Manufacturing Energy and Carbon Footprint Assumptions and Definitions

A number of parameters are used to interpret the manufacturing energy and carbon footprints. These parameters are defined below, in the order they generally appear:

Energy Footprint Analysis

Total primary energy use – The total energy consumed as a fuel by the manufacturing sector. It is the sum of energy purchases (fuel, steam and electricity), the offsite losses associated with these energy purchases (see *offsite losses*, below), byproduct energy produced onsite, and energy from renewables and biomass. Total primary energy use does not include energy consumed as a feedstock, that is, energy used for purposes other than for heat, power, and electricity generation.

Offsite steam generation and transmission losses – The energy losses incurred during the generation and transport of steam to the plant boundary. Energy losses are assumed to be 19% during the generation of steam and 10% during the transmission of steam to the plant boundary. See Table 1 for a listing of energy loss assumptions.

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 32%. This does not represent the state-of-the-art, but an average value for the national grid.

Offsite energy – Energy that is 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 feedstocks.

Offsite steam generation – The sum of net steam transfers, generation from renewables, and purchased steam from the local utility or other sources.

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

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 industrial plant boundary. Electricity includes purchased electricity and any electricity produced onsite that is later sold or transferred offsite. Losses from offsite steam and electricity are not included.

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***.

Byproduct fuel[1] – A secondary or additional product resulting from nonfuel feedstocks that is subsequently used for fuel purposes, such as coal gas (byproduct of coke ovens) or black liquor

[1] In this analysis, the value of coke and breeze fuel use has been adjusted to avoid the duplication of fuel use with blast furnace gas. The Manufacturing Energy Consumption Survey (MECS) assumes for purposes of estimation that all energy sources used for fuel are completely consumed in the process. However, in the case of a blast furnace used in the iron making process, incomplete consumption of blast furnace fuel inputs may be a significant cause of duplication. Literature reviews and consultation have revealed that the majority of blast furnace gas formation would arise from the input fuel use of coke. To address this issue, MECS suggests adjusting the fuel use of coal coke downward by the heat content of the blast furnace gas consumed in the industry, which is approximately two-thirds [2002 Manufacturing Energy Consumption Survey (MECS) Methodology, http://www.eia.doe.gov/emeu/mecs/mecs2002/methodology_02/meth_02.html]. This adjustment is reflected in the Iron and Steel industry footprint 'Fuel Type Detail' table, with blast furnace gas indicated as being a byproduct of coke and breeze.

(byproduct fuel used in the forest products industry). Byproduct fuels are quantified in the footprints and shown as a contributing portion of the onsite fuel use.

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

Conventional boiler – A boiler vessel that consumes fossil fuels as the primary energy source to produce heat and generate steam or hot water.

Boiler losses represent energy lost due to boiler inefficiency. In practice, boiler efficiency can be as low as 55-60%, or as high as 90%. The age of the boiler, boiler size, maintenance practices, and fuel type are important factors. Power generation losses vary depending on whether cogeneration is employed (systems producing both steam and electricity). An average boiler efficiency of 80% was used for all industries, boiler types and fuels [ADL 2000][2].

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

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 renewables including solar, wind, hydropower, and geothermal; does not include wood/biomass.

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.

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.

Steam distribution losses – The energy losses incurred during the distribution of steam within the plant boundaries. Losses in steam pipes and traps have been reported to be as high as 20 to 40% [PNNL 1999][3]. For this analysis, a value of 20% was used for onsite steam distribution losses.

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.

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 (defined 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 the temperature of substances involved in the manufacturing process. Examples include the use of heat to melt scrap for electric-arc furnaces in steel-making, to separate components of crude oil in petroleum refining, to dry paint in automobile manufacturing, and to cook packaged foods.

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[2] *Overview of Energy Flow for Industries in Standard Industrial Classifications 20-39,* Arthur D. Little, Inc., for the U.S. Department of Energy, Office of Industrial Technology, December 2000.

[3] Steam Trap Performance Assessment, Pacific Northwest National Laboratory, July 1999; "How Efficient is Your Steam Distribution System?" Frederic A. Hooper and Ronald D. Gillette, 2002. www.swopnet.com/engr/stm/steam_dist_eff.html

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.

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).

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 there rather than in machine drive.

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

Process heating losses – Process heating losses have been separated to show system losses and exhaust losses. System losses represent radiation, convection, insulation, and cooling losses. Exhaust losses, the energy that leaves the flue, or stack, of a process heater, are not estimated in this analysis due to the wide variance in loss.

Machine drive losses (shaft losses) – The energy lost in the conversion of thermal or electric energy into kinetic or mechanical energy. Machine drive losses are estimated from electric motor, turbine, and engine efficiencies.

Machine-driven systems losses – The sum of machine-driven systems losses: specifically losses in pumps, fans, compressed air systems, materials handling systems, materials processing systems, and other systems. Machine drive (motor) losses are considered separately from these system losses. The distribution of these six categories of losses is unique within each industry sector [ORNL 2002][4].

Nonprocess energy – Energy used for purposes other than industry-specific processes, defined 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.

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.

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.

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.

Table 1: Manufacturing Energy Footprint Loss Assumptions

[4] U.S. Industrial Electric Motor Systems Market Opportunities Assessment, ORNL/Xenergy, for the U.S. Department of Energy, Office of Industrial Technology, 2002.

Energy System	Percent Energy Lost
Energy Generation, Transmission and Distribution Losses	
Offsite generation	Offsite electricity generation and transmission (grid) – 68.4% Offsite steam generation – 19% Offsite steam transmission – 10%
Onsite generation	Onsite steam generation (conventional boiler) – 20% Onsite CHP/cogeneration – 24.4% to 36.3%, see Table 2 Onsite steam distribution – 20%
Onsite Process and Nonprocess Losses	
Process energy	Process heating – to be determined, analysis currently underway Process cooling and refrigeration – 35% Electro-chemical – 60% Other processes – 10% Machine drive (shaft energy) – electric 7%, fuel 63%, steam 60% Machine driven systems - Pumps – 40% Fans – 40% Compressed air – 80% Materials handling – 15% Materials processing (e.g., grinders) – 90% Other systems – 5%
Nonprocess energy	Facility HVAC – 25% Facility lighting – 88% Other facility support – 10% Onsite transportation – 60% Other nonprocesses – 10%

Sources: The values in this table are used to generate order-of-magnitude energy loss estimates. Energy generation and transmission loss assumptions are primarily based on EIA data. Process and nonprocess loss assumptions are drawn from published references and discussions with industry and process experts. 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. Further explanations of the assumptions used in the footprint model are provided in the Manufacturing Energy Use and Loss and Emissions Analysis Report, to be published by Energetics in 2012.

Table 2: Cogeneration Efficiency by Sector

Sector	Cogeneration Efficiency
Chemicals	63.7%
Food and Beverage	74.5%
Forest Products	75.6%
Petroleum Refining	69.0%
Iron and Steel	69.0%
All Manufacturing Average *also used for the following sectors where there is insufficient data:* Cement; Textiles; Transportation Equipment; Aluminum; Machinery; Fabricated Metals; Plastics and Rubber Products; Computers, Electronics, and Appliances*; Foundries*; Glass and Fiber Glass*.	71.6%

Sources: Energy Information Administration (EIA), Form EIA-906, EIA-920, and EIA-923 2006 Databases
* CHP energy use shown to be 0 TBtu, so CHP Efficiency is immaterial in the energy footprint.

Carbon Footprint Analysis

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 3, the emission factors used were sourced primarily from the Environmental Protection Agency's (EPA) Mandatory Greenhouse Gas Reporting Rule[5] and the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks*[6]. 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 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 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

[5] *Mandatory Greenhouse Gas Reporting Rule*, U.S. Environmental Protection Agency, 40 CFR Part 98, 2009. http://www.epa.gov/climatechange/emissions/ghgrulemaking.html
[6] *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

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. Indirect emissions are distributed to direct end uses in the accompanying report.

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

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

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)[7]. 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)[8].

[7] 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.

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

Table 3: Fuel Combustion Emission Factors (kg CO_2e per million Btu)

Fuel Type	CO_2	CH_4	N_2O	Total GHG	Source
Natural Gas (pipeline weighted avg.)	53.02	0.03	0.03	53.07	a
Residual Fuel Oil (No. 5, No. 6)	75.10	0.08	0.18	75.35	a
Distillate Fuel Oil (No. 1, No. 2, No. 4)	73.96	0.08	0.18	74.21	a
LPG	62.98	0.08	0.18	63.23	a
Coal (Industrial Sector)	93.91	0.28	0.48	94.66	a
Coke (from coke)	102.04	0.28	0.48	102.79	a
Still Gas	66.72	0.08	0.18	66.97	a
Petroleum Coke	102.41	0.08	0.18	102.66	a
Other Fuels	74.49	0.08	0.18	74.74	a
Wood and Wood Residuals	*93.80**	0.80	1.25	2.05	a
Agricultural Byproducts	*118.17**	0.80	1.25	2.05	a
Pulping Liquor/Black Liquor	*94.40**	0.75	1.49	2.24	a
Offsite Steam Generation				86.85	b
Offsite Electricity Generation	190.02	0.10	0.87	190.98	c

** CO_2 emissions from biomass fuel combustion (also known as biogenic CO_2) are not included in the total 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] EIA Voluntary Reporting of Greenhouse Gases, Appendix N, p 164, 2/13/2008

[c] EPA Emissions & Generation Resource Integrated Database (eGRID). eGRID2007 Version 1.1 www.epa.gov/cleanenergy/egrid (adjusted to reflect transmission losses)