MER	Monthly Energy Review (EIA)
MMBtu	Million British thermal units
N_2O	Nitrous oxide
NAICS	North American Industry Classification System
NF_3	Nitrogen trifluoride
PBA	Principal Building Activity
PFC	Perfluorinated compound
SF_6	Sulfur hexafluoride
TBtu	Trillion British thermal units

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1. Introduction and Tool Overview

Economic input-output models are used to study transactions of goods between industries and across economies. Environmentally extended input-output (EEIO) models leverage economic input-output approaches to examine resource flows and environmental impacts as they accrue in supply chains. These models can provide robust data for analysis of industrial decarbonization opportunities and hotspots, including consideration of Scope 1, 2, and 3 emissions. However, a limitation of many EEIO models is that the underlying energy and environmental data are typically static (and therefore provide only a "snapshot" of the model base year). Data recency and lack of adjustability can constrain the utility of these models for forward-looking analysis, especially for the rapidly evolving supply chains and energy systems that characterize the U.S. industrial sector today.

To enhance capabilities for adjustable EEIO-based scenario modeling in the industrial sector, the U.S. Department of Energy's (DOE's) Industrial Efficiency and Decarbonization Office (IEDO) has developed the *Environmentally Extended Input-Output for Industrial Decarbonization Analysis* (EEIO-IDA) tool. EEIO-IDA is designed for rapid "what-if" analysis based on user-defined industrial decarbonization assumptions. As a decision-support tool, EEIO-IDA can provide information on how and to what extent decarbonization technologies can contribute to overall emissions reductions across the industrial sector and across industrial product supply chains. The tool runs on a Microsoft Excel platform without macros, and users can develop and run custom scenarios in a few minutes.

In EEIO-IDA, the U.S. economy is represented in its entirety by 71 distinct subsectors. A complete list of these 71 subsectors with their corresponding North American Industry Classification System (NAICS) codes is given in Appendix A. Of the 71 total subsectors included in the model, 25 subsectors are *industrial* subsectors, with the remaining 46 subsectors corresponding to non-industrial commercial, transportation, and governmental activities. Because EEIO-IDA is primarily an industrial decarbonization scenario modeling tool, the EEIO-IDA user interface focuses on adjustability of assumptions within the 25 industrial subsectors, which are listed in Table 1. The 19 manufacturing subsectors are shaded in green and designated with a single asterisk (*), and the 6 non-manufacturing industrial subsectors are shaded in yellow and designated with a double asterisk (**).

Table 1. Industrial Subsectors Included in the EEIO-IDA Model, with Corresponding NAICS Codes

Farms** (111, 112)	Forestry, fishing, and related activities** (113, 114, 115)	Oil and gas extraction** (211)	Mining, except oil and gas** (212)
Support activities for mining** (213)	Construction** (23)	Wood products* (321)	Nonmetallic mineral products* (327)
Primary metals* (331)	Fabricated metal products* (332)	Machinery* (333)	Computer and electronic products* (334)
Electrical equipment, appliances, and components* (335)	Motor vehicles, bodies and trailers, and parts* (3362, 3363)	Other transportation equipment* (3364, 3365, 3366, 3369)	Furniture and related products* (337)
Miscellaneous manufacturing* (339)	Food and beverage and tobacco products* (311, 312)	Textile mills and textile product mills* (313, 314)	Apparel and leather and allied products* (315, 316)
Paper products* (322)	Printing and related support activities* (323)	Petroleum and coal products* (324)	Chemical products* (325)
Plastics and rubber products* (326)			

Through its scenario-building user interface and capabilities for dynamic updating of environmental impact vectors, the EEIO-IDA tool provides a unique sandbox for rapidly exploring the potential impacts of technology changes in the industrial sector. Supply and demand relationships between subsectors are integral to the EEIO methodology and are built into the tool. This makes the EEIO-IDA tool well suited for exploring impacts of technology changes on Scope 1, 2, and 3 emissions, including emissions accrual in complex industrial supply chains.

The scenario-building dashboard in EEIO-IDA is aligned with the four industrial decarbonization "pillars" introduced in DOE's *Industrial Decarbonization Roadmap* (Cresko et al. 2022):

- Energy efficiency,
- Industrial electrification,
- Low-carbon fuels, feedstocks, and energy sources, and
- Carbon capture, utilization, and storage (CCUS).

Dashboard elements in the EEIO-IDA user interface allow users to select and modify assumptions in individual industrial subsectors or across multiple industrial subsectors, including parameters for each industrial decarbonization pillar. Scenario assumptions for the U.S. electric grid mix are applied to all subsectors in the model. The base case for the model (which can be modified through user assumptions) reflects a 2018 base year, corresponding to the most recent U.S. Energy Information Administration (EIA) Manufacturing Energy Consumption Survey (MECS) data available as of August 2023 (the tool release date for EEIO-IDA, version 1.0). EEIO-IDA dashboard elements are summarized in Table 2, and the use of each element is further described in the next section (Using the EEIO-IDA Model and Scenario Building Tool).

Table 2. User-Adjustable Assumptions in EEIO-IDA

Dashboard Element	Industrial Decarbonization Pillar(s)	Description of User-Adjustable Parameters in the EEIO-IDA tool
U.S. Electric Grid Mix	Industrial Electrification	User can define the U.S. average electric grid makeup by specifying the **fraction of electricity generated from each of the following energy sources: coal, natural gas, petroleum, nuclear, biofuels, and renewable sources other than biofuels** (summing to 100%). Eight built-in grid scenarios are provided, ranging from the 2018 actual U.S. grid to a hypothetical net-zero 2050 grid. The user can work from a built-in scenario or create a custom one.
Biogenic Emissions Toggle	Other	User can toggle **inclusion of biogenic emissions** from combustion of biofuels in the calculation of CO_2-equivalent greenhouse gas emissions totals.
Energy Mix by Subsector	Low-Carbon Fuels, Feedstocks, and Energy Sources; Industrial Electrification	For each of the 25 industrial subsectors in the model, the user can define the energy mix by specifying the **fraction of subsector energy supplied by the following energy sources: electricity, coal, natural gas, petroleum, biofuels, and other renewables** (summing to 100%). Reference values for the 2018 base case are provided as the default and can be retained or adjusted for each subsector.
Total Energy Demand by Subsector	Energy Efficiency	For each of the 25 industrial subsectors in the model, the user can specify the **total energy requirements of the subsector** (in trillion British thermal units [TBtu]). Reference values for the year 2018 are provided as the default and can be retained or adjusted for each subsector.

Dashboard Element	Industrial Decarbonization Pillar(s)	Description of User-Adjustable Parameters in the EEIO-IDA tool
Non-Energy Emissions by Subsector	Other	For the eight industrial subsectors in the model with significant non-energy-related process emissions,[1] the user can specify the **total non-energy-related emissions of CO_2, CH_4, N_2O, and fluorinated compounds resulting from the industrial activity** (in million metric tons). Reference values for the 2018 base case are provided as the default and can be retained or adjusted for each subsector.
Carbon Capture, Utilization, and Storage by Subsector	Carbon Capture, Utilization, and Storage	For each of the 25 industrial subsectors in the model, the user can specify the **fraction of energy-related CO_2 and (for applicable subsectors) the fraction of non-energy-related CO_2 captured using CCUS technologies**. The default value for all subsectors is zero (i.e., no carbon capture). This value can be retained or adjusted for each subsector.
Demand Change by Subsector	Energy Efficiency; Other	For each of the 25 industrial subsectors in the model, and up to 4 additional commercial or governmental subsectors the user can select, the user can specify a **percent change in demand** for the subsector. A change in final product demand in one subsector will also result in upstream impacts to other subsectors that supply materials to that industry, and this dashboard element captures those impacts. The default value for all subsectors is zero (i.e., product demand is assumed by default to be the same as in 2018). This value can be retained or adjusted for each subsector.

EEIO-IDA's scenario-modeling functionality is enabled by the fuel-use vectors that comprise the foundation of the model. Rather than using the standard EEIO technique of deploying static emissions vectors (such as CO_2 emissions by subsector), EEIO-IDA deploys adjustable energy consumption vectors (electricity and fuel use by subsector) as the data foundation, from which the resultant greenhouse gas emissions are calculated dynamically. Base-case fuel use data for 2018 are drawn from primary sources such as the EIA MECS and are supplemented by vectors for non-energy-related process emissions in applicable industrial subsectors (such as Farms) to complete the foundational model accounting (see Section 3). As the user creates a decarbonization scenario, electricity and fuel consumption data auto-update in the model, and emissions (CO_2, CH_4, N_2O, and fluorinated compounds) are recalculated based on standard emissions factors for stationary and/or mobile combustion to generate results.

In results tables for each subsector, EEIO-IDA displays detailed greenhouse gas emissions projections broken down by energy/non-energy source (e.g., electricity, coal, petroleum, or non-energy process emissions), greenhouse gas (CO_2, CH_4, N_2O, and fluorinated compounds), Scope (Scope 1, 2, and 3), and subsector contributing upstream Scope 3 emissions. Scenario modeling results are presented side-by-side with 2018 base case data to illustrate the change in net greenhouse gas emissions that could result from the technology interventions implicit in the scenario assumptions.

Base-case (2018) results for all subsectors are summarized in Figure 1, illustrating the differences in sources of embodied emissions across industries. For upstream subsectors (like Farms or Primary Metals),

[1] The eight industrial subsectors with adjustable non-energy-related emissions are Farms; Oil and Gas Extraction; Mining, Except Oil and Gas; Nonmetallic Mineral Products; Primary Metals; Computer and Electronic Products; Electrical Equipment, Appliances, and Components; and Chemical Products. The remaining subsectors do not have significant non-energy-related emissions today, based on an analysis of data in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021* (U.S. Environmental Protection Agency, 2023).

most emissions are Scope 1 direct emissions and Scope 2 electricity-related emissions, whereas for downstream subsectors (like Food and Beverage and Tobacco Products or Motor Vehicles, Bodies and Trailers, and Parts), most emissions are upstream Scope 3 emissions (inherited from suppliers). This information can be used for decision-support to aid in the identification of impactful decarbonization strategies that could be applied in different subsectors and under different background conditions.

In EEIO-IDA, users can drill down to explore detailed embodied emissions breakdowns by subsector, both for the 2018 base case and for user-created decarbonization scenarios. As examples, two summary donut plots (for the Primary Metals subsector and the Motor Vehicles, Bodies and Trailers, and Parts subsector—both for the 2018 base case) are shown in Figure 2. In each diagram, the central pie chart shows the overall breakdown of emissions by Scope, while the outer donut plot further breaks down the source of these emissions by combusted fuel and non-energy emissions (for Scope 1), by biogenic and non-biogenic electricity components (for Scope 2), and by the supply chain subsectors responsible for upstream emissions (for Scope 3).

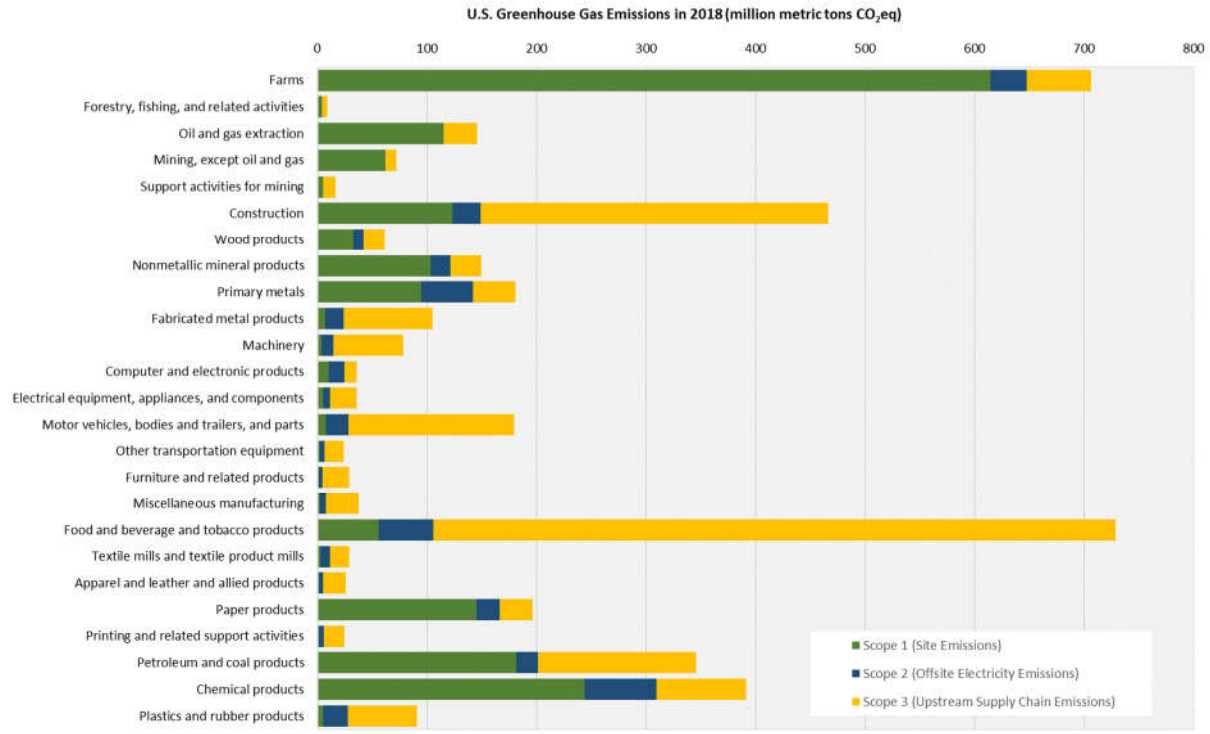

Figure 1. Summary of Scope 1, Scope 2, and upstream Scope 3 emissions for all industrial subsectors in EEIO-IDA

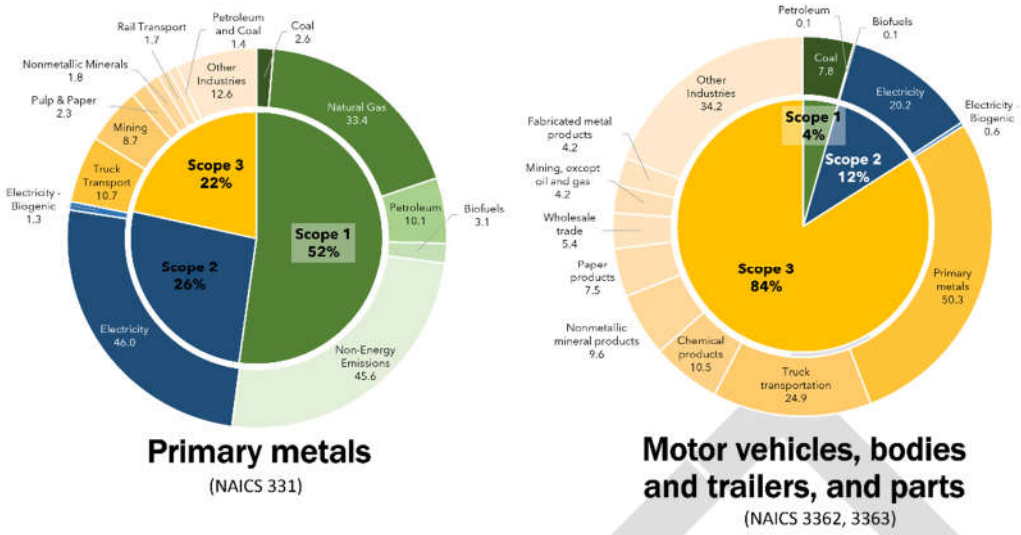

Figure 2. Embodied emissions (million metric tons of CO2-equivalent) breakdowns for products of the Primary Metals subsector (left) and the Motor Vehicles, Bodies and Trailers, and Parts subsector (right)—including Scope 1, Scope 2, and upstream Scope 3 contributions to the embodied emissions of each

As an example, consider the Motor Vehicles, Bodies and Trailers, and Parts subsector (subsequently referred to here as the Motor Vehicles subsector). As shown in Figure 2, the embodied emissions in this subsector's products are predominantly Scope 3 and arise from upstream subsectors such as Primary Metals and Truck Transportation. Some of the most effective decarbonization strategies will therefore focus on materials substitution and/or sourcing lower-emissions-intensity input materials from suppliers. In EEIO-IDA, users define decarbonization scenarios through an interface that includes the seven major dashboard elements listed in Table 2. The adjustable elements are high-level and technology-agnostic, allowing for a flexible and intuitive user experience. However, because specific technologies are not explicitly modeled in the tool, it is the user's responsibility to determine the technology improvements that will be implemented and to define suitable assumptions (such as the fuel-mix change resulting from the intervention) for a technology-focused decarbonization scenario.

For example, the user may wish to define a scenario where all paint curing at motor vehicle production facilities would be electrified. This intervention could involve multiple adjustments in the user dashboard. In the "Energy Mix" dashboard element, the user would need to make assumptions about how electrification of paint curing would impact the fractional breakdown of electricity and other fuels within the subsector. Electrification would also be likely to change the efficiency of paint curing and, therefore, the absolute quantity of energy consumed by the subsector; these assumptions would be applied in the "Total Energy Demand" dashboard element. Finally, the user might want to adjust the electric grid mix in the "U.S. Electric Grid Mix" dashboard element to quantify the effects of a forward-looking cleaner grid on emissions results.

The waterfall chart in Figure 3 shows the CO_2-equivalent emissions reductions achieved through implementation of a representative user-defined decarbonization scenario that provides a 48% reduction in cradle-to-gate emissions for the Motor Vehicles subsector. While EEIO-IDA does not currently include a built-in capability to generate waterfall charts, EEIO-IDA's detailed tabular results output can support generation of a wide range of user-created visualizations like this one.

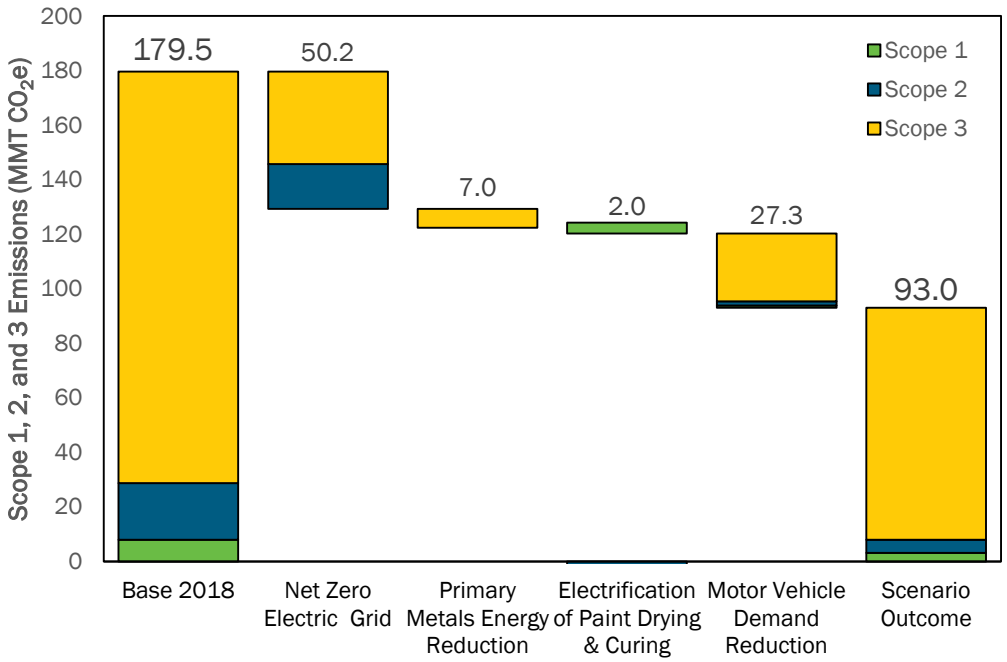

Figure 3. EEIO-IDA modeling results for a representative user-defined decarbonization scenario in the Motor Vehicles, Bodies and Trailers, and Parts subsector, showing a 48% overall reduction in greenhouse gas emissions

2. Using the EEIO-IDA Model and Scenario Building Tool

The EEIO-IDA tool includes a total of 33 tabs to contain all model data and calculations; however, most users will only need to access the first three tabs to access base case data, build decarbonization scenarios, and view detailed results within the tool:

- *Welcome* tab: a landing page that provides build information and guidance on using the tool;
- *User Interface* tab: the worksheet used to input user assumptions and build scenarios; and
- *Results* tab: the worksheet that displays tabular and graphical results from the scenario build.

The remaining tabs in the EEIO-IDA tool, all of which are hidden by default, include the underlying data and calculations required to run the model; descriptions of each tab are summarized in Appendix B. EEIO-IDA is an open-source tool, and these tabs can be unhidden if a user wishes to view or modify data or build new capabilities for the model. However, these hidden tabs are not needed for typical scenario building.

To build a scenario, users will start on the *User Interface* tab to input their model assumptions. Numeric data entries can be made in the white cells with blue text, as shown in the brief example below. The cell background color changes automatically to yellow when the default data have been modified; this serves to highlight that the user updates are being implemented in the scenario. The grey cells provide contextual information and are not meant to be edited.

Example of Data Entry Cell	**<-- User input cells have a WHITE background and BLUE default numeric values**
Example of Modified Data Cell	**<-- Cell background color changes to YELLOW when data have been modified**

The user interface includes seven different user-adjustable dashboard elements: *U.S. Electric Grid Mix*; *Biogenic Emissions Toggle*; *Energy Mix by Subsector*; *Total Energy Demand by Subsector*; *Non-Energy Emissions by Subsector*; *Carbon Capture, Utilization, and Storage by Subsector*; and *Demand Change by Subsector*. The functionality of each dashboard element in the *User Interface* tab is reviewed in this section. Throughout the model, the default parameters reflect a 2018 base case; user inputs override the 2018 data to generate the custom scenario.

Most dashboard elements include a separate data entry field for each of the 25 industrial subsectors in the model, and users can adjust numeric values for one or more subsectors in a single scenario. Exceptions include the assumptions for U.S. electric grid mix and biogenic emissions, which apply by default to all 71 subsectors (industrial and non-industrial) in the model. The *Demand Change by Subsector* element includes the capability to adjust all 25 industrial subsectors plus up to four additional non-industrial subsectors. The *Non-Energy Emissions by Subsector* element includes the capability to adjust data only for the eight industrial subsectors with significant non-energy-related emissions (see footnote on page 11).

2.1. U.S. Electric Grid Mix Dashboard Element

In the *U.S. Electric Grid Mix* dashboard element, the user can define the U.S. average electric grid generation mix by working from a built-in scenario or creating a custom scenario. These assumptions apply to electricity use for all 71 subsectors (industrial and non-industrial) in the model. EEIO-IDA includes values for eight built-in grid scenarios that the user can choose from if desired:

- **U.S. 2018 (EIA MER).** This option represents the 2018 actual grid mix in the United States, based on data reported by EIA in the *Monthly Energy Review* (MER) (U.S. Energy Information Administration 2023c). This grid mix is the default setting, based on the 2018 base year of the EEIO-IDA tool and data.

- **U.S. 2022 (EIA MER).** This option represents the 2022 actual grid mix in the United States (the most recent available data year), based on data reported in the MER (U.S. Energy Information Administration 2023c).
- **U.S. 2030, Base Case Scenario (EIA AEO).** This option represents the *projected* grid mix for the year 2030 specified in EIA's *Annual Energy Outlook* (AEO) 2023 reference case (U.S. Energy Information Administration 2023a). AEO's reference case reflects EIA's baseline (business-as-usual) assumptions for economic growth, policy, oil and gas supply, and technology cost.
- **U.S. 2050, Base Case Scenario (EIA AEO).** This option represents the *projected* grid mix for the year 2050 specified in the AEO 2023 reference case (U.S. Energy Information Administration 2023a).
- **U.S. 2030, Low Zero-Carbon Technology Cost Scenario (EIA AEO).** This option represents the *projected* grid mix for the year 2030 specified in the AEO 2023 low zero-carbon technology cost case (U.S. Energy Information Administration 2023a). AEO's low zero-carbon technology cost case includes accelerated commercialization for zero-emission electricity-generating technologies including renewables and nuclear (compared to the reference case) but does not achieve net-zero emissions by 2050.
- **U.S. 2050, Low Zero-Carbon Technology Cost Scenario (EIA AEO).** This option represents the *projected* grid mix for the year 2050 specified in the AEO 2023 low zero-carbon technology cost case (U.S. Energy Information Administration 2023a).
- **World 2030, Net Zero by 2050 Scenario (IEA).** This option represents the *projected* grid mix for the year 2030 specified in the International Energy Agency's (IEA's) *Net Zero by 2050—A Roadmap for the Global Energy Sector* (Bouckaert et al. 2021). As a net-zero scenario, this IEA scenario is significantly more aggressive in terms of decarbonizing the electric grid than EIA's low zero-carbon technology cost scenario.
- **World 2050, Net Zero by 2050 Scenario (IEA).** This option represents the *projected* grid mix for the year 2050 specified in IEA's *Net Zero by 2050—A Roadmap for the Global Energy Sector* (Bouckaert et al. 2021).

Since EEIO-IDA uses a 2018 base year, the U.S. 2018 grid mix is selected by default. To create a custom grid scenario, the user can overwrite the default data in the user input row to specify a custom breakdown of electricity generated from each source (coal, natural gas, petroleum, nuclear, biofuels, and other renewables). Electricity generation from all sources must sum to 100%, and a green checkmark appears in the Total column when the entered values sum to 100%, as shown in the screenshot of Figure 4. To use a built-in scenario, the user can simply copy the values in the row of the desired built-in grid scenario and paste the values (Paste Special > Paste Values) into the user input row.

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Environmentally Extended Input-Output for Industrial Decarbonization Analysis

EEIO-IDA User Interface

User instructions: modify model assumptions by editing cells with a WHITE background and BLUE text: Example <-- User input cells with WHITE background and BLUE numeric values

U.S. Electric Grid Mix Assumptions (Industrial Electrification Pillar)

Assumed Electric Grid Mix (U.S. Average)		Coal	Natural Gas	Petroleum	Nuclear	Biofuels	Renewables (except bio)	Total (100%)
USER INPUT VALUES (% net electricity generation)		28.4%	34.1%	0.6%	20.1%	0.8%	15.8%	100%
REFERENCE SCENARIOS (% net electricity generation)	U.S. 2018 (EIA MER)	28.4%	34.1%	0.6%	20.1%	0.8%	15.8%	100%
	U.S. 2022 (EIA MER)	20.1%	38.9%	0.5%	18.9%	0.7%	20.9%	100%
	U.S. 2030, Base Case Scenario (EIA AEO)	8.4%	22.6%	0.2%	18.4%	0.0%	50.4%	100%
	U.S. 2050, Base Case Scenario (EIA AEO)	5.0%	19.4%	0.1%	12.9%	0.0%	62.6%	100%
	U.S. 2030, Low Zero-Carbon Test Cost Scenario (EIA AEO)	7.0%	20.0%	0.2%	18.4%	0.0%	54.5%	100%
	U.S. 2050, Low Zero-Carbon Tech Cost Scenario (EIA AEO)	0.7%	7.7%	0.1%	14.2%	0.0%	77.3%	100%
	World 2030, Net Zero by 2050 Scenario (IEA)	8.9%	16.8%	1.0%	9.9%	4.0%	59.4%	100%
	World 2050, Net Zero by 2050 Scenario (IEA)	1.0%	1.0%	0.0%	8.0%	5.0%	85.0%	100%

Figure 4. Screenshot of the U.S. Electric Grid Mix dashboard element in the EEIO-IDA user interface

2.2. Biogenic Emissions Toggle

In the single-selection *Biogenic Emissions Toggle* (Figure 5), the user can toggle on or off the inclusion of biogenic emissions (from combustion of biofuels) in final greenhouse gas emissions results. When the user selects yes ("Y"), CO_2-equivalent emissions from combustion of biofuels are included in greenhouse gas totals in scenario results. When the user selects no ("N"), biofuels are treated as zero-emissions energy sources, and greenhouse gas emissions from biogenic sources are excluded from totals. This toggle selection is global and applies to all subsectors in the model. For subsector decarbonization strategies (or electric grid scenarios) that include significant reliance on biofuels, this selection can significantly impact overall results. Greenhouse gas totals in results will be higher when emissions from combustion of biofuels are included through a yes ("Y") selection in this toggle.

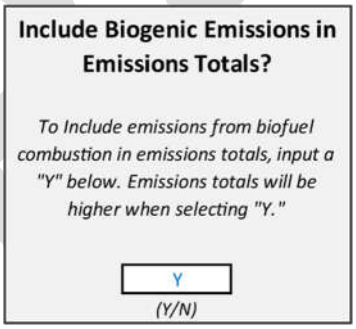


Figure 5. Screenshot of the Biogenic Emissions Toggle in the EEIO-IDA user interface

2.3. Energy Mix by Subsector Dashboard Element

In the *Energy Mix by Subsector* dashboard element, the user can define the industrial energy mix (percentage of energy supplied by electricity, coal, natural gas, petroleum, biofuels, and other renewables) for each of the 25 industrial subsectors in the model, as shown in the screenshot of Figure 6. Fuel breakdowns in this section reflect energy consumption on-site at industrial facilities and should not include breakdowns of fuels consumed to produce electricity off-site or fuels consumed to produce input materials. Reference data provided to the right of the data input table (not shown in the screenshot) reflect the actual 2018 energy breakdowns, which are largely drawn from the EIA MECS for the manufacturing subsectors (see Section 3 for more details). These 2018 data are also the default data for user scenarios.

Energy Mix Adjustments by Subsector (Low-Carbon Fuels and Industrial Electrification Pillars)

NAICS Code(s)	*Nonmanufacturing Industries*	USER INPUT VALUES (%) Electricity	Coal	Natural Gas	Petroleum	Biofuels	Renewables (except bio)	Total (100%)
111, 112	Farms	24.3%	0.0%	17.5%	58.2%	0.0%	0.0%	100.0%
113, 114, 115	Forestry, fishing, and related activities	6.2%	1.2%	13.3%	79.3%	0.0%	0.0%	100.0%
211	Oil and gas extraction	0.0%	0.0%	80.5%	19.5%	0.0%	0.0%	100.0%
212	Mining, except oil and gas	0.0%	1.6%	41.2%	57.2%	0.0%	0.0%	100.0%
213	Support activities for mining	0.0%	0.0%	16.3%	83.7%	0.0%	0.0%	100.0%
23	Construction	10.5%	0.0%	0.8%	88.7%	0.0%	0.0%	100.0%

NAICS Code(s)	*Manufacturing Industries*	USER INPUT VALUES (%) Electricity	Coal	Natural Gas	Petroleum	Biofuels	Renewables (except bio)	Total (100%)
321	Wood products	18.5%	0.0%	17.4%	4.2%	59.9%	0.0%	100.0%
327	Nonmetallic mineral products	15.9%	23.3%	42.9%	16.7%	1.2%	0.0%	100.0%
331	Primary metals	30.8%	2.1%	51.0%	12.5%	3.7%	0.0%	100.0%
332	Fabricated metal products	49.0%	0.0%	49.0%	1.9%	0.1%	0.0%	100.0%
333	Machinery	55.2%	0.0%	40.7%	4.0%	0.2%	0.0%	100.0%
334	Computer and electronic products	71.5%	0.0%	28.2%	0.2%	0.1%	0.0%	100.0%
335	Electrical equipment, appliances, and components	50.0%	0.0%	48.7%	1.3%	0.0%	0.0%	100.0%
3362, 3363	Motor vehicles, bodies and trailers, and parts	52.6%	0.0%	46.5%	0.7%	0.2%	0.0%	100.0%
3364, 3365, 3366, 3369	Other transportation equipment	48.6%	0.0%	47.7%	2.8%	0.9%	0.0%	100.0%
337	Furniture and related products	50.0%	0.0%	46.9%	3.1%	0.0%	0.0%	100.0%
339	Miscellaneous manufacturing	55.9%	0.0%	42.4%	1.7%	0.0%	0.0%	100.0%
311, 312	Food and beverage and tobacco products	29.9%	3.9%	59.5%	2.5%	4.3%	0.0%	100.0%
313, 314	Textile mills and textile product mills	56.0%	1.2%	40.5%	2.1%	0.3%	0.0%	100.0%
315, 316	Apparel and leather and allied products	50.0%	0.0%	50.0%	0.0%	0.0%	0.0%	100.0%
322	Paper products	8.7%	2.7%	28.6%	2.0%	58.0%	0.0%	100.0%
323	Printing and related support activities	57.6%	0.0%	40.7%	1.7%	0.0%	0.0%	100.0%
324	Petroleum and coal products	5.3%	0.0%	32.0%	61.8%	0.9%	0.0%	100.0%
325	Chemical products	14.4%	3.2%	67.2%	14.3%	0.9%	0.0%	100.0%
326	Plastics and rubber products	65.6%	0.0%	32.4%	2.0%	0.0%	0.0%	100.0%

Figure 6. Screenshot of the Energy Mix by Subsector dashboard element in the EEIO-IDA user interface

2.4. Total Energy Demand by Subsector Dashboard Element

In the *Total Energy Demand by Subsector* dashboard element, the user can specify the total energy requirement in trillion British thermal units (TBtu) for each of the 25 industrial subsectors in the model, as shown in Figure 7. The fuel breakdown percentages specified in the *Energy Mix by Subsector* element apply to the energy totals specified in this dashboard element. The reference data shown to the right of the data input table reflect the actual 2018 energy consumption totals (drawn from the MECS and other sources, as further described in Section 3 and Appendix C). These 2018 data are also the default data for user scenarios.

Total Energy Demand Adjustments by Subsector (Energy Efficiency Pillar)

		USER INPUT VALUES (TBtu)		REF. VALUES (2018, TBtu)
NAICS Code(s)	*Nonmanufacturing Industries*	Total	% of 2018 Reference Consumption	2018 Total
111, 112	Farms	1,083	1	1,083
113, 114, 115	Forestry, fishing, and related activities	57	1	57
211	Oil and gas extraction	332	1	332
212	Mining, except oil and gas	311	1	311
213	Support activities for mining	78	1	78
23	Construction	1,763	1	1,763

		USER INPUT VALUES (TBtu)		REF. VALUES (2018, TBtu)
NAICS Code(s)	*Manufacturing Industries*	Total	% of 2018 Reference Consumption	2018 Total
321	Wood products	384	1	384
327	Nonmetallic mineral products	811	1	811
331	Primary metals	1,252	1	1,252
332	Fabricated metal products	253	1	253
333	Machinery	145	1	145
334	Computer and electronic products	106	1	106
335	Electrical equipment, appliances, and components	76	1	76
3362, 3363	Motor vehicles, bodies and trailers, and parts	228	1	228
3364, 3365, 3366, 3369	Other transportation equipment	107	1	107
337	Furniture and related products	32	1	32
339	Miscellaneous manufacturing	59	1	59
311, 312	Food and beverage and tobacco products	1,216	1	1,216
313, 314	Textile mills and textile product mills	84	1	84
315, 316	Apparel and leather and allied products	6	1	6
322	Paper products	2,002	1	2,002
323	Printing and related support activities	59	1	59
324	Petroleum and coal products	3,366	1	3,366
325	Chemical products	3,487	1	3,487
326	Plastics and rubber products	256	1	256

Figure 7. Screenshot of the Total Energy Demand by Subsector dashboard element in the EEIO-IDA user interface

2.5. Non-Energy Emissions by Subsector Dashboard Element

For the eight industrial subsectors with significant non-energy (process) emissions, the user can specify the total quantity of four non-energy greenhouse gas emissions (CO_2, CH_4, N_2O, and fluorinated compounds) in the *Non-Energy Emissions by Subsector* dashboard element. Values are specified in physical units (million metric tons of greenhouse gas released) for each subsector, as shown in Figure 8. The subsectors with adjustable non-energy-related emissions are Farms; Oil and Gas Extraction; Mining, Except Oil and Gas; Nonmetallic Mineral Products; Primary Metals; Computer and Electronic Products; Electrical Equipment, Appliances, and Components; and Chemical Products.

The remaining subsectors do not have significant non-energy-related emissions today, based on an analysis of data in the U.S. Environmental Protection Agency's (EPA's) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021* (U.S. Environmental Protection Agency 2023).The reference data shown on the right-hand side of the dashboard element (not shown in the screenshot) reflect EPA data for the year 2018 and include a short description of the key emissions sources for each subsector. For example, non-energy emissions for the Farms subsector arise from enteric fermentation, fertilizer use, manure management, and field burning, whereas the non-energy emissions for the Nonmetallic Mineral Products subsector are mostly process CO_2 emissions released during cement and lime production.

Non-Energy Emissions Assumptions by Subsector (Process Approaches)

NAICS Code(s)	*Nonmanufacturing Industries with Non-Energy Emissions*	*USER INPUT VALUES (million metric tons of emission)* CO2	CH4	N2O	Fluorinated Gases	Total CO2 Eq.	% of 2018 Reference Emissions
111, 112	Farms	7.4	10.2	1.2	0.00000	612	100%
113, 114, 115	Oil and gas extraction	0.0	5.3	0.0	0.00000	148	100%
212	Mining, except oil and gas	3.1	2.1	0.0	0.00000	62	100%

NAICS Code(s)	*Manufacturing Industries with Non-Energy Emissions*	*USER INPUT VALUES (million metric tons of emission)* CO2	CH4	N2O	Fluorinated Gases	Total CO2 Eq.*	% of 2018 Reference Emissions
327	Nonmetallic mineral products	53.4	0.0	0.0	0.00000	53	100%
331	Primary metals	47.7	0.0	0.0	0.00031	52	100%
334	Computer and electronic products	0.0	0.0	0.0	0.00044	6	100%
335	Electrical equipment, appliances, and components	0.0	0.0	0.0	0.00022	3	100%
325	Chemical products	45.7	0.0	0.1	0.00022	68	100%

Figure 8. Screenshot of the Non-Energy Emissions by Subsector dashboard element in the EEIO-IDA user interface

2.6. Carbon Capture, Utilization, and Storage by Subsector Dashboard Element

In the *Carbon Capture, Utilization, and Storage by Subsector* dashboard element, the user can specify the fraction of energy-related and (for applicable sectors) non-energy-related CO_2 captured using CCUS technologies for each of the 25 industrial subsectors in the model, as shown in the screenshot of Figure 9. The default for all subsectors is zero (i.e., no carbon capture).

Assumptions for Emissions Reductions Through Carbon Capture, Utilization, and Storage (CCUS Pillar)

NAICS Code(s)	*Nonmanufacturing Industries*	*USER INPUT VALUES (% captured)* % CO2 Captured - Combustion	% CO2 Captured - Process	*REFERENCE VALUES (no capture)* % CO2 Captured - Combustion	% CO2 Captured - Process
111, 112	Farms	0%	0%	0%	0%
113, 114, 115	Forestry, fishing, and related activities	0%		0%	
211	Oil and gas extraction	0%	0%	0%	0%
212	Mining, except oil and gas	0%	0%	0%	0%
213	Support activities for mining	0%		0%	
23	Construction	0%		0%	

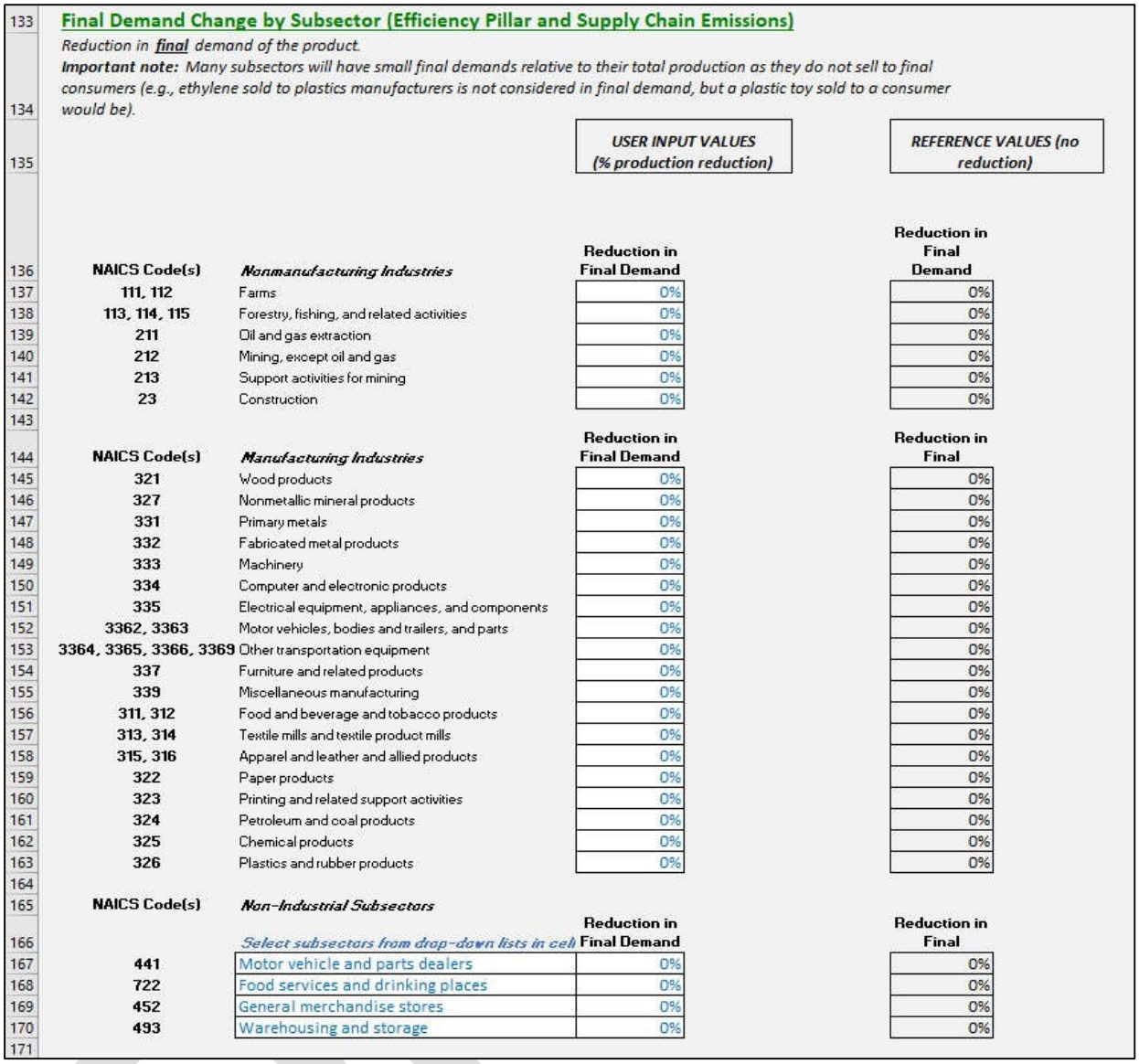
NAICS Code(s)	*Manufacturing Industries*	% CO2 Captured - Combustion	% CO2 Captured - Process	% CO2 Captured - Combustion	% CO2 Captured - Process
321	Wood products	0%		0%	
327	Nonmetallic mineral products	0%	0%	0%	0%
331	Primary metals	0%	0%	0%	0%
332	Fabricated metal products	0%		0%	
333	Machinery	0%		0%	
334	Computer and electronic products	0%	0%	0%	0%
335	Electrical equipment, appliances, and components	0%	0%	0%	0%
3362, 3363	Motor vehicles, bodies and trailers, and parts	0%		0%	
3364, 3365, 3366, 3369	Other transportation equipment	0%		0%	
337	Furniture and related products	0%		0%	
339	Miscellaneous manufacturing	0%		0%	
311, 312	Food and beverage and tobacco products	0%		0%	
313, 314	Textile mills and textile product mills	0%		0%	
315, 316	Apparel and leather and allied products	0%		0%	
322	Paper products	0%		0%	
323	Printing and related support activities	0%		0%	
324	Petroleum and coal products	0%		0%	
325	Chemical products	0%	0%	0%	0%
326	Plastics and rubber products	0%		0%	

Figure 9. Screenshot of the Carbon Capture, Utilization, and Storage by Subsector dashboard element in the EEIO-IDA user interface

2.7. Demand Change by Subsector Dashboard Element

The final dashboard element, shown in Figure 10, is *Demand Change by Subsector*. Here the user can specify a percent reduction in final product demand for each of the 25 industrial subsectors in the model, plus up to four additional subsectors of the user's choice. Changes made in this section impact not only energy use in the subsector with the demand change, but also demand in upstream subsectors because the overall volume of goods produced is assumed to be reduced—resulting in a proportional reduction to input materials produced by suppliers and thus the production-related greenhouse gas emissions from those industries. For example, a decrease in demand for the Motor Vehicles, Bodies and Trailers, and Parts subsector would result in a decrease in emissions of all types from upstream industries such as Primary Metals and Truck Transportation, among others.

One important note for this dashboard element is that adjustments apply to the "final demand" of an industry's products—which only includes production sold to household consumers, investors, and governments. It does not include production of intermediaries sold to other manufacturers. Some industries have relatively low final demands relative to their total production as they do not sell to final consumers. For example, ethylene sold to a plastics manufacturer would not be considered final demand; but a plastic toy sold to a consumer would be.



Final Demand Change by Subsector (Efficiency Pillar and Supply Chain Emissions)

*Reduction in **final** demand of the product.*

***Important note:** Many subsectors will have small final demands relative to their total production as they do not sell to final consumers (e.g., ethylene sold to plastics manufacturers is not considered in final demand, but a plastic toy sold to a consumer would be).*

			USER INPUT VALUES (% production reduction)	REFERENCE VALUES (no reduction)
NAICS Code(s)	*Nonmanufacturing Industries*		Reduction in Final Demand	Reduction in Final Demand
111, 112	Farms		0%	0%
113, 114, 115	Forestry, fishing, and related activities		0%	0%
211	Oil and gas extraction		0%	0%
212	Mining, except oil and gas		0%	0%
213	Support activities for mining		0%	0%
23	Construction		0%	0%
NAICS Code(s)	*Manufacturing Industries*		Reduction in Final Demand	Reduction in Final
321	Wood products		0%	0%
327	Nonmetallic mineral products		0%	0%
331	Primary metals		0%	0%
332	Fabricated metal products		0%	0%
333	Machinery		0%	0%
334	Computer and electronic products		0%	0%
335	Electrical equipment, appliances, and components		0%	0%
3362, 3363	Motor vehicles, bodies and trailers, and parts		0%	0%
3364, 3365, 3366, 3369	Other transportation equipment		0%	0%
337	Furniture and related products		0%	0%
339	Miscellaneous manufacturing		0%	0%
311, 312	Food and beverage and tobacco products		0%	0%
313, 314	Textile mills and textile product mills		0%	0%
315, 316	Apparel and leather and allied products		0%	0%
322	Paper products		0%	0%
323	Printing and related support activities		0%	0%
324	Petroleum and coal products		0%	0%
325	Chemical products		0%	0%
326	Plastics and rubber products		0%	0%
NAICS Code(s)	*Non-Industrial Subsectors*			
		Select subsectors from drop-down lists in cell	Reduction in Final Demand	Reduction in Final
441		Motor vehicle and parts dealers	0%	0%
722		Food services and drinking places	0%	0%
452		General merchandise stores	0%	0%
493		Warehousing and storage	0%	0%

Figure 10. Screenshot of the Demand Change by Subsector dashboard element in the EEIO-IDA user interface

2.8. Scenario Building in EEIO-IDA

In EEIO-IDA, industrial decarbonization scenarios are built by modifying assumptions related to energy and fuel consumption, non-energy emissions, CCUS, and product demand through the user interface. A user can choose to build a scenario focusing on a single subsector by modifying assumptions in that subsector alone—or to create a scenario involving modifications to multiple subsectors, up to all 25 industrial subsectors in the model. Once the user has specified the scenario assumptions in the user interface, the model will automatically recalculate the Scope 1, Scope 2, and upstream Scope 3 emissions and compare results to the 2018 model base case.

The streamlined user inputs in EEIO-IDA make this tool intuitive and quick to use. It takes only a few minutes to input assumptions and build a scenario, and results generate immediately. While the tool is technology-agnostic in that specific technologies are not built into the tool itself, the tool can be leveraged to explore the potential impacts of specific technology interventions on the greenhouse gas emissions of a subsector, a supply chain, or of the entire U.S. economy. As discussed earlier, the user is responsible for

the "homework" of defining appropriate assumptions (such as energy and fuel consumption changes) for technology-focused scenarios. Once assumptions are set, the EEIO-IDA tool can generate detailed results that can help the user to better understand the potential impacts (including potential supply-chain impacts) of technology interventions and to support decision-making. One example scenario for the Motor Vehicles, Bodies and Trailers, and Parts subsector was laid out in the prior section (see page 14); additional scenarios are included in a recent paper by the authors (Gause et al. 2023).

Since EEIO-IDA operates essentially as an input/output calculator tool, model adjustments can be made quickly and easily to explore the relative impact of different types of changes. This functionality, rare in an input-output model, makes EEIO-IDA well suited for hotspot detection in the U.S. supply chain. The tool's rapid results generation also allows for serialization, supporting studies that require sensitivity analysis or parameterization/design of experiments with multiple runs of the model. EEIO-IDA can also be used to produce data for waterfall plots (such as the one shown in Figure 3) by implementing multiple interventions one by one and recording results after each newly added intervention.

2.9. Results and Data Visuals

Once the user has entered all desired assumptions for the scenario in the *User Interface* tab, the user can move to the *Results* tab to view results for the scenario, including a comparison to the 2018 model base case. At the top of the *Results* tab is the *Emissions Overview* display, which shows detailed results for the industrial sector as a whole with emissions broken down by combusted fuel and by greenhouse gas (Figure 11).

U.S. DEPARTMENT OF ENERGY (DOE) OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY (EERE)

Environmentally Extended Input-Output for Industrial Decarbonization Analysis

Emissions Overview

	User Case	Base Case	Units
Total Industrial Sector Emissions	2,256	2,256	MMT CO2e
Industrial Sector Emissions from Energy Production	1,371	1,371	MMT CO2e
Industrial Sector Emissions from Non-Energy Producing Sources	885	885	MMT CO2e
Industrial Sector Emissions by Fuel Type:			
Electricity	406	406	MMT CO2e
Electricity - Biogenic	11	11	MMT CO2e
Coal	43	43	MMT CO2e
Natural Gas	381	381	MMT CO2e
Petroleum	379	379	MMT CO2e
Biofuels	150	150	MMT CO2e
Industrial Sector Emissions by Greenhouse Gas, All Sources:			
CO2	1,513	1,513	MMT CO2
CH4	15	15	MMT CH4
N2O	1.2	1.2	MMT N2O
Fluorinated Gases	1.3	1.3	kMT SF6e
Industrial Sector Emissions by Greenhouse Gas, All Sources CO2e:			
CO2	1,513	1,513	MMT CO2e
CH4	414	414	MMT CO2e
N2O	313	313	MMT CO2e
Fluorinated Gases	17	17	MMT CO2e

Figure 11. Screenshot of Emissions Overview for user case and base case in the EEIO-IDA results

Following the sector-wide results tables are the industry-specific results. For this section, the user can select the subsector of interest from the dropdown menu to display results for that subsector (Figure 12 shows an excerpt). Results displayed include the top subsector sources of upstream Scope 3 emissions; the top destination subsectors for downstream Scope 3 emissions; emissions breakdowns by fuel; and emissions breakdowns by greenhouse gas. A variety of visualizations of EEIO-IDA results are also

automatically generated for user-case and base-case results.[2] These visualizations include a summary plot of Scope 1, 2, and 3 emissions for all 25 industrial sectors (similar to the example of Figure 1); pie charts of total direct emissions breakdowns for all industrial subsectors (examples shown in Figure 13); and donut plots for Scope 1, 2, and 3 emissions for each subsector (similar to the examples of Figure 2), among other figures.

Industry Specific Data

Select Industry: Primary Metals

Top 10 Emission Sources for Primary Metals

		User Case		Base Case	
	Emissions Source by Subsector	**% of emissions**	**Emissions, MMT CO2e**	**% of emissions**	**Emissions, MMT CO2e**
1	Primary metals	78%	142	78%	142
2	Truck transportation	6%	11	6%	11
3	Mining, except oil and gas	5%	9	5%	9
4	Paper products	1%	2	1%	2
5	Nonmetallic mineral products	1%	2	1%	2
6	Rail transportation	1%	2	1%	2
7	Petroleum and coal products	1%	1	1%	1
8	Wholesale trade	1%	1	1%	1
9	Chemical products	1%	1	1%	1
10	Other real estate	1%	1	1%	1
	Other industries	5%	9	5%	9
	Total		**181**		**181**

Figure 12. Screenshot of industry-specific top emission sources by subsector in the EEIO-IDA results

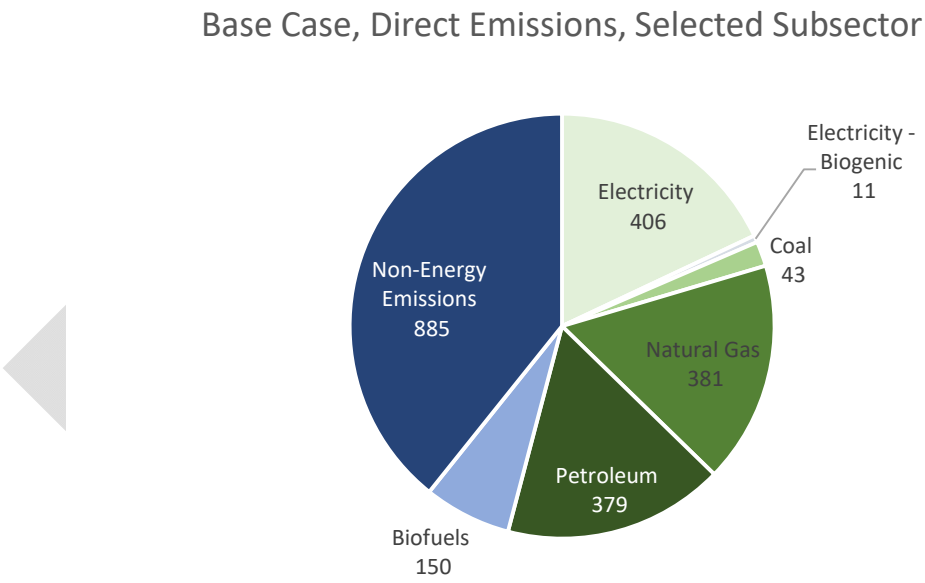


Figure 13. Screenshot of total direct base-case emissions for all industrial subsectors pie charts in the EEIO-IDA results

[2] While Excel autoformats the plots, the authors note that users may wish to make some aesthetic formatting adjustments to the automatically generated visualizations and plots prior to using in a report or presentation (particularly with respect to the data label positions).

3. Methods and Data Sources

EEIO-IDA is powered by publicly available data sources for energy use, economic flows, and emissions across the U.S. economy. The model base year is 2018, corresponding to the most recent available MECS dataset for manufacturing energy use (U.S. Energy Information Administration 2021) as well as U.S. Bureau of Economic Analysis (BEA) economic input-output data (U.S. Bureau of Economic Analysis 2022b) for the same year.

3.1. Economic Input-Output Data Foundation for Model

A mid-resolution ("summary" level) representation of the overall economy (71 commodities) is used in EEIO-IDA. This level of resolution was selected because BEA releases input-output accounts data annually at this level of resolution.[3] The core of this model is BEA's summary-level Total Requirements table for "Industry by Industry/After Redefinitions/Producer Value" for the year 2018 (U.S. Bureau of Economic Analysis 2018). The Total Requirements table provides data on the total dollar-value of inputs required (directly and indirectly) from each industry to deliver one dollar of industry output to final users. An excerpt is shown in Table 3. The purchasing industries are shown at the top of the table as column headers, and the producing industries are shown at the left-hand side of the table as row headers. For example, to deliver $1.00 of Forestry, Fishing, and Related Activities industry output to final consumers, this subsector required $0.03 of industry output from the Farms subsector, $1.15 of output from the Forestry, Fishing, and Related Activities subsector itself, $0.01 of output from the Oil and Gas Extraction subsector, and so on. Importantly, the Total Requirements table includes contributions from both direct and indirect suppliers required to produce industry output. More details on the Total Requirements table and its derivation from industry "make" and "use" tables using the Leontief inverse can be found elsewhere (U.S. Bureau of Economic Analysis 2011).

Table 3. Excerpt of the 2018 Industry-by-Industry Total Requirements Matrix (After Redefinitions, Summary Level) from BEA (U.S. Bureau of Economic Analysis 2018)

Industry	Farms	Forestry, fishing, and related activities	Oil and gas extraction	Mining, except oil and gas	Support activities for mining	Utilities	…
Farms	1.2522	0.03069	0.0011	0.0023	0.0011	0.0010	…
Forestry, fishing, and related activities	0.0715	1.1465	0.0005	0.0025	0.0008	0.0006	…
Oil and gas extraction	0.0288	0.0115	1.1341	0.0414	0.0170	0.1064	…
Mining, except oil and gas	0.0092	0.0013	0.0047	1.0647	0.0028	0.0230	…
Support activities for mining	0.0017	0.0006	0.0522	0.0174	1.0082	0.0053	…
Utilities	0.0265	0.0062	0.0257	0.0390	0.0064	1.0587	…
…	…	…	…	…	…	…	…

[3] EEIO-IDA, version 1.0 (71 commodities), makes use of BEA's annual summary-level input/output accounts datasets and uses a 2018 base year. At the 71-commodity level of resolution, most industrial subsectors are represented at the level of their three-digit NAICS code. BEA's detail-level benchmark datasets (405 commodities) are released less frequently—only every five years. Currently, the most recent benchmark dataset has a base year of 2012.

3.2 Environmental Extension

As an environmentally extended input-output model, EEIO-IDA leverages economic information on transactions between industries (in dollars) to understand how materials flow through industrial supply chains to produce goods delivered to final consumers. This economic information is environmentally extended by using the flow of goods as a proxy for the accrual of greenhouse gas emissions in supply chains. This is achieved through the introduction of an environmental impact intensity vector in the input-output accounting framework, where the environmental impact intensity vector is expressed in physical units (e.g., million metric tons of CO_2-equivalent [CO_2e], for greenhouse gas emissions) per dollar of final demand. This allows for environmental impacts to be calculated through equation (1),

$$E = L \cdot d \cdot e, \quad (1)$$

where:

E is a vector containing the total environmental impact for each industry (physical units);
L is the square Total Requirements matrix, also called the Leontief inverse ($/$);
d is a vector containing the final demand in dollars for each industry ($); and
e is a vector containing the environmental impact intensity of each industry (physical units/$).

EEIO-IDA quantifies greenhouse gas emissions as its single environmental impact category, though multiple environmental vectors are included in the model to enable the drill-down functionality of displaying emissions breakdowns in various ways (e.g., by greenhouse gas and by fuel). In EEIO-IDA, greenhouse gas emissions for each subsector are calculated dynamically based on user inputs in the tool. This scenario-modeling functionality is made possible by the fuel-use and non-energy (process) emissions vectors that comprise the basis of the underlying model dataset. The adjustable energy and non-energy vectors are used to calculate the emissions ($e_{k,t}$) for each industry *k* and greenhouse gas *t* dynamically in the model through Equation (2):

$$e_{k,t} = C_{1,k} * \sum_i (f_i * x_{i,t}) + C_{2,k} * p_t \quad (2)$$

Here, f_i is the quantity of fuel *i;* $x_{i,t}$ is the emissions factor for fuel *i* and greenhouse gas *t*; p_t is the process emissions of greenhouse gas *t*; and C_1 and C_2 are scaling constants whose values are both equal to one in the base case scenario and modified by user-defined scenario assumptions for energy and non-energy related emissions, respectively. All user-adjustable features (except for demand change, which induces a proportional decrease in the final demand vector, *d*, for the selected industry) modify portions of equation (2), producing a custom emissions-by-industry vector for each unique user scenario.

For fuel combustion, emissions factors are drawn from the Intergovernmental Panel on Climate Change's (IPCC's) *Guidelines for National Greenhouse Gas Inventories* for each fuel/industry permutation, applying appropriate emissions factors for stationary or mobile combustion (Gomez et al. 2006; Waldron et al. 2006). Electricity is treated as a "fuel" in the model, with a weighted-average emissions factor defined based on the assumed generation mix for the electric grid. The generation mixes for the eight built-in grid scenarios, described in section 2.1, are shown in

Table 4. Because electricity is treated as a fuel in the model, emissions associated with utility-scale electricity production are attributed to the industry using the electricity (i.e., as Scope 2 emissions) and not to the utilities subsector.

Table 4. Electricity Generation Mixes for Eight Built-In Grid Scenarios in EEIO-IDA

Grid Scenario	Coal	Natural Gas	Petroleum	Nuclear	Biofuels	Renewables (except bio)
U.S. 2018 (EIA MER)	28.4%	34.1%	0.6%	20.1%	0.8%	15.8%
U.S. 2022 (EIA MER)	20.1%	38.9%	0.5%	18.9%	0.7%	20.9%
U.S. 2030, Base Case Scenario (EIA AEO)	8.4%	22.6%	0.2%	18.4%	0.0%	50.4%
U.S. 2050, Base Case Scenario (EIA AEO)	5.0%	19.4%	0.1%	12.9%	0.0%	62.6%
U.S. 2030, Low Zero-Carbon Tech Cost Scenario (EIA AEO)	7.0%	20.0%	0.2%	18.4%	0.0%	54.5%
U.S. 2050, Low Zero-Carbon Tech Cost Scenario (EIA AEO)	0.7%	7.7%	0.1%	14.2%	0.0%	77.3%
World 2030, Net Zero by 2050 Scenario (IEA)	8.9%	16.8%	1.0%	9.9%	4.0%	59.4%
World 2050, Net Zero by 2050 Scenario (IEA)	1.0%	1.0%	0.0%	8.0%	5.0%	85.0%

For summary reporting, greenhouse gas emissions of CO_2, CH_4, and N_2O are converted to a CO_2e value using 100-year global warming potential (GWP) values from IPCC's Fifth Assessment Report, also called "AR5" (Myhre et al. 2014). Fluorinated compounds represent a smaller volume of industrial greenhouse gas releases compared to CO_2, CH_4, and N_2O, but they still have significant impact on global warming because of their long lifetimes in the atmosphere and high GWP multipliers. In EEIO-IDA, two weighted averages are used for the GWP of fluorinated compound releases: one for the industrial sector and one for the transportation sector. These weighted averages are based on the breakdown of fluorinated compounds released in each sector, as reported in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021* (U.S. Environmental Protection Agency 2023) for the year 2018. Weighted averages are used in the EEIO-IDA model rather than individual values for each gas to streamline the process of user scenario definition in this rapid-data-entry tool (i.e., the user adjusts the quantity of fluorinated compounds as a single data input rather than being required to provide a detailed fluorinated gas breakdown for each new scenario). Overall, fluorinated gases comprise about 3% of annual CO_2e greenhouse gas emissions in the United States (U.S. Environmental Protection Agency 2023).

For the industrial sector, major process-related releases of fluorinated compounds include HFC-23 (trifluoromethane) released during HCFC-22 (difluoromonochloromethane) production in the chemicals industry (NAICS 325); SF_6 (sulfur hexafluoride) and HFC-134a (tetrafluoroethane) released during magnesium production and processing (part of 331); mixed perfluorinated compounds (PFCs) released in the aluminum industry (also part of 331); and mixed fluorinated gases released in the electronics and electrical equipment industries (334 and 335), especially SF_6 and CH_4. For the transportation sector, refrigerant use for commercial vehicle air conditioning and refrigerated transport (assumed to be HFC-134a) is the major contributor to fluorinated gas releases (NAICS 482, 483, 484, and 485). The atmospheric lifetimes and GWP values of CO_2, CH_4, and N_2O, as well as the most common fluorinated compounds included in the weighted average calculations, are listed in Table 5. Full calculations for the weighted averages included in the EEIO-IDA model are included in Appendix D.

Table 5. Atmospheric Lifetimes and 100-Year GWP for Greenhouse Gases Included in the EEIO-IDA Model (Myhre et al. 2014)

Greenhouse Gas	Atmospheric Lifetime (years)	100-Year GWP
CO_2	variable	1
CH_4	12.4	28
N_2O	121	265
Fluorinated Compounds		
HFC-23	222	12,400
HFC-134a	13.4	1,300
CF_4 (tetrafluoromethane)	50,000	6,630
C_2F_6 (hexafluoroethane)	10,000	11,100
C_3F_8 (perfluoropropane)	2,600	8,900
C_4F_8 (perfluorocyclobutane)	3,200	9,540
SF_6	3,200	23,500
NF_3 (nitrogen trifluoride)	500	16,100
Industrial Fluorinated Compounds—Weighted Average		12,500
Transportation Fluorinated Compounds—Weighted Average		1,300

3.2. Estimation of Electricity, Fuel Use, and Process Emissions by Subsector

In EEIO-IDA, core model datasets capture information on electricity use, fuel consumption, and non-energy-related (process) emissions in each of the 71 model subsectors. Fuel data are aggregated to six fuel categories (electricity, coal, natural gas, petroleum, biofuels, and other renewables), as illustrated by the six-industry excerpt of Table 6. Fuel consumption data are converted within the model to emissions of greenhouse gases (CO_2, CH_4, and N_2O) using stationary and mobile combustion emissions factors from IPCC, and to CO_2e greenhouse gas emissions using the 100-year GWP of each gas. Inclusion of biogenic emissions in CO_2e totals is optional and is controlled in the tool by a toggle in the *User Interface* tab. When biogenic emissions are included through a "Y" selection in the toggle, non-zero GWP values for biofuel combustion are applied, and overall emissions shown in scenario results will be higher. When biogenic emissions are excluded, the GWP for biofuel combustion is set to zero and biofuels are treated identically to other renewable energy resources such as solar and wind (i.e., with zero emissions). Life-cycle emissions for renewable energy production are not included in this version of the model.

Table 6. Excerpt of Fuel Consumption by Subsector Data in EEIO-IDA for the 2018 Model Base Case

NAICS Code(s)	Industry Name	Fuel Consumption (TBtu)						
		Electricity (TBtu)	Coal (TBtu)	Natural Gas (TBtu)	Petroleum (TBtu)	Biofuels (TBtu)	Other Renewables (TBtu)	Total Energy (TBtu)
111, 112	Farms	263	0	190	630	0	0	1,083
113, 114, 115	Forestry, fishing, and related activities	4	1	8	45	0	0	57
211	Oil and gas extraction	0	0	267	65	0	0	332
212	Mining, except oil and gas	0	5	128	178	0	0	311
213	Support activities for mining	0	0	13	66	0	0	78
22	Utilities	25	0	4	12	0	0	41
…	…	…	…	…	…	…	…	…

Fuel use data are drawn from primary sources such as the MECS (U.S. Energy Information Administration 2021) as well as the *Annual Survey of Manufactures* (ASM) for manufacturing data (U.S. Census Bureau 2018); the U.S. Census of Agriculture (U.S. Department of Agriculture 2019b) for agriculture data; the *Transportation Energy Data Book* (Davis & Boundy 2022) for transportation data; and other sources. Data sources are summarized at the two-digit NAICS level in Table 7, with further detail for all 71 subsectors provided in Appendix C. Since the model base year is 2018, data sources were selected to align with that data year as closely as possible, but 2018 data were not available from all major data sources. In such cases, time-based adjustments to datasets for years other than 2018 were made to project data to 2018. To do this, the project team utilized growth factors based on relevant data points from multiple years. An example of this type of growth factor is BEA's Chain Type Quantity Index (U.S. Bureau of Economic Analysis 2022a).

Table 7. Summary of Data Sources for Electricity and Fuel Use by Subsector

Industries (and Corresponding NAICS Codes)	Data Sources—Electricity and Fuel Use
Agriculture, Forestry, Fishing, and Hunting (11)	Farm Production Expenditures 2018 Summary (U.S. Department of Agriculture 2018); Census of Agriculture – 2017 (U.S. Department of Agriculture 2019b); Census of Irrigation – 2018 (U.S. Department of Agriculture 2019a); Census of Horticultural Specialties – 2019 (U.S. Department of Agriculture 2020); BEA – Input-Output (IO) Tables – 2012 & 2018 (U.S. Bureau of Economic Analysis 2022c); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)
Mining (21)	Economic Census 2017 (U.S. Census Bureau 2017)
Utilities (22)	BEA – IO Tables – 2012 & 2018 (U.S. Bureau of Economic Analysis 2022c); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)
Construction (23)	EIA – AEO (U.S. Energy Information Administration 2023a)
Manufacturing (31–33)	EIA – MECS 2018 (U.S. Energy Information Administration 2021); ASM 2018 (U.S. Census Bureau 2018)
Wholesale Trade (42)	BEA – IO Tables – 2012 & 2018 (U.S. Bureau of Economic Analysis 2022c); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)
Retail Trade (44)	BEA – IO Tables – 2012 & 2018 (U.S. Bureau of Economic Analysis 2022c); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b); EIA – Commercial Buildings Energy Consumption Survey (CBECS) 2018 (U.S. Energy Information Administration 2018); Economic Census 2017 (U.S. Census Bureau 2017)
Transportation and Warehousing, Excluding Postal Service (48, 49)	Transportation Energy Data Book (Davis & Boundy 2022); BEA – IO Tables – 2012 & 2018 (U.S. Bureau of Economic Analysis 2022c); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b); EIA – CBECS 2018 (U.S. Energy Information Administration 2018)
Other Service-Providing Industries, Except Government (51–81)	BEA – IO Tables – 2012 & 2018 (U.S. Bureau of Economic Analysis 2022c); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b); EIA – CBECS 2018 (U.S. Energy Information Administration 2018)
Government (no NAICS code)	Comprehensive Annual Energy Data and Sustainability Performance (U.S. Department of Energy 2022); Association of American Railroads, Railroad Facts (Association of American Railroads 2023); EIA – CBECS 2018 (U.S. Energy Information Administration 2018); Federal Transportation Administration (FTA) Annual Database Energy Consumption 2018 (Federal Transit Administration 2018)

In some cases, source datasets for fuel consumption included insufficient resolution to determine the fuel breakdown for all 71 subsectors in this model (i.e., the source dataset included more highly aggregated

industry definitions than the "summary"-level representation of the economy). For these situations, an allocation strategy was used to assign fuel consumption to applicable subsectors. Allocation was based on energy purchases (of electricity, petroleum, natural gas, and coal) as specified in the "use" tables of BEA's 2012 benchmark (405-subsector) dataset, following a similar allocation methodology to that of Carnegie Mellon's Economic Input-Output Life Cycle Assessment (EIO-LCA) model (Chen et al. 2016; Espinosa et al. 1997; Weber et al. 2009). The allocation subsectors are shown in Table 8. It was necessary to use the 2012 benchmark dataset (405 subsectors) rather than the 2018 summary dataset (71 subsectors) to resolve purchases of the four different energy types. Fuel purchase values were converted to fuel consumption values (in TBtu) using average 2012 fuel costs from EIA data. The conversions from purchase values to fuel consumption values are shown in Table 9. These fuel consumption values were then projected to 2018 utilizing the BEA Chain Type Quantity Index for Intermediate Inputs and reaggregated to the 71-subsector level. While energy and fuel consumption allocations estimated using this method are not as accurate as primary U.S. EIA or other governmental data reported explicitly for an industry, this provided a reasonable allocation strategy for subsectors for which no better data sources were available.

Table 8. Industry Definitions for Allocation of Energy via BEA Use Table Data on Energy Expenditures

Energy to Allocate	Industry Purchases (in Use Table) Used for Allocation	
	NAICS Code	Industry
Electricity	221100	Power Generation and Supply
Petroleum	324110	Petroleum Refineries
Natural Gas	221200	Natural Gas Distribution
Coal	212100	Coal Mining

Table 9: Factors for Converting Fuel Purchase Values to Fuel Energy Consumption Values

Fuel Type	Conversion Factor, Purchase Values to Fuel Consumption Values
Electricity	0.0337 MMBtu/$ (million British thermal units/dollar)
Petroleum	0.0348 MMBtu/$
Natural Gas	0.1267 MMBtu/$
Coal	0.2840 MMBtu/$

Non-energy-related emissions are collected for each subsector in four different greenhouse gas families (CO_2, CH_4, N_2O, and fluorinated compounds), as illustrated by the six-industry excerpt of

Table 10. These data are predominantly drawn from EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021* (U.S. Environmental Protection Agency 2023). Among the 71 subsectors in the model, only 15 subsectors (8 of which are industrial subsectors) include significant non-energy-related emissions. The remaining subsectors were assumed to have zero non-energy-related emissions. Details on sources, as well as descriptions of the non-energy-related greenhouse gas emitting processes arising in the 15 applicable subsectors, are provided in Appendix C.

Table 10. Excerpt of Non-Energy Emissions by Subsector Data in EEIO-IDA

NAICS Code(s)	Industry Name	Non-Energy Emissions (million metric tons)			
		CO_2	CH_4	N_2O	Fluorinated Compounds
111, 112	Farms	7.44	10.2	1.20	0
113, 114, 115	Forestry, fishing, and related activities	0	0	0	0
211	Oil and gas extraction	0	5.3	0	0
212	Mining, except oil and gas	3.1	2.1	0	0
213	Support activities for mining	0	0	0	0
22	Utilities	0.004	0.12	0	0
…	…	…	…	…	…

4. Suggested Citation

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Appendix A. Subsectors in EEIO-IDA and Corresponding NAICS Codes

The 71 economic subsectors included in the model, along with their corresponding 2-, 3-, or 4-digit NAICS codes, are listed in the table below. These 71 subsectors represent the entire U.S. economy. Of the 71 total subsectors, the 19 manufacturing subsectors are shaded in green and designated with a single asterisk (*), and the 6 non-manufacturing industrial subsectors are shaded in yellow and designated with a double asterisk (**). Scenario modeling capabilities in the EEIO-IDA model focus on adjustments to assumptions in these 25 industrial subsectors (19 manufacturing and 6 non-manufacturing), while certain global assumptions (such as electric grid mix) impact all 71 subsectors.

Table 11. Definitions of the 71 Economic Subsectors Included in the EEIO-IDA Model, with Corresponding NAICS Codes

Farms** (111, 112)	Forestry, fishing, and related activities** (113, 114, 115)	Oil and gas extraction** (211)	Mining, except oil and gas** (212)
Support activities for mining** (213)	Utilities (22)	Construction** (23)	Wood products* (321)
Nonmetallic mineral products* (327)	Primary metals* (331)	Fabricated metal products* (332)	Machinery* (333)
Computer and electronic products* (334)	Electrical equipment, appliances, and components* (335)	Motor vehicles, bodies and trailers, and parts* (3362, 3363)	Other transportation equipment* (3364, 3365, 3366, 3369)
Furniture and related products* (337)	Miscellaneous manufacturing* (339)	Food and beverage and tobacco products* (311, 312)	Textile mills and textile product mills* (313, 314)
Apparel and leather and allied products* (315, 316)	Paper products* (322)	Printing and related support activities* (323)	Petroleum and coal products* (324)
Chemical products* (325)	Plastics and rubber products* (326)	Wholesale trade (42)	Motor vehicle and parts dealers (441)
Food and beverage stores (445)	General merchandise stores (452)	Other retail (442, 443, 444, 446, 447, 448, 451, 453, 454)	Air transportation (481)
Rail transportation (482)	Water transportation (483)	Truck transportation (484)	Transit and ground passenger transportation (485)
Pipeline transportation (486)	Other transportation and support activities (487, 488, 492)	Warehousing and storage (493)	Publishing industries, except internet (includes software) (511)

Motion picture and sound recording industries (512)	Broadcasting and telecommunications (513)	Data processing, internet publishing, and other information services (514)	Federal Reserve banks, credit intermediation, and related activities (521, 522)
Securities, commodity contracts, and investments (523)	Insurance carriers and related activities (524)	Funds, trusts, and other financial vehicles (525)	Housing (NAICS n/a for owner-occupied housing; subset of 531 for tenant-occupied housing)
Other real estate (subset of 531)	Rental and leasing services and lessors of intangible assets (532, 533)	Legal services (5411)	Computer systems design and related services (5415)
Miscellaneous professional, scientific, and technical services (5412, 5413, 5414, 5417, 5418, 5419)	Management of companies and enterprises (55)	Administrative and support services (561)	Waste management and remediation services (562)
Educational services (61)	Ambulatory health care services (621)	Hospitals (622)	Nursing and residential care facilities (623)
Social assistance (624)	Performing arts, spectator sports, museums, and related activities (711, 712)	Amusements, gambling, and recreation industries (713)	Accommodation (721)
Food services and drinking places (722)	Other services, except government (81)	Federal general government (defense) (NAICS n/a)	Federal general government (nondefense) (NAICS n/a)
Federal government enterprises (NAICS n/a except 591 for postal service)	State and local general government (NAICS n/a)	State and local government enterprises (NAICS n/a)	

Appendix B. Summary of Tool Tabs and Functionality in the EEIO-IDA Model

Table 12. List of Tabs Included in the EEIO-IDA Model and Descriptions

Tab Name	Description
Welcome	Landing page with model build information and table of contents
User Interface	Interactive worksheet used to input user assumptions and build scenarios
Results	Displays tabular and graphical results from the user-defined and base-case scenarios
Chart Data*	Organization and calculation of data used to create charts in Results tab
Top Emission Sources*	Calculation of top emissions sources displayed in Results tab
Subsector Emission Factors*	Calculation of user-case and base-case emission factors for each subsector
Fuel Emission Factors*	Emission factors for each subsector by fuel type
Total Requirements Table*	Industry-by-industry table in producers' prices showing the sum of direct and indirect industry output required to produce a product for use in final demand
Final Demand*	Includes base-case final demand (household consumption, government spending, investment, and exports) and calculates user-case final demand from assumptions in demand reductions
Market Share Table*	Industry-by-commodity market share table in producers' prices
Grid Mixes - Base*	Calculation of percent electricity generation by fuel for built-in grid mix scenarios
Grid Mix - Calculated*	Calculation of user case fuel consumption and updated emissions factors
2018 EEIO Data*	Calculation of 2018 base case percent energy consumption by fuel for each subsector
IO Table - Total CO_2e*	Calculation of total Scope 1, 2, and 3 (energy and non-energy) CO_2e emissions for each subsector
IO Table - Energy CO_2e*	Calculation of Scope 1, 2, and 3 (energy) CO_2e emissions for each subsector
IO Table - Non-Energy CO_2e*	Calculation of Scope 1, 2, and 3 (non-energy) CO_2e emissions for each subsector
IO Table - All CO_2*	Calculation of Scope 1, 2, and 3 single-component (energy and non-energy) CO_2 emissions for each subsector
IO Table - All CH_4*	Calculation of Scope 1, 2, and 3 single-component (energy and non-energy) CH_4 emissions for each subsector
IO Table - All N_2O*	Calculation of Scope 1, 2, and 3 single-component (energy and non-energy) N_2O emissions for each subsector
IO Table - All SF_6*	Calculation of Scope 1, 2, and 3 single-component (energy and non-energy) SF_6 emissions for each subsector
IO Table - Energy CO_2*	Calculation of Scope 1, 2, and 3 single-component (energy) CO_2 emissions for each subsector
IO Table - Energy CH_4*	Calculation of Scope 1, 2, and 3 single-component (energy) CH_4 emissions for each subsector
IO Table - Energy N_2O*	Calculation of Scope 1, 2, and 3 single-component (energy) N_2O emissions for each subsector

IO Table - Non-Energy CO_2*	Calculation of Scope 1, 2, and 3 single-component (non-energy) CO_2 emissions for each subsector
IO Table - Non-Energy CH_4*	Calculation of Scope 1, 2, and 3 single-component (non-energy) CH_4 emissions for each subsector
IO Table - Non-Energy N_2O*	Calculation of Scope 1, 2, and 3 single-component (non-energy) N_2O emissions for each subsector
IO Table - Non-Energy SF_6*	Calculation of Scope 1, 2, and 3 single-component (non-energy) SF_6 emissions for each subsector
IO Table - CO_2e (Electricity)*	Calculation of Scope 1, 2, and 3 non-biogenic CO_2e emissions from electricity for each subsector
IO Table - CO_2e (Biofuels)*	Calculation of Scope 1, 2, and 3 CO_2e emissions from biofuels for each subsector
IO Table - CO_2e (Petroleum)*	Calculation of Scope 1, 2, and 3 CO_2e emissions from petroleum for each subsector
IO Table - CO_2e (Natural Gas)*	Calculation of Scope 1, 2, and 3 CO_2e emissions from natural gas for each subsector
IO Table - CO_2e (Coal)*	Calculation of Scope 1, 2, and 3 CO_2e emissions from coal for each subsector
IO Table - CO_2e (Biogenic Elec)*	Calculation of Scope 1, 2, and 3 biogenic CO_2e emissions from electricity for each subsector

* Tab is hidden by default

Appendix C. Data Source Detail by Subsector for Fuel Use, Electricity, and Emissions Data

Table 13 provides full details of data sources consulted to build the base-case environmental vectors for the 2018 base year of the EEIO-IDA model. This includes information on fuel and electricity consumption (used to calculate combustion-related greenhouse gas emissions) and non-energy-related emissions. Brief descriptions of the non-energy-related emissions source processes for each subsector are also included where applicable. For many of the 71 subsectors in the model, best-available primary datasets did not offer sufficient resolution to definitively quantify the energy and emissions of every subsector explicitly due to data aggregation in the primary sources. In these cases, the known energy or emissions totals for higher-order subsector definitions included in the primary source were disaggregated to estimate the fractional contribution of each child subsector. Disaggregation assumptions are described in Table 13 for each subsector and were typically based on energy purchase information provided in BEA make/use tables, as described earlier in section 3.2. Disaggregation methods were based on best engineering judgment and were applied only when primary governmental data reporting the energy/emissions detail explicitly for a subsector were unavailable.

Table 13. Data Sources for Fuel and Electricity Consumption and Non-Energy-Related Greenhouse Gas (GHG) Emissions Comprising the Core Dataset for the 2018 Base Year in EEIO-IDA

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Farms (111, 112)	Farms Production Expenditures 2018 Summary (U.S. Department of Agriculture 2018); Census of Agriculture – 2017 (U.S. Department of Agriculture 2019b); Census of Irrigation – 2018 (U.S. Department of Agriculture 2019a); Census of Horticultural Specialties – 2019 (U.S. Department of Agriculture 2020)	EPA Inventory of GHG Emissions – 1990-2020, Table 5.1 (U.S. Environmental Protection Agency 2023)	Enteric fermentation, manure management, field burning of residue, liming, and urea fertilizers	

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Forestry, fishing, and related activities (113, 114, 115)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Oil and gas extraction (211)	Economic Census – 2017, Sector 21, Table EC1721MATFUEL (U.S. Census Bureau 2017)	EPA Inventory of GHG Emissions – 1990-2020, Tables 3-43 and 3-69 (U.S. Environmental Protection Agency 2023)	Natural gas and oil well leaks, venting, fugitives, etc.	
Mining, except oil and gas (212)	Economic Census – 2017, Sector 21, Table EC1721MATFUEL (U.S. Census Bureau 2017)	EPA Inventory of GHG Emissions – 1990-2020, Tables 3-33, 3-34, 3-38 (U.S. Environmental Protection Agency 2023)	Coal mining ventilation, emissions from surface mines, underground mines, and post-mining	
Support activities for mining (213)	Economic Census – 2017, Sector 21, Table EC1721MATFUEL (U.S. Census Bureau 2017)			
Utilities (22)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)	EPA Inventory of GHG Emissions – 1990-2020 (U.S. Environmental Protection Agency 2023)	Natural gas pipeline leaks	See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Construction (23)	Annual Energy Outlook – 2022 (U.S. Energy Information Administration 2023a)			
Wood products (321)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Nonmetallic mineral products (327)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)	EPA Inventory of GHG Emissions – 1990-2020, Table 4-2 (U.S. Environmental Protection Agency 2023)	Cement and lime process emissions	
Primary metals (331)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)	EPA Inventory of GHG Emissions – 1990-2020, Table 4-2 (U.S. Environmental Protection Agency 2023)	Process emissions from production of alumina and aluminum, zinc, lead, magnesium, iron and steel, and metallurgical coke	
Fabricated metal products (332)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Machinery (333)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Computer and electronic products (334)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)	EPA Inventory of GHG Emissions – 1990-2020, Table 4-97 (U.S. Environmental Protection Agency 2023)	Semiconductor production process emissions	

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Electrical equipment, appliances, and components (335)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)	EPA Inventory of GHG Emissions – 1990-2020, Table 4-109 (U.S. Environmental Protection Agency 2023)	Electrical equipment manufacturing process emissions	
Motor vehicles, bodies and trailers, and parts (3362, 3363)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021); ASM – 2018 (U.S. Census Bureau 2018)			Assumed 70% of NAICS 336 electricity allocated to Motor vehicles, bodies and trailers, and parts based on ASM 2018 data on quantity of electricity purchased for heat and power for subsectors 3361–3369
Other transportation equipment (3364, 3365, 3366, 3369)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021); ASM – 2018 (U.S. Census Bureau 2018)			Assumed 30% of NAICS 336 electricity allocated to 3364OT based on ASM 2018 data on quantity of electricity purchased for heat and power for subsectors 3361–3369. Allocated distillate fuel oil and residual fuel oil from NAICS 336 to 3364OT, likely used in 3366 ship and boat building
Furniture and related products (337)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Miscellaneous manufacturing (339)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Food and beverage and tobacco products (311, 312)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Textile mills and textile product mills (313, 314)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Apparel and leather and allied products (315, 316)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Paper products (322)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Printing and related support activities (323)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Petroleum and coal products (324)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			
Chemical products (325)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)	EPA Inventory of GHG Emissions – 1990-2020, Table 4-2 (U.S. Environmental Protection Agency 2023)	Process emission for production of carbide, ammonia, soda ash, titanium dioxide, phosphoric acid, petrochemicals, nitric acid, adipic acid, caprolactam, glyoxal, glyoxylic acid, and HCFC-22	
Plastics and rubber products (326)	MECS – 2018, Tables 3.2, 3.5, 3.6 (U.S. Energy Information Administration 2021)			

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Wholesale trade (42)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Motor vehicle and parts dealers (441)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018); Economic Census – 2017, Table EC1744BASIC (U.S. Census Bureau 2017)			"Retail (other than mall)" Principal Building Activity (PBA) category, excluding government facilities. Multiplied by fraction of establishments in Economic Census 2017, Sector 44, categorized as "Motor vehicle and parts dealers," excluding NAICS 445 and 452 establishments from the total.
Food and beverage stores (445)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Food Sales" category in CBECS Microdata, excluding government facilities
General merchandise stores (452)	CBECS – 2018, Table C1 (U.S. Energy Information Administration 2018)			"Enclosed and Strip Malls" category

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Other retail (442, 443, 444, 446, 447, 448, 451, 453, 454)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018); Economic Census – 2017, Table EC1744BASIC (U.S. Census Bureau 2017)			"Retail (other than mall)" PBA category, excluding government facilities. Multiplied by fraction of establishments in Economic Census 2017, Sector 44, NOT categorized as "Motor vehicle and parts dealers," excluding NAICS 445 and 452 establishments from the total.
Air transportation (481)	Transportation Energy Data Book, Table 2.7 (Davis & Boundy 2022)	EPA Inventory of GHG Emissions – 1990-2020, Table 2-13 (U.S. Environmental Protection Agency 2023)	Lubricants	
Rail transportation (482)	Transportation Energy Data Book, Table 2.7 (Davis & Boundy 2022)	EPA Inventory of GHG Emissions – 1990-2020, Table 2-13 (U.S. Environmental Protection Agency 2023)	Refrigerants and lubricants	
Water transportation (483)	Transportation Energy Data Book, Table 2.7 (Davis & Boundy 2022)	EPA Inventory of GHG Emissions – 1990-2020, Table 2-13 (U.S. Environmental Protection Agency 2023)	Refrigerants and lubricants	

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Truck transportation (484)	Transportation Energy Data Book, Table 2.7 (Davis & Boundy 2022)	EPA Inventory of GHG Emissions – 1990-2020, Table 2-13 (U.S. Environmental Protection Agency 2023)	Refrigerants and lubricants	
Transit and ground passenger transportation (485)	Transportation Energy Data Book, Table 2.7 (Davis & Boundy 2022)	EPA Inventory of GHG Emissions – 1990-2020, Table 2-13 (U.S. Environmental Protection Agency 2023)	Refrigerants and lubricants	
Pipeline transportation (486)	Transportation Energy Data Book, Table 2.7 (Davis & Boundy 2022)			
Other transportation and support activities (487, 488, 492)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Warehousing and storage (493)	CBECS – 2018, Table C1 (U.S. Energy Information Administration 2018)			"Warehouse and storage" category

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Publishing industries, except internet (includes software) (511)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Motion picture and sound recording industries (512)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Broadcasting and telecommunications (513)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Data processing, internet publishing, and other information services (514)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Federal Reserve banks, credit intermediation, and related activities (521, 522)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Securities, commodity contracts, and investments (523)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Insurance carriers and related activities (524)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Funds, trusts, and other financial vehicles (525)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Housing (NAICS n/a for owner-occupied housing; subset of 531 for tenant-occupied housing)	N/A			Fuel use for housing is included in personal consumption expenditures and is excluded from this model.
Other real estate (subset of 531)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Rental and leasing services and lessors of intangible assets (532, 533)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Legal services (5411)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Computer systems design and related services (5415)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Miscellaneous professional, scientific, and technical services (5412, 5413, 5414, 5417, 5418, 5419)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Management of companies and enterprises (55)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Administrative and support services (561)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Waste management and remediation services (562)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)	EPA Inventory of GHG Emissions – 1990-2020 (U.S. Environmental Protection Agency 2023)	Aerobic and anaerobic digestion of organics and nitrous materials	See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Educational services (61)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Education" PBA category, excluding government facilities
Ambulatory health care services (621)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Outpatient Health Care" PBA category and "Medical Office (Non-Diagnostic)" PBAPlus category
Hospitals (622)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Inpatient Health Care" PBA category
Nursing and residential care facilities (623)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Nursing" PBA category

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Social assistance (624)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Performing arts, spectator sports, museums, and related activities (711, 712)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Amusements, gambling, and recreation industries (713)	BEA IO Use Table – 2012 (U.S. Bureau of Economic Analysis 2022c); BEA IO Chain-Type Quantity Index – 2018 (U.S. Bureau of Economic Analysis 2022a); EIA – Electric Power Monthly – 2020 (U.S. Energy Information Administration 2023b)			See Section 3.2 discussion on allocation estimation using 2012 BEA Use Table.
Accommodation (721)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Lodging" PBA category
Food services and drinking places (722)	CBECS – 2018, Table C1 (U.S. Energy Information Administration 2018)			"Food Service" category
Other services, except government (81)	CBECS – 2018, Microdata (U.S. Energy Information Administration 2018)			"Service" and "Religious Worship" PBA categories

EEIO-IDA Subsector (and NAICS code)	Sources for Fuel & Electricity Energy Consumption Data	Sources for Non-Energy-Related Emissions Data	Descriptions of Non-Energy-Related Emissions Sources	Disaggregation Method (if Applicable)
Federal general government (defense) (NAICS n/a)	DOE's Comprehensive Annual Energy Data and Sustainability Performance – 2023, Table A-8 (U.S. Department of Energy 2022)			"Defense" category
Federal general government (nondefense) (NAICS n/a)	DOE's Comprehensive Annual Energy Data and Sustainability Performance – 2023, Table A-8 (U.S. Department of Energy 2022)			"Civilian Agencies", excluding "Postal Service" and "Tennessee Valley Authority"
Federal government enterprises (NAICS n/a except 591 for postal service)	DOE Comprehensive Annual Energy Data and Sustainability Performance – 2023, Table A-8 (U.S. Department of Energy 2022); Association of American Railroads, Railroad Facts (Association of American Railroads 2023)			"Postal Service" emissions from Comprehensive Annual Energy Data and Sustainability Performance and Amtrak emissions from Railroad Facts
State and local general government (NAICS n/a)	CBECS – 2018, Table C1 (U.S. Energy Information Administration 2018)			"State" and "Local" government-owned facilities
State and local government enterprises (NAICS n/a)	Federal Transit Administration's Annual Database Energy Consumption – 2018 (Federal Transit Administration 2018)			State- and municipally owned public transit

Appendix D. Weighted Average Calculations for Fluorinated Compound Global Warming Potentials

For fluorinated compound releases, weighted average GWP values were calculated for the industrial and transportation sectors. These weighted averages were based on an analysis of fluorinated gas releases by source in the year 2018, as reported in the EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021* (U.S. Environmental Protection Agency, 2023). CO_2-equivalent releases of fluorinated gases reported in the *Inventory* were back-calculated to physical units (million metric tons of fluorinated compound) by dividing by the GWP. This was done to satisfy the required data form for primary emissions data in the EEIO-IDA model; data are specified in physical units to allow for manual user adjustment of GWP values if required.

Summary data used to calculate the weighted average for the industrial sector and transportation sector are summarized in Table 14 and Table 15, respectively. For the industrial sector, this includes details about the specific processes that release fluorinated compounds and an industry mapping for each release. These data were synthesized from a number of tables and sections in the *Inventory* (U.S. Environmental Protection Agency, 2023), and data locator citations are also given in the table. Analysis was simpler for the transportation sector, as the weighted average was assumed to be the GWP value for refrigerant 134a. Based on data provided in the *Inventory* Table 2-12, the sole process included is refrigeration and air conditioning in commercial transportation (trucks, buses, ships and boats, and rail), and the dominant refrigerant was assumed to be HFC-134a based on the footnote provided in the same table.

Table 14. Industrial Sector Fluorinated Compound Releases and Weighted Average GWP

Source of Fluorinated Compound Release	Fluorinated Gas Emitted	EEIO-IDA Industry Mapping	Reported CO_2e Emissions (million metric tons)	GWP*	Back-Calculated to Million Metric Tons of Fluorinated Gas	Sources in EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021*
HCFC-22 production	HFC-23	Chemical products (325)	2.7	12,400	2.18×10^{-4}	Table 4-1, Section 4.14
Electronics industry	CF_4	Computer and electronic products (334)	1.6	6,630	2.41×10^{-4}	Table 4-1, Table 4-109
	C_2F_6		1.0	11,100	9.01×10^{-5}	
	C_3F_8		0.1	8,900	1.12×10^{-5}	
	C_4F_8		0.1	9,540	1.05×10^{-5}	
	HFC-23		0.3	12,400	2.42×10^{-5}	
	SF_6		0.8	23,500	3.40×10^{-5}	
	NF_3		0.5	16,100	3.11×10^{-5}	
Magnesium production and processing	HFC-134a	Primary metals (331)	0.1	1,300	7.69×10^{-5}	Table 4-1, Sec. 4.20
	SF_6		1.1	23,500	4.68×10^{-5}	
Aluminum production	CF_4	Primary metals (331)	1.0	6,630	1.51×10^{-4}	Table 4-1, Table 4-91
	C_2F_6		0.4	11,100	3.60×10^{-5}	

Electrical transmission and distribution	SF_6	Electrical equipment, appliances, and components (335)	5.2	23,500	2.21×10^{-4}	Table 4-1
INDUSTRIAL SECTOR WEIGHTED AVERAGE				**12,500**		

* IPCC AR5 GWP values, as listed in Table A-222 in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021*

Table 15. Transportation Sector Fluorinated Compound Releases and Weighted Average GWP

Source of Fluorinated Compound Release	Fluorinated Gas Emitted	EEIO-IDA Industry Mapping	Reported CO_2e Emissions (million metric tons)	GWP*	Back-Calculated to Million Metric Tons of Fluorinated Gas	Sources in EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021*
Light-duty trucks	HFC-134a	Truck transportation (484)	16.4	1,300	1.26×10^{-2}	Table 2-12
Medium- and heavy-duty trucks	HFC-134a	Truck transportation (484)	5.6	1,300	4.31×10^{-3}	Table 2-12
Buses	HFC-134a	Transit and ground passenger transportation (485)	0.4	1,300	3.08×10^{-4}	Table 2-12
Ships and boats	HFC-134a	Water transportation (483)	3.6	1,300	2.77×10^{-3}	Table 2-12
Rail	HFC-134a	Rail transportation (482)	0.1	1,300	7.69×10^{-5}	Table 2-12
TRANSPORTATION SECTOR WEIGHTED AVG.				**1,300**		

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