2010 Manufacturing Energy and Carbon Footprints: Definitions and Assumptions

A number of key terms are used to interpret the manufacturing energy and carbon footprints. The terms associated with the energy footprint analysis are defined below in alphabetical order. Key definitions and assumptions associated with the greenhouse gas (GHG) footprint analysis are shown on pages 12 and 13.

Energy Footprint Analysis Definitions

CHP/Cogeneration – The production of electrical energy and 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. The footprint analysis considers only the net electricity consumed onsite, so electricity export is not included in the total primary and onsite energy use value, and hence it is not directly connected to the energy flow diagram. This figure is included 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).

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 MECS Table 5.2 to include facility HVAC, facility lighting, other facility support (e.g., cooking, water heating, office equipment), onsite transportation, and other nonprocess use.

Offsite electricity generation – The sum of purchased electricity and electricity transfers into the plant boundary.

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 33.2%, a representative average value for the national grid.

Offsite energy – Energy that is originally sourced or generated outside the plant boundary (offsite). Includes offsite fuel, offsite steam, and offsite electricity.

Offsite fuel – The sum of purchased fuel, fuel transferred into the plant boundary, and byproduct fuel (from nonfuel sources) produced and consumed onsite.

Offsite steam generation – 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 – 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. Onsite electricity and steam each include purchased energy, energy transferred on and offsite and onsite-generated energy. 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 as a nonfuel feedstock, that is, energy supplied to the plant boundary that is converted to a manufactured product and not used for heat, power, or electricity generation. Energy used as a nonfuel feedstock is quantified separately for each manufacturing sector in EIA MECS Table 2.2; though caution should be exercised when combining nonfuel feedstock 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 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 (onsite) – Consists of 1) electricity obtained from generators running on combustible energy sources including natural gas, fuel oils, and coal and 2) electricity generated onsite from renewable sources other than biomass (e.g., solar, wind, hydropower, and geothermal).

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.

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.

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

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.

Total primary energy use – The total energy consumed as a fuel by the manufacturing sector. It is the sum of onsite energy use and offsite steam and electricity losses (see *offsite losses*, defined above). Total primary energy use does not include energy consumed as a nonfuel feedstock, that is, energy supplied to the plant boundary that is converted to a manufactured product and not used for heat, power, or electricity generation. Energy used as a nonfuel feedstock is 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.

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[b]	66.8%	[15]
	Offsite steam generation	20%	[20], [30]
	Offsite steam transmission	10%	[30]
Onsite Generation	Onsite steam generation (conventional boiler)	18% to 22% *(varies, sector dependent)*	[12], [16] See Table 2
	Onsite CHP/cogeneration	18% to 29% *(varies, sector dependent)*	[14], [16], [17] See Table 3
	Onsite steam distribution	20%	[33]
Onsite Direct End Use (Process and Nonprocess) Losses			
Process Energy	Process heating	18% to 72% *(varies, sector dependent)*	See Table 4
	Process cooling, refrigeration	35%	[32]
	Electro-chemical	Chemicals 35%	[9]
		Aluminum 60%	[3], [22]
		All manufacturing and other sectors 48%	Average
	Other processes e.g., computer-controlled equipment, process tools	Electric 5%	Estimation[c]
		Fuel 70%	
		Steam 40%	
	Machine drive i.e., shaft energy	Electric 6% to 8% *(varies, sector dependent)*	[2], [7], [24], [25], [26], [27]
		Fuel 63%	[18]
		Steam 60%	[5], [6], [23]
	Machine driven systems	Pumps 40%	[20], [21]
		Fans 40%	[13], [31]
		Compressed air[d] 85%	[28]
		Materials handling 15%	[8]
		Materials processing (e.g., grinders) 80%	Estimation[e]
		Other systems 52%	Average of identified machine driven systems
Nonprocess Energy	Facility HVAC	35%	[10]
	Facility lighting	74.1% to 74.6% *(varies, sector dependent)*	[11], [35] See Table 5
	Other facility support	Electric 10%	Estimation[f]
		Fuel 35%	[4]
	Onsite transportation	65%	[1], [29], [34]
	Other nonprocess e.g., cleaning equipment, maintenance tools	Electric 33%	Estimation[g]
		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 2010 are quantified by EIA in Table 2.1d of the EIA Annual Energy Review (AER) 2011 [15] (equal to 6,934 TBtu). Using these losses and electricity retail sales to the industrial sector (equal to 3,313 TBtu), percentage losses are calculated to be 67.7%. However, footnote 12 in Table 2.1d of the EIA AER 2011 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 2.1f of the EIA AER 2011, 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 AER 2011 Table 8.2c, Table 8.3b, and 8.5c. As a result, generation and transmission losses are adjusted from 67.7% to 66.8%.

[c] 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.

[d] The sourced Oak Ridge National Laboratory report [28] references a typical efficiency range for industrial pneumatic systems that includes motor shaft losses. This analysis assumes an efficiency equal to the mid-point of the efficiency range and adjusts the efficiency to not include motor shaft losses, which are considered in a different analysis assumption.

[e] 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.

[f] 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.

[g] 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.

Table 1 References

1. 21st Century Truck Partnership. 2013. *Roadmap and Technical White Papers.* http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/21ctp_roadmap_white_papers_2013.pdf
2. Actel. 2009. *Motor Efficiency Depends Upon Power Factor.* http://www.actel.com/documents/Motor_PowerFactor_WP.pdf
3. Ahmed, Ludna. 2011. *Chlor-Alkali Industries: Caustic soda, Chlorine, Soda Ash*. PowerPoint presentation. http://teacher.buet.ac.bd/lubna/coursecontent/Caustic%20soda%20ChE%20308.pdf
4. ACEEE (American Council for an Energy-Efficient Economy). 2012. "Water Heating." http://aceee.org/consumer/water-heating
5. AMO (Advanced Manufacturing Office), EERE (Energy Efficiency and Renewable Energy). 2012. *Consider Installing High-Pressure Boilers with Backpressure Turbine-Generators.* U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/steam22_backpressure.pdf
6. AMO (Advanced Manufacturing Office), EERE (Energy Efficiency and Renewable Energy). 2012. *Consider Steam Turbine Drives for Rotating Equipment.* U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/steam21_rotating_equip.pdf
7. AMO (Advanced Manufacturing Office), EERE (Energy Efficiency and Renewable Energy). 2012. *Estimating Motor Efficiency in the Field*. DOE/GO-102012-3734. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/estimate_motor_efficiency_motor_systemts2.pdf
8. AMO (Advanced Manufacturing Office), EERE (Energy Efficiency and Renewable Energy). 2012. *Replace V-Belts with Notched or Synchronous Belt Drives*. DOE/GO-102012-3740. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/replace_vbelts_motor_systemts5.pdf
9. Beck, Theodore R. 2001. "Electrolytic Production of Aluminum." Case Western Reserve University. Last modified May 2008. http://electrochem.cwru.edu/encycl/art-a01-al-prod.htm
10. Bell, Arthur. *HVAC Equations, Data, and Rules of Thumb.* 2nd ed. United States: McGraw Hill, 2007.
11. BTP (Buildings Technology Program), EERE (Energy Efficiency and Renewable Energy). 2012. *2010 U.S. Lighting Market Characterization*. Prepared by Navigant Consulting. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf
12. DOE (U.S. Department of Energy). 2012. "Furnaces and Boilers." U.S. Department of Energy. http://energy.gov/energysaver/articles/furnaces-and-boilers
13. EERE (Energy Efficiency and Renewable Energy). 2003. *Improving Fan System Performance: A Sourcebook for Industry*. DOE-GO-102003-1822. Prepared by Lawrence Berkeley National Laboratory, Washington, DC, and Resource Dynamics Corporation, Vienna, VA. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/fan_sourcebook.pdf
14. EIA (U.S. Energy Information Administration). 2011. *2010: EIA-923.* U.S. Department of Energy. http://www.eia.gov/electricity/data/eia923/
15. EIA (U.S. Energy Information Administration). 2012. *Annual Energy Review 2011.* DOE/EIA-0384 (2011), U.S. Department of Energy. www.eia.gov/totalenergy/data/annual/pdf/aer.pdf
16. EIA (U.S. Energy Information Administration). 2013. *Model Documentation Report: Industrial Demand Module of the National Energy Modeling System.* U.S. Department of Energy. http://www.eia.gov/forecasts/aeo/nems/documentation/industrial/pdf/m064(2013).pdf
17. EPA (U.S. Environmental Protection Agency). 2008. *Catalog of CHP Technologies.* U.S. Environmental Agency Combined Heat and Power Partnership. http://www.epa.gov/chp/documents/catalog_chptech_full.pdf
18. EPA (U.S. Environmental Protection Agency). 2008. *Technology Characterization: Gas Turbines*. Prepared by Energy and Environmental Analysis, Arlington, VA. U.S. Environmental Protection Agency. www.epa.gov/chp/documents/catalog_chptech_gas_turbines.pdf

19. EPA (U.S. Environmental Protection Agency). 2011. *ENERGY STAR Performance Ratings Methodology for Incorporating Source Energy Use.* U.S. Environmental Protection Agency. www.energystar.gov/ia/business/evaluate_performance/site_source.pdf
20. ITP (Industrial Technologies Program), EERE (Energy Efficiency and Renewable Energy). 2005. *Test for Pumping System Efficiency*. DOE/GO-102005-2158. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/test_pumping_system__pumping_systemts4.pdf
21. ITP (Industrial Technologies Program), EERE (Energy Efficiency and Renewable Energy). 2006. *Improving Pumping System Performance: A Sourcebook for Industry, Second Edition*. DOE-GO 102006-2079. Prepared by Lawrence Berkeley National Laboratory, Berkeley, CA, Resource Dynamics Corporation, Vienna, VA, and the Alliance to Save Energy, Washington, DC. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/pump.pdf
22. ITP (Industrial Technologies Program), EERE (Energy Efficiency and Renewable Energy). 2006. *Low-Temperature Reduction of Alumina Using Fluorine-Containing Ionic Liquids.* U.S. Department of Energy. www1.eere.energy.gov/manufacturing/industries_technologies/aluminum/pdfs/ionicliquids.pdf
23. ITP (Industrial Technologies Program), EERE (Energy Efficiency and Renewable Energy). 2010. *BestPractices Steam Specialist Qualification Training.* U.S. Department of Energy.
24. Lowe, Marcy, Ruggero Golini, and Gary Gereffi. 2010. *U.S. Adoption of High-Efficiency Motors and Drives: Lessons Learned.* Center on Globalization, Governance & Competitiveness, Duke University. www.cggc.duke.edu/pdfs/CGGC-Motor_and_Drives_Report_Feb_25_2010.pdf
25. Motor Challenge. 1996. *Buying an Energy-Efficient Electric Motor*. DOE/GO-10096-314. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/mc-0382.pdf
26. Motor Challenge. 1997. *Determining Electric Motor Load and Efficiency.* DOE/GO-10097-517. U.S. Department of Energy. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/10097517.pdf
27. OIT (Office of Industrial Technologies), EERE (Energy Efficiency and Renewable Energy). 2002. *United States Industrial Electric Motor Systems Market Opportunities Assessment*, Prepared by Xenergy, Inc., Burlington, MA. U.S. Department of Energy and Oak Ridge National Laboratory. www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/mtrmkt.pdf
28. ORNL (Oak Ridge National Laboratory). 2012. *Estimating the Impact (Energy, Emissions and Economics) of the U.S. Fluid Power Industry*. ORNL/TM-2011/14. Prepared by Love, Lonnie J., Eric Lanke, and Pete Alles. http://info.ornl.gov/sites/publications/files/Pub28014.pdf
29. PERC (Propane Education & Research Council). 2009. *Propane Reduces Greenhouse Gas Emissions: A Comparative Analysis*. Prepared by Energetics, Incorporated, Columbia, MD. www.propanecouncil.org/WorkArea/DownloadAsset.aspx?id=3314
30. PI (Office of Policy and International Affairs). 2007. *Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program*. U.S. Department of Energy. www.eia.gov/oiaf/1605/January2007_1605bTechnicalGuidelines.pdf
31. Platts. 2004. "HVAC: Fans." Platts. www.reliant.com/en_US/Platts/PDF/P_PA_32.pdf
32. Sustainability Victoria. 2009. *Energy Efficiency Best Practice Guide Industrial Refrigeration*. Prepared by Climate Managers. Sustainability Victoria. www.resourcesmart.vic.gov.au/documents/BP_Refrigeration_Manual.pdf
33. Swagelok Energy Advisors, Inc. 2011. *Steam Systems Best Practices*. Document No. 33. www.swagelok.com/Chicago/Services/Energy-Services/~/media/Distributor%20Media/C-G/Chicago/Services/ES%20-%20Thermal%20Cycle%20Efficiency_BP_33.ashx
34. VTP (Vehicle Technologies Program), EERE (Energy Efficiency and Renewable Energy). 2003. *Just the Basics: Diesel Engine*. U.S. Department of Energy. www1.eere.energy.gov/vehiclesandfuels/pdfs/basics/jtb_diesel_engine.pdf
35. Zyga, Lisa. 2010. "White LEDs with super-high luminous efficacy could satisfy all general lighting needs." Last modified August 31, 2010. http://phys.org/news202453100.html

Table 2: Conventional Boiler Efficiency by Sector

Sector	Conventional Boiler Efficiency
Aluminum	87%
Cement	81%
Chemicals	82%
Computers, Electronics, and Electrical Equipment	79%
Fabricated Metals	78%
Food and Beverage	79%
Forest Products	86%
Foundries	78%
Glass and Glass Products	81%
Iron and Steel	80%
Machinery	86%
Petroleum Refining	81%
Plastics and Rubber Products	83%
Textiles	82%
Transportation Equipment	82%
All Manufacturing (weighted average)	**81%**

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 approach 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 2013 in order to estimate boiler efficiencies by fuel type for the footprint sectors. The breakdown of conventional boiler fuel use by sector is provided by 2010 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), and the breakdown of boiler fuel use by sector is available through MECS. Two sources were consulted in determining boiler fuel type efficiency: 1) Energy Information Administration, 2013 Model Documentation Report: Industrial Demand Module of the National Energy Modeling System [16] – 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., Energy Management Services – 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 (3% of boiler fuel for All Manufacturing) an efficiency of 98% is assumed [12]. The results of this approach are shown in the table above.

Table 3: CHP/Cogeneration Efficiency by Sector

Sector	CHP/Cogeneration Efficiency
Cement	80%
Chemicals	71%
Fabricated Metals	80%
Food and Beverage	81%
Forest Products	72%
Iron and Steel	78%
Machinery	82%
Petroleum Refining	71%
Textiles	82%
Transportation Equipment	73%
All Manufacturing (weighted average)	**72%**
All Manufacturing *used for the following sectors where there is insufficient data:* Aluminum; Computers, Electronics, and Electrical Equipment; Foundries; Glass and Glass Products; Machinery; Plastics and Rubber Products.	**73%**

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 2010 are provided in [14] by fuel and prime mover. For steam turbine CHP systems (which consume a majority of the CHP input fuel in manufacturing), the values from [14] 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 [17]. In both cases, steam efficiency was adjusted to account for actual electric output reported in [14] and used to determine steam generated and overall efficiency. While the All Manufacturing CHP efficiency average value determined through this analysis based on [14] 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. Other sources: [16]

Table 4: Process Heating Loss Assumptions by Sector

Sector	Percent of Process Heating Energy Lost
Chemicals; Plastics and Rubber Products	23%
Food and Beverage; Textiles	56%
Forest Products	72%
Petroleum Refining	18%
Iron and Steel; Aluminum; Foundries	46%
Glass and Glass Products	55%
Cement	40%
All Manufacturing Average *also used for the following sectors where there is insufficient data:* Transportation Equipment; Machinery; Fabricated Metals; Computers, Electronics, and Electrical Equipment	**36%**

Approach/Sources: A Manufacturing Process Heating Energy Loss Working Group was formed in January 2012 in order to estimate energy losses from key process heating equipment for seven energy-intensive manufacturing 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. Interviews with manufacturers, 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. More details regarding methodology are available in Appendix F of the Manufacturing Energy Use and Loss and Emissions Analysis (October 2012), available for download here: www1.eere.energy.gov/manufacturing/resources/energy_analysis.html.Values for the 2010 footprints differ marginally from the 2006 footprints due to updated MECS 2010 consumption data.

Table 5: Facility Lighting Loss Assumptions by Sector

Sector	Percent of Facility Lighting Energy Lost
Aluminum	74.4%
Cement	74.3%
Chemicals	74.3%
Computers, Electronics, and Electrical Equipment	74.2%
Fabricated Metals	74.2%
Food and Beverage	74.5%
Forest Products	74.3%
Foundries	74.4%
Glass and Glass Products	74.3%
Iron and Steel	74.4%
Machinery	74.3%
Petroleum Refining	74.6%
Plastics and Rubber Products	74.4%
Textiles	74.2%
Transportation Equipment	74.1%
All Manufacturing	**74.3%**

Approach/Sources: Efficiency was determined in each manufacturing sector by taking into account the mix of lighting sources in each sector, as detailed in [11]. Efficiency is calculated by dividing the sector-specific efficacy by the maximum practical lighting efficacy. The maximum practical 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 [35]) is used to calculate efficiency, rather than the maximum efficacy for green light at 555 nm, equal to 683 lumens/watt.

Table 6: 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
Aluminum and Alumina	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%**	**11%**	**3%**

Approach/Sources: A Manufacturing Steam End Use Working Group was formed in 2011 in order 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 end use of steam for 15 manufacturing sectors was considered. An industry survey was issued by the working group 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: http://www1.eere.energy.gov/manufacturing/resources/energy_analysis.html.

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)[viii]. 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)[ix].

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 7, the emission factors used were sourced primarily from the Environmental Protection Agency's (EPA) Mandatory Greenhouse Gas Reporting Rule[x] and the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks*[xi]. 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 in order 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.

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.

Emissions from the combustion of blast furnace gas, coke, and coke oven gas are considered process emissions and are thus not included in this analysis, in accordance with EPA and IPCC guidelines. Also excluded are CO_2 emissions from biomass use.

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

Table 7: Fuel Combustion Emission Factors (kg CO_2e per million Btu)

Fuel Type*	CO_2	CH_4	N_2O	Total GHG	Source
Agricultural Byproducts	*118.17***	0.800	1.252	*2.05*	[a]
Coal (Industrial Sector)	93.91	0.275	0.477	94.66	[a]
Distillate Fuel Oil No. 2	73.96	0.075	0.179	74.21	[a]
Electricity Generation (offsite)	173.85	0.086	0.770	174.70	[c]
Kerosene	75.20	0.075	0.179	75.45	[a]
LPG (energy use)	62.98	0.075	0.179	63.23	[a]
Natural Gas (pipeline weighted average)	53.02	0.025	0.030	53.07	[a]
Petroleum Coke	102.41	0.075	0.179	102.66	[a]
Pulping Liquor/Black Liquor	*94.40***	0.063	0.596	*0.66*	[a]
Residual Fuel Oil No. 6	75.10	0.075	0.179	75.35	[a]
Steam Generation (offsite)	88.18	0.205	0.179	88.56	[a], [d]
Still Gas	66.72	0.075	0.179	66.97	[a]
Waste Oils, Tars, and Waste Materials	74.49	0.075	0.179	74.74	[a], [b]
Wood and Wood Residuals	*93.80***	0.800	1.252	*2.05*	[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 included this analysis.*
*** 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.*

Sources:

- *[a] Federal Register/Vol. 74, No. 209/Friday, October 30, 2009/Part 98, Tables C-1, C-2, and AA-1 (EPA Mandatory Reporting Rules)*
- *[b] EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2012, Annex 2. Tables A-32, A-33, A-35, data for 2010. www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Annex-2-Emissions-from-Fossil-Fuel-Combustion.pdf*
- *[c] EPA Emissions & Generation Resource Integrated Database (eGRID). eGRID2012 Version 1.0 www.epa.gov/cleanenergy/egrid (adjusted to reflect losses in transmission)*
- *[d] EIA - Voluntary Reporting of Greenhouse Gases, 2010 Appendix N, "Emission Factors for Steam and Chilled/Hot Water" p 171: http://www.eia.gov/survey/form/eia_1605/pdf/Appendix%20N_20110128.pdf*

[viii] 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) [IPCC 2007]. The GWP-weighted emissions in the U.S. Inventory are presented in terms of CO_2e emissions with units of teragrams (Tg) of carbon dioxide equivalent (Tg CO_2e) [EPA 2009a]. Specifically the GWPs used for CO_2, CH_4, and N_2O are 1, 25, and 298 Tg CO_2e [IPCC 2007] respectively.

[ix] *Glossary of Climate Change Terms*, U.S. Environmental Protection Agency, 2009. http://www.epa.gov/climatechange/glossary.html

[x] *Mandatory Greenhouse Gas Reporting Rule*, U.S. Environmental Protection Agency, 40 CFR Part 98, 2009. http://www.epa.gov/climatechange/emissions/ghgrulemaking.html

[xi] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, U.S. Environmental Protection Agency, 2010. http://www.epa.gov/climatechange/emissions/usinventoryreport.html