2018 Manufacturing Energy and Carbon Footprints: Definitions and Assumptions

The U.S. Department of Energy Advanced Manufacturing Office *Manufacturing Energy and Carbon Footprints* map energy flow and carbon dioxide emissions in the U.S. manufacturing sector, from energy supply to end use. The footprints show where energy is used and lost in manufacturing—and the associated greenhouse gas (GHG) emissions. Each footprint visualizes the flow of energy (in the form of fuel, electricity, or steam) to major end uses in manufacturing, including boilers, power generators, process heaters, process coolers, machine-driven equipment, facility heating, ventilation, and air conditioning (HVAC), and lighting. The GHG emissions associated with offsite electricity and steam generation and all onsite GHG emissions are also mapped. Footprints are available for 15 manufacturing sectors that collectively represent 95% of all manufacturing primary energy consumption, five manufacturing subsectors, and U.S. manufacturing as a whole in 2018 (the most recent available data).

Each footprint presents data at three levels of detail. The first page provides a high-level view of manufacturing sector primary energy supply and end use, the second page shows details of how energy is distributed to onsite end uses, and the third page, newly added for the 2018 analysis, depicts the GHG emissions from each point of generation, onsite end use, and process emissions (i.e., non-combustion emissions). The analyses are based on manufacturing energy consumption data from the U.S. Energy Information Administration's (EIA's) 2018 Manufacturing Energy Consumption Survey (MECS), along with referenced energy loss and emission factors, and input from industry and subject matter experts. Greenhouse gas emissions analyses incorporate data from MECS as well as U.S. Environmental Protection Agency's (EPA's) 2021 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019.

This publication documents the key terms and assumptions that are used in the footprints:

- Key terms associated with the energy footprint analysis are defined below in alphabetical order.
- Assumptions associated with the energy footprint analysis are detailed on pages 4 – 13.
- Key terms and assumptions associated with the GHG footprint analysis are detailed on pages 14 – 15.
- References are detailed on pages 16 – 22.

Energy Footprint Analysis Key Term Definitions

Combined heat and power (CHP)/cogeneration – The production of electrical energy along with another form of useful energy (such as heat or steam) through the sequential use of energy.

Conventional boiler – A boiler vessel that consumes fuels or electricity as the primary energy source to produce heat that generates steam or hot water. Boiler losses represent energy lost due to boiler inefficiency.

Electricity export – Sales and transfers offsite of electricity to utilities and to other entities including consumers (e.g., other manufacturers, households, commercial entities), generators of electricity (e.g., independent power purchasers, small power purchasers, and cogenerators not located within the plant boundary), and electricity suppliers (e.g., brokers, marketers, and marketing subsidiaries of utilities). Because electricity export is already taken into account in the footprint analysis in the offsite electricity generation (net) figure, this value is not directly connected to the energy flow diagram. It is provided instead for informative purposes.

Electro-chemical – The direct process end use in which electricity is used to cause a chemical transformation (e.g., reduction of alumina to aluminum and oxygen).

Energy for all purposes – The total first use of energy onsite plus offsite generation and transmission losses. Includes primary energy use for heat and power plus net energy consumed for nonfuel purposes, including feedstock use. This value eliminates potential double counting of feedstock and fuel use from data in MECS Tables 2.2 and 3.2.

Excess steam – Sales and transfers of onsite steam to offsite users or purging of onsite surplus steam. Excess steam is not used within the manufacturing plant boundary and therefore, this value is not directly connected to the energy flow diagram.

Facility HVAC – The direct nonprocess end use that includes energy used to provide heating, ventilation, and air conditioning for building envelopes within the industrial plant boundary.

Facility lighting – The direct nonprocess end use that includes energy used in equipment that illuminates buildings and other areas within the industrial plant boundary.

Industrial plant boundary – Includes all plant facilities and processes (industrial processes, support facilities, and generation facilities) at a single location where mechanical or chemical transformations of materials or substances into new products are performed. This boundary is also termed ***onsite***.

Machine drive – The direct process end use in which thermal or electric energy is converted into mechanical energy and is used to power motor-driven systems, such as compressors, fans, pumps, and materials handling and processing equipment. Motors are found in almost every process in manufacturing. Therefore, when motors are found in equipment that is wholly contained in another end use (such as a compressor in process cooling and refrigeration), the energy is classified in that end use rather than in machine drive.

Machine drive losses – Machine drive losses includes two components:

1) Shaft losses include energy lost in the conversion of thermal or electric energy into kinetic or mechanical energy. Shaft losses are estimated from electric motor, turbine, and engine efficiencies.
2) System losses include energy lost in specific machine driven system applications including fans, pumps, compressed air, materials handling, materials processing, and other systems. The distribution of these six categories of losses is unique within each industry sector.

Nonprocess energy – Energy used for purposes other than industry-specific processes, as reported in EIA MECS Table 5.2 to include facility HVAC, facility lighting, other facility support (e.g., cooking, water heating, and office equipment), onsite transportation, and other nonprocess use.

Offsite electricity generation (net) – The sum of purchased electricity and electricity transfers into the plant boundary (including electricity generated onsite from noncombustion renewable resources to align with MECS Table 5.2 values), less quantities sold and transferred out. This value does not include onsite generation from combustible fuels or onsite cogeneration which are all accounted for by the “other electricity generation” and “CHP/cogeneration” values.

Offsite electricity generation and transmission losses – The energy losses incurred during the generation and transmission of electricity to the plant boundary. The efficiency of utility power generation and transmission is assumed to be 34.1%, a representative average value for the U.S. grid in 2014 (see Table 1 for sources).

Offsite energy – Energy that is originally sourced or generated outside the plant boundary (offsite), including energy produced onsite from feedstocks or nonenergy inputs that is consumed as a fuel within the plant boundary. Includes offsite fuel, offsite steam generation, and offsite electricity generation.

Offsite fuel – The sum of purchased fuel, fuel transferred into the plant boundary, and byproduct fuel (from externally sourced feedstocks or nonenergy inputs) produced and consumed onsite.

Offsite steam generation (net) – The sum of steam transfers and purchased steam from the local utility or other sources, less quantities sold and transferred out.

Offsite steam generation and transmission losses – The energy losses incurred during the generation and transport of steam to the plant boundary.

Onsite electricity generation losses – The energy losses incurred during the onsite generation of electricity. This term includes losses from electricity cogeneration and other onsite electricity generation.

Onsite energy use – Energy inputs used for heat and power (including electricity generation) within the manufacturing plant boundary for the sector. This includes both direct (process and nonprocess end uses) and indirect (steam and electricity generation) uses of fuels, steam, and electricity within the manufacturing plant boundary. Losses that occur in generating and transporting steam and electricity to the plant boundary are not included. Onsite energy use also does not include energy consumed for nonfuel purposes, such as energy feedstocks supplied to the plant that are converted to a manufactured product and not used for heat, power, or electricity generation. Energy used for nonfuel purposes are quantified separately for each manufacturing sector in EIA MECS Table 2.2; though caution should be exercised when combining nonfuel energy with onsite energy use values due to potential double-counting issues.

Onsite generation – The generation of steam or electricity within the plant boundaries using fuel or electricity. Onsite generation includes three categories: "conventional boilers" (to produce steam), "CHP/cogeneration" (to produce steam and electricity), and "other electricity generation" (defined below).

Onsite steam distribution losses – The energy losses incurred during the distribution of steam within the plant boundaries.

Onsite steam generation losses – The energy losses incurred during the generation of steam within plant boundaries. This term includes steam cogeneration and conventional boiler steam generation losses.

Onsite transportation – The direct nonprocess end use that includes energy used in vehicles and transportation equipment that primarily consume energy within the boundaries of the establishment.

Other electricity generation – Consists of onsite electricity obtained from generators running on combustible energy sources including natural gas, fuel oils, and coal. Amounts of electricity generated onsite from renewable sources other than biomass (e.g., solar, wind, hydropower, and geothermal) are noted on the footprints, however this output is excluded from "other electricity generation" values and instead is incorporated within the offsite electricity generation values to align with MECS Table 5.2 values.

Other facility support – The direct nonprocess end use that includes energy used in diverse applications that are normally associated with office or building operations such as cooking, operation of office equipment, and the operation of elevators.

Other nonprocess – The direct nonprocess end use that includes energy used for nonprocess uses other than the defined nonprocess energy categories.

Other process – The direct process end use that includes energy used for other direct process uses not falling under a specified process end use category.

Primary energy use – The total consumption associated with energy inputs used for heat and power (including electricity generation) within the manufacturing plant boundary for the sector. It is the sum of onsite energy use and offsite steam and electricity losses (see "offsite electricity generation and transmission losses", defined above). Primary energy use does not include energy consumed for nonfuel purposes, such as energy feedstocks supplied to the plant that are converted to a manufactured product and not used for heat, power, or electricity generation. Energy used for nonfuel purposes are separately quantified for each manufacturing sector in EIA MECS Table 2.2; though caution should be exercised when combining with primary energy use values due to potential double-counting issues.

Process cooling and refrigeration – The direct process end use in which energy is used to lower the temperature of substances involved in the manufacturing process. Examples include freezing processed meats for later sale in the food industry and lowering the temperature of chemical feedstocks below ambient temperature for use in reactions in the chemical industry.

Process energy – Energy used in industry-specific processes, such as chemical reactors, steel furnaces, glass melters, casting, concentrators, distillation columns, etc. Categories of process energy (as reported in MECS Table 5.2) include process heating (e.g., kilns, ovens, furnaces, strip heaters), process cooling and refrigeration, machine drive (e.g., motors, pumps associated with process equipment), electro-chemical processes (e.g., reduction process), and other direct process uses.

Process heating – The direct process end use in which energy is used to raise or maintain the temperature of substances involved in the manufacturing process. Examples include the use of heat to melt scrap in electric-arc furnaces to make steel, to separate components of crude oil in petroleum refining, to dry paint in automobile manufacturing, or to process food for packaging.

Process heating losses – Process heating losses include both system losses (radiation, convection, insulation, and cooling losses) and exhaust losses (stack, vent losses, etc.). Process heating energy losses are estimated by sector (see Table 4); an industry peer review group was formed to guide this estimation approach.

2018 Energy Footprint Analysis Assumptions

Table 1. Manufacturing Energy Footprint Loss Assumptions[a]

Energy System Type	Energy System Description	Percent Energy Lost	Sources
Energy Generation, Transmission and Distribution Losses			
Offsite Generation	Offsite (grid) electricity generation and transmission	64.6%[b]	[1], [2]
	Offsite steam generation	20%	[3], [4], [5]
	Offsite steam transmission	7.5%	[4]
Onsite Generation	Onsite steam generation (conventional boiler)	11% to 25% *(varies, sector dependent)*	[6], See Table 2
	Onsite CHP/cogeneration	18% to 26% *(varies, sector dependent)*	[6], [7], [8], See Table 3
	Onsite steam distribution	20%	[9], [10], [11]
Onsite Direct End Use (Process and Nonprocess) Losses			
Process Energy	Process heating	17% to 60% *(varies, sector dependent)*	See Table 4
	Process cooling, refrigeration	32%[c]	[12], Estimation
	Electro-chemical	Chemicals 37%	[13]
		Alumina and aluminum 59%	[14], [15]
		All manufacturing and other sectors 48%	Average
	Other processes	Electric 5%	Estimation[d]
		Fuel 70%	

Energy System Type	Energy System Description	Percent Energy Lost	Sources
	e.g., computer-controlled equipment, process tools	Steam 40%	
	Machine drive i.e., shaft energy	Electric 6%	[16], [17], [18]
		Fuel 62%	[19], [20], [21], [22], [23]
		Steam 60%	[24], [25], [26]
	Machine driven systems	Pumps 32%[e]	[27], [28], [29], [30], [31], [32], [33]
		Fans 32%[e]	[27], [28], [31], [32], [33], [34]
		Compressed air 83%[e]	[27], [28], [31], [32], [33], [35], [36]
		Materials handling 10%	[37], [38], [39]
		Materials processing (e.g., grinders) 80%	Estimation[f]
		Other systems 47%	Average of identified machine-driven systems
Nonprocess Energy	Facility HVAC	32%[g]	[12]
	Facility lighting	69% to 72% *(varies, sector dependent)*	[40], [41], [42], See Table 5
	Other facility support	Electric 10%	Estimation[h]
		Fuel 31%	[43], [44], Estimation[h]
	Onsite transportation	30% to 71% *(varies, sector dependent)*	[45], [46], See Table 6
	Other nonprocess e.g., cleaning equipment, maintenance tools	Electric 33%	Estimation[i]
		Fuel 35%	
		Steam 30%	

Table 1 Notes

[a] The values in this table are used to generate order-of-magnitude energy loss estimates. In practice, these energy generation, process, and nonprocess losses are highly dependent on specific operating equipment and conditions and vary greatly within and across manufacturing sectors.

[b] This analysis adjusted the EIA-calculated value for offsite electricity generation and transmission (grid) losses to eliminate double-counting of generation losses from offsite-derived steam from CHP plants. Industrial sector electrical system energy losses in 2018 are quantified by EIA in Table 2.4 of the EIA Monthly Energy Review (MER) 2021 [1] (equal to 6,481 trillion British thermal units [TBtu]). Using these losses and electricity retail sales to the industrial sector (equal to 3,414 TBtu), percentage losses are calculated to be 65.5%. However, footnote j in Table 2.4 of the EIA MER 2021 makes it clear that "Total losses are calculated as the primary energy consumed by the electric power sector minus the energy content of electricity retail sales. Total losses are allocated to the end-use sectors in proportion to each sector's share of total electricity retail sales." Furthermore, in reviewing Table 2.6 of the EIA MER 2021, which details primary energy consumption for the electric power sector, it is noted that "data are for fuels consumed to produce electricity and useful thermal output" and that "the electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants within the NAICS 22 category whose primary business is to sell electricity, or electricity and heat, to the public." Thus,

energy for any offsite derived steam from certain CHP facilities is inherently already included in the electricity loss data (meaning that without adjustment, any generation losses for this CHP-derived steam would double-count losses). The double-counting of these losses is eliminated by relying on data from EIA MER 2021 Table 2.4 [1] and EIA Electric Power Annual 2021 Tables 3.24 and 3.26 [2]. As a result, generation and transmission losses are adjusted from 65.5% to 64.6%.

[c] An autonomous energy efficiency improvement factor is being used to take into account process cooling system energy efficiency improvements in the years since the release of the 2010 Manufacturing Energy Footprints. Losses in 2010 are 35% according to [12], while losses in each subsequent year are diminished to 99% of preceding year.

[d] Loss assumptions for electric, fuel, and steam other process energy were estimated after an extensive literature search and discussions with EIA staff and manufacturing process experts. EIA/MECS does not define specific other process end uses, so representative examples of other processes were first identified by examining the sectors with the largest consumption of other process energy in the MECS data; loss factors associated with these examples were then estimated.

[e] Leveraging available data, loss assumptions for pumps, fans and compressed air motor systems were adjusted to take into account market penetration of various drive technologies, along with typical system degradation losses since 2010. The prior loss assumptions for pumps, fans, and compressed air motor systems used in the 2014 Footprints were, respectively, 39%, 39%, and 84%.

[f] The loss assumption for materials processing was estimated after an extensive literature search and discussions with EIA staff and manufacturing sector experts. Representative examples of materials processing end uses were first identified and loss factors associated with these examples were then estimated.

[g] An autonomous energy efficiency improvement factor is being used to take into account HVAC system energy efficiency improvements in the years since the release of the 2010 Manufacturing Energy Footprints. Losses in 2010 are 35% according to [12], while losses in each subsequent year are diminished to 99% of preceding year.

[h] Loss assumptions for electric and fuel other facility support energy were estimated after an extensive literature search and discussions with EIA staff and manufacturing sector experts. EIA/MECS does not define specific other facility support end uses, so representative examples of other facility support end uses were first identified by examining the sectors with the largest consumption of other facility support energy in the MECS data; loss factors associated with these examples were then estimated.

[i] Loss assumptions for fuel and steam nonprocess energy were estimated after an extensive literature search and discussions with EIA staff and manufacturing sector experts. EIA/MECS does not define specific other nonprocess end uses, so representative examples of other nonprocesses were first identified by examining the sectors with the largest consumption of other nonprocess energy in the MECS data; loss factors associated with these examples were then estimated. Because electricity is a minor energy source for nonprocesses, the loss factor is assumed as the average of fuel and steam.

Table 2. Conventional Boiler Efficiency by Sector

Sector	Conventional Boiler Efficiency
Alumina and Aluminum	89%
Cement	80%
Chemicals	82%
Computers, Electronics, and Electrical Equipment	80%
Fabricated Metals	85%
Food and Beverage	78%
Forest Products	75%
Foundries	80%
Glass and Glass Products	80%
Iron and Steel	81%
Machinery	85%
Petroleum Refining	80%
Plastics and Rubber Products	84%
Textiles	81%
Transportation Equipment	81%
All Manufacturing (weighted average)	**80%**

Approach/Sources: In practice, the efficiency of a fuel-consuming boiler can be as low as 55-60%, or as high as 90%. Electric boilers can have efficiencies approaching 100%. The age of the boiler, boiler size, maintenance practices, and fuel type are all important considerations when determining efficiency. Sector specific boiler efficiencies are not readily available through literature search. As a result, an analysis was conducted in 2021 to estimate boiler efficiencies by fuel type for the footprint sectors. The breakdown of conventional boiler fuel use by sector is provided by 2018 EIA MECS and is adjusted to be consistent with the overall footprint methodology. Boiler efficiency is known to vary by fuel type (along with other variables such as thermal recovery and combustion control, which are not detailed here). Two sources were consulted in determining boiler fuel type efficiency: 1) Energy Information Administration, 2020 Model Documentation Report: Industrial Demand Module of the National Energy Modeling System [6] – determined to be representative of small to medium sized plants, and 2) field data collected by industrial efficiency consultant Greg Harrell, Ph.D., P.E., Milligan University – determined to be representative of larger plants. Through consultation with Bob Bessette/President, Council of Industrial Boiler Operators and Thomas Wenning/Program Manager, Oak Ridge National Laboratory, an approximation of small to medium versus large facilities was determined in estimating boiler efficiency by sector. For the small portion of boiler input energy that is electrical (2% of boiler fuel for All Manufacturing in 2018) an efficiency of 98% is assumed [47]. The results of this approach are shown in the table above. The subsectors included in the expanded scope of the 2018 analysis were assumed to have the same conventional boiler efficiency as its three-digit NAICS code sector. These include aerospace product and parts (NAICS 336), automobile and light duty motor vehicle (NAICS 336), petrochemicals (NAICS 325), plastics material and resins (NAICS 325), and semiconductors (NAICS 334).

Table 3. CHP/Cogeneration Efficiency by Sector

Sector	CHP/Cogeneration Efficiency
Chemicals	74%
Food and Beverage	82%
Forest Products	74%
Iron and Steel	80%
Petroleum Refining	75%
All Manufacturing (weighted average)	**75%**
All Manufacturing *used for the following sectors where there is insufficient data:* Alumina and Aluminum; Cement; Computers, Electronics, and Electrical Equipment; Fabricated Metals; Foundries; Glass and Glass Products; Machinery; Plastics and Rubber Products, Textiles; Transportation Equipment	**75%**

Approach/Sources: Sector-specific CHP output components and efficiencies were estimated by adjusting reported data from two separate EIA surveys. For each individual sector and all manufacturing, total CHP fuel consumption and electricity generated in 2018 are provided in [7] by fuel and prime mover. For steam turbine CHP systems (which consume a majority of the CHP input fuel in manufacturing), the values from [7] were used for electricity production and steam output was determined by using the electricity output and the boiler efficiencies by fuel type estimated for the analysis described in Table 2. For other CHP systems, efficiency estimates were derived from estimates provided in [8]. In both cases, steam efficiency was adjusted to account for actual electric output reported in [7] and used to determine steam generated and overall efficiency. While the All Manufacturing CHP efficiency average value determined through this analysis based on [7] is used for sectors where there is insufficient data, a weighted average using the efficiencies estimated and the actual MECS-based CHP energy input and electricity output was determined for the All Manufacturing CHP efficiency in order to balance the footprint. The subsectors included in the expanded scope of the 2018 analysis were assumed to have the same CHP/cogeneration efficiency as its three-digit NAICS code sector. These include aerospace product and parts (NAICS 336), automobile and light duty motor vehicle (NAICS 336), petrochemicals (NAICS 325), plastics material and resins (NAICS 325), and semiconductors (NAICS 334). Other sources: [6]

Table 4. Process Heating Loss Assumptions by Sector

Sector	Percent of Process Heating Energy Lost
Alumina and Aluminum	45%
Cement	46%
Chemicals	24%
Computers, Electronics, and Electrical Equipment	34%
Fabricated Metals	34%
Food and Beverage	55%
Forest Products	60%
Foundries	51%
Glass	58%
Iron and Steel	45%
Machinery	34%
Petroleum Refinery	17%
Plastics and Rubber Products	23%
Textiles	59%
Transportation Equipment	45%
All Manufacturing (weighted average)	**33%**

Approach/Sources: A Manufacturing Process Heating Energy Loss Working Group was formed in June 2021 to estimate energy losses from key process heating equipment for the footprints sectors. Process heating energy loss, as defined in the energy footprint, is not a value that is readily available through literature search. As a result, the working group was formed to contribute to this important piece of the footprint analysis effort. Available plant assessment results and relevant industrial studies were all considered in estimating process heating energy loss by manufacturing sector and subsector, shown in this table. All Manufacturing process heating energy loss was determined by taking a weighted average of sector-specific process heating loss and MECS-based energy input. The subsectors included in the expanded scope of the 2018 analysis were assumed to have the same process heating energy loss as its three-digit NAICS code sector. These include aerospace product and parts (NAICS 336), automobile and light duty motor vehicle (NAICS 336), petrochemicals (NAICS 325), plastics material and resins (NAICS 325), and semiconductors (NAICS 334).

References used by the Process Heating Energy Loss Working Group: [14], [28], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91]

Table 5. Facility Lighting Loss Assumptions by Sector

Sector	Percent of Facility Lighting Energy Lost
Alumina and Aluminum; Cement; Computers, Electronics, and Electrical Equipment; Foundries; Glass and Glass Products; Iron and Steel	69%
Fabricated Metals; Food and Beverage; Forest Products; Machinery; Petroleum Refining; Plastics and Rubber Products; Textiles	70%
Transportation Equipment	71%
Chemicals	72%
All Manufacturing	**70%**

Approach/Sources: Efficiency was determined in each individual manufacturing sector by considering the mix of lighting sources (with associated efficacies) in each sector, as detailed in [40] and [42]. Efficiency is calculated by dividing the sector-specific efficacy by the maximum practical lighting efficacy for the most efficient lighting technology in use today. LED lighting, with maximum practical lighting efficacy estimated to be equal to 300 lumens/watt according to [41], is used to calculate efficiency. The subsectors included in the expanded scope of the 2018 analysis were assumed to have the same facility lighting loss as its three-digit NAICS code sector. These include aerospace product and parts (NAICS 336), automobile and light duty motor vehicle (NAICS 336), petrochemicals (NAICS 325), plastics material and resins (NAICS 325), and semiconductors (NAICS 334).

Table 6. Onsite Transportation Loss Assumptions by Sector

Sector	Percent of Facility Onsite Transportation Energy Lost
Alumina and Aluminum	60%
Cement	58%
Chemicals	52%
Computers, Electronics, and Electrical Equipment	71%
Fabricated Metals	51%
Food and Beverage	30%
Forest Products	59%
Foundries	71%
Glass and Glass Products*	N/A
Iron and Steel	58%
Machinery	45%
Petroleum Refining	58%
Plastics and Rubber Products	38%
Textiles*	N/A
Transportation Equipment	42%
All Manufacturing	51%

Approach/Sources: Efficiency was determined in each individual manufacturing sector by considering the mix of fuels from MECS 2018 data used for onsite transportation (with associated efficiencies). Diesel fuel losses are assumed to be 58% based on [45]. Hydrocarbon gas liquids (HGL, lifting), HGL (propulsion), natural gas, and electric (forklift) losses are assumed to be, respectively, 72%, 70%, 72%, and 5% based on [46].

The subsectors included in the expanded scope of the 2018 analysis were assumed to have the same onsite transportation energy loss as its three-digit NAICS code sector. These include aerospace product and parts (NAICS 336), automobile and light duty motor vehicle (NAICS 336), petrochemicals (NAICS 325), plastics material and resins (NAICS 325), and semiconductors (NAICS 334).

* No onsite transportation energy consumption was reported by MECS in these sectors.

Table 7. Steam Distribution to End Uses by Sector

Sector	Steam End Use					
	Process Heating	Machine Drive	Process Cooling and Refrigeration	Other Process Uses	Facility HVAC	Other Nonprocess Uses
Alumina and Aluminum	31%	13%	0%	27%	21%	7%
Cement	45%	6%	1%	16%	27%	6%
Chemicals	67%	10%	3%	8%	9%	4%
Computers, Electronics, and Electrical Equipment	16%	0%	1%	7%	73%	4%
Fabricated Metals	35%	1%	1%	16%	46%	2%
Food and Beverage	69%	4%	5%	8%	10%	3%
Forest Products	70%	9%	2%	5%	9%	4%
Foundries	13%	15%	0%	9%	60%	3%
Glass and Glass Products	5%	5%	0%	22%	63%	5%
Iron and Steel	46%	7%	0%	8%	38%	1%
Machinery	24%	29%	1%	7%	37%	1%
Petroleum Refining	66%	16%	2%	10%	4%	2%
Plastics and Rubber Products	71%	1%	0%	7%	18%	3%
Textiles	63%	2%	2%	10%	21%	2%
Transportation Equipment	27%	2%	7%	9%	53%	2%
All Manufacturing	**66%**	**10%**	**3%**	**8%**	**10%**	**3%**

Approach/Sources: A Manufacturing Steam End Use Working Group was formed in 2011 to estimate the allocation of steam to process and nonprocess end uses across 15 manufacturing sectors. Comparative steam use by sector for the process and nonprocess end uses defined in the footprint is not a value that is readily available through literature search. As a result, the working group was formed to contribute to this important piece of the footprint analysis effort. The results from the working group were applied to determine steam allocation for the 2010, 2014, and 2018 footprints. The end use of steam for 15 manufacturing sectors was considered. The working group issued an industry survey to solicit industry expertise, and results from the survey were referenced in determining the final steam allocations by sector. Results from the peer review are shown in this table. Methodology details are available in Appendix E of the Manufacturing Energy Use and Loss and Emissions Analysis (October 2012), available for download here: https://energy.gov/eere/amo/downloads/us-manufacturing-energy-use-and-greenhouse-gas-emissions-analysis.

The subsectors included in the expanded scope of the 2018 analysis were assumed to have the same steam allocation as its three-digit NAICS code sector. These include aerospace product and parts (NAICS 336), automobile and light duty motor vehicle (NAICS 336), petrochemicals (NAICS 325), plastics material and resins (NAICS 325), and semiconductors (NAICS 334).

Adjustments to Blast Furnace Gas in the Iron and Steel Sector

MECS data reporting of Fuel Consumption includes numerous types of fuel including Coke and Breeze, and "Other" fuel, where the Other fuel category includes the sum of blast furnace gas/coke oven gas (BFG/COG). MECS methodology acknowledges that these reported values involve some double counting, since they consider that the reported fuels are completely consumed and are not transformed to other energy sources later. EIA also notes that they assume (based on their research) that blast furnace gas is produced in the blast furnace from the input fuel use of coke. As a result, they suggest adjusting the fuel use of coke downward by the heat content of the blast furnace gas consumed (which is reported by AISI in the Annual Statistical Report) in order to account for the double counting. In other words, because the BFG (later used as fuel onsite) is produced from the coke fuel input, counting both the total value of coke and BFG would be double counting; the energy (heat content) of the BFG used as fuel reported in the MECS is produced as a result of the coke fuel input to the blast furnace, so the amount of energy of the coke used to produce BFG should not be accounted in addition to the amount of energy of the BFG. Thus, to eliminate double counting, the consumption of Coke and Breeze is adjusted downward by the heat content of the BFG.

Full MECS Methodology note on Duplication in Fuel Use of Coal Coke and Blast Furnace Gas in the Iron and Steel Industry

"MECS analysts have assumed for purposes of estimation that all energy sources used for fuel are completely consumed in the process. That means that an energy source used as fuel will not be transformed into another substance that can later be used for fuel or nonfuel purposes. The assumption holds well enough in most cases even though waste substance that was not consumed in the heater or boiler may accumulate. In the case of a blast furnace used in the iron making process (NAICS 331111), the effect of not completely consuming the blast furnace fuel inputs may be a significant cause of duplication. Literature reviews and consultation have revealed that most of the formation of the blast furnace gas would arise from the input fuel use of coke. Other sources may contribute to the generation of blast furnace gas, but they appear to be minor compared with coke.

One possible solution to adjusting the MECS data so that the energy flows in NAICS 331111 appear reasonable is to adjust the fuel use of coal coke downward by the heat content of the blast furnace gas consumed in that industry. As implied in the preceding paragraph, this adjustment would be imperfect because not all of the blast furnace gas would necessarily arise from the incomplete combustion of coal coke. Another complication is that the MECS has historically published only a combined estimate for coke oven gas and blast furnace gas to meet publication requirements. However, the proportion of blast furnace gas in those combined estimates has been about two-thirds."

Adjustments to CHP Fuel and Electricity Generation

For certain sectors, the values reported in MECS Tables 5.2/5.4 and Table 11.3 did not align for 2018. As shown in the Table 8, Plastics, Fabricated Metals, and Automobile and Light Duty Motor Vehicles all have a 0% electricity output for CHP, while Aluminum has a 91% electricity output. Based on the analysis of EIA-923 data done for the CHP loss values for the Footprints, a value of around 16% is expected for these sectors (using the All Manufacturing average). EIA confirmed that if there is an estimate for CHP fuel consumption in Table 5.2, there should be an estimate for CHP electricity generation in Table 11.3.

The proposed and implemented solution for the sectors with 0% electricity output, Plastics, Fabricated Metals, Automobile and Light Duty Motor Vehicle, and the sector with excessive CHP electricity output, Aluminum, is to replace the Table 11.3 CHP electricity generation value with what is expected based on the analysis of EIA-923 data for 2018. Because the sectors involved do not have enough facility data in EIA-923 to determine a sector-specific CHP efficiency and electricity output value, the All Manufacturing average (75% CHP efficiency; 16% electricity output) is used to calculate an adjusted CHP electricity generation value for 2018, summarized below.

Table 8: CHP Fuel Consumption, Electricity Generation, and Adjusted Electricity Generation for Sectors with Data Inconsistencies

Sector/Subsector	NAICS Code	Table 5.2 Adjusted CHP Fuel Consumption (TBtu)	Table 11.3 CHP Electricity Generation (TBtu)	Implied Electricity Output[a]	Adjusted CHP Electricity Generation (TBtu)[b]
Plastics	326	19.8	0	0%	3
Aluminum	3313	13.9	11.7	91%	2
Fabricated Metals	332	11.4	0	0%	2
Automobile and Light Duty Motor Vehicle	33611	2.9	0.003	0.1%	0.5

[a] Implied electricity output is calculated as: $\frac{CHP\ Electricity\ Generation}{CHP\ Fuel\ Consumption}$. Based on analysis of EIA-923 data for 2018, the average electricity output for all manufacturing is 16%.

[b] Adjusted CHP electricity generation is calculated as: $CHP\ Fuel\ Consumption \times CHP\ Electricity\ Output$. Based on analysis of EIA-923 data for 2018, the average electricity output for all manufacturing is 16%. These are the values that appear in the footprints.

2018 Carbon Footprint Analysis Definitions and Assumptions

Carbon dioxide equivalent (CO_2e) – A measure used to compare the emissions of various greenhouse gases, such as CH_4 and N_2O, based upon their global warming potential (GWP).[1] The functionally equivalent amount or concentration of CO_2 serves as the reference. CO_2e is derived by multiplying the mass of the gas by its associated GWP, with units commonly expressed as million metric tons of carbon dioxide equivalent (MMT CO_2e) [92].

Greenhouse gas (GHG) combustion emissions – For this analysis, the emissions considered from the fuel use of energy include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as these are the greenhouse gases released during the combustion of fuel. As shown in Table 9, the emission factors used were sourced primarily from the Environmental Protection Agency's (EPA) Mandatory Greenhouse Gas Reporting Rule and the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* [93, 94]. Over 99% of the emissions from combustion are CO_2. While CH_4 and N_2O contribute only a small amount to total emissions, they were included in this analysis to best adhere to the EPA reporting rule.

Offsite GHG combustion emissions – The emissions released by the fuel use of energy (i.e., combustion) outside an industrial facility, but associated with energy later consumed by the facility. For example, a power plant generates electricity by burning coal as fuel. An industrial facility then purchases this electricity and consumes it at its facility. The offsite emissions associated with this electricity use are those that were released during the combustion of coal at the power plant while generating that electricity. Similarly, emissions are released during the generation of steam offsite. The offsite GHG combustion emissions in the footprints diagrams account for the sectors scope 2 emissions.

Onsite GHG combustion emissions – The emissions released by the fuel use of energy (i.e., combustion) within the industrial plant boundary. This fuel is used "indirectly," to generate steam and electricity for later use, and "directly," to power processes and supporting equipment. In the footprint diagram, the emissions from indirect end uses, namely onsite steam and power generation, are not distributed to the direct end uses of that energy. For example, process heating onsite emissions do not include the emissions released during onsite generation of steam used for process heating. GHG combustion emissions generated from onsite generation, process energy, and nonprocess energy contribute to the sector's scope 1 emissions.

Emissions from the combustion of blast furnace gas, coke, and coke oven gas are considered process emissions and are thus not considered combustion emissions, in accordance with EPA and Intergovernmental Panel on Climate Change (IPCC) guidelines. Also excluded are CO_2 emissions from biomass use.

Process Emissions – The emissions generated and emitted as byproducts of various non-energy-related industrial processes and not directly a result of energy consumed during the process. For example, raw materials can be chemically or physically transformed from one state to another. This transformation can result in the release of GHGs and would be consider a process emission. Process emissions data was sourced from

[1] GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. For this analysis, a 100-year time interval is used, with GWPs sourced from the Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) [98]. The GWP-weighted emissions in the U.S. Inventory are presented in terms of CO2e emissions with units of teragrams (Tg) of carbon dioxide equivalent (Tg CO2e) [93]. Specifically, the GWPs used for CO_2, CH_4, and N_2O are 1, 25, and 298 Tg CO_2e [IPCC 2007] respectively [98].

EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks, Chapter 4: Industrial Processes and Product Use Emissions*.[2] Process emissions generated from process energy contribute to the sector's scope 1 emissions.

Total GHG emissions – The sum of offsite and onsite GHG combustion emissions and process emissions.

Table 9. Fuel Combustion Emission Factors (kg CO_2e per million British thermal units (MMBtu))

Fuel Type[a]	CO_2	CH_4	N_2O	Total GHG	Source
Agricultural Byproducts	*118.17*[b]	0.80	1.25	*2.05*	[94]
Coal (Industrial Sector)	94.67	0.28	0.48	95.43	[94]
Distillate Fuel Oil No. 2	73.96	0.075	0.18	74.22	[94]
Electricity Generation (offsite)[c]	132	0.30	0.050	132.80	[94, 95]
Kerosene	75.20	0.075	0.18	75.46	[94]
LPG (energy use)	61.71	0.075	0.18	61.97	[94]
Natural Gas (pipeline weighted average)	53.06	0.025	0.030	53.12	[94]
Petroleum Coke	102.41	0.075	0.18	102.67	[94]
Pulping Liquor/Black Liquor	*94.40*[b]	0.048	0.13	*0.18*	[94]
Residual Fuel Oil No. 6	75.10	0.075	0.18	75.36	[94]
Steam Generation (offsite)[c]	71.71	0.035	0.0414	71.78	[94, 96]
Still Gas	66.72	0.075	0.18	66.98	[94]
Waste Oils, Tars, and Waste Materials	74.54	0.075	0.18	74.80	[94]
Wood and Wood Residuals	*93.80*[b]	0.18	1.07	*1.25*	[94]

[a] Emissions from the combustion of blast furnace gas and coke oven gas are considered to be process emissions because the source of the carbon contained in these gases stems from coking coal and metallurgical coke that is already accounted for in non-combustion emissions. Emissions from the combustion of coke are also considered a process emission as well. Therefore, in accordance with EPA GHG inventory and IPCC guidelines, emissions from consumption of coal coke (i.e., identified as "coke and breeze" in EIA MECS data tables), blast furnace gas, and coke oven gas are not considered combustion emissions in this analysis.

[b] Only CH_4 and N_2O emissions are considered from biomass fuels; CO_2 emissions from biomass fuel combustion (also known as biogenic CO_2) are not included in the total GHG emission factor because the uptake of CO_2 during biomass growth results in zero net emissions over time.

[c] Factors adjusted to reflect losses in transmission.

[2] In accordance with EPA's emissions reporting for the petroleum refining sector, all emissions from hydrogen production plants located at refineries are allocated to the chemicals sector.

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