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## Appendix A. GLOSSARY

**Applied energy** – the amount of energy actually employed in a manufacturing direct end use, with consideration of all energy losses incurred by or associated with that end use, including: (1) onsite process/nonprocess losses (system and equipment losses), (2) onsite generation losses (generation and distribution losses associated with producing and transporting steam and electricity onsite), and (3) offsite generation losses (generation and transmission losses associated with bringing steam and electricity to the plant boundary).

**Byproduct fuel**[19] **–** a secondary or additional product derived from feedstock in the production process that is subsequently used for fuel purposes, such as coal gas (byproduct of coke ovens) or black liquor (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.

**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).[20] 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 $CO_2e$).[21]

**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 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 sectors, boiler types, and fuels [OIT EERE 2000].[22]

**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; hence, it is not directly connected to the energy flow diagram. This figure is included for informative purposes.

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[19] 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.

[20] 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.

[21] EPA (U.S. Environmental Protection Agency). 2009. "Glossary of Climate Change Terms." U.S. Environmental Protection Agency. Last modified June 14. http://www.epa.gov/climatechange/glossary.html

[22] OIT (Office of Industrial Technologies), EERE (Energy Efficiency and Renewable Energy). 2000. *Overview of Energy Flow for Industries in Standard Industrial Classifications 20-39.* 71563-00. Prepared by Arthur D. Little, Inc., Cambridge, MA. U.S. Department of Energy. http://steamingahead.org/library/adlittle.pdf

**Electricity generation losses** – the energy losses incurred during the onsite or offsite generation of electricity. This term includes losses from offsite generated electricity, electricity cogeneration, and other onsite electricity generation.

**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 manufacturing plant boundary.

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

**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 D.5, the emission factors used were sourced primarily from the Environmental Protection Agency's (EPA) Mandatory Greenhouse Gas Reporting Rule[23] and the EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[24] Over 99% of the emissions from combustion are $CO_2$. While $CH_4$ and $N_2O$ contribute a small portion of total emissions, they are included in this analysis to best adhere to the EPA reporting rule.

**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.

**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 [OIT EERE 2002b].[25]

**Net electricity –** the sum of electricity purchases, transfers in, and generation from noncombustible renewable resources, minus quantities sold and transferred out. Net electricity does not include electricity inputs from onsite cogeneration or generation from combustible fuels because that energy has already been included as generating fuel (for example, coal).

**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.

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[23] EPA (U.S. Environmental Protection Agency). 2009. "Mandatory Greenhouse Gas Reporting Rule." U.S. Environmental Protection Agency, 40 CFR Part 98. Last modified August 30. http://www.epa.gov/ghgreporting/basic-info/index.html

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

[25] 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. http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/mtrmkt.pdf

**Offsite GHG combustion emissions** – the emissions released by the combustion of fuels outside a manufacturing facility, but associated with energy later consumed by the facility. For example, a power plant generates electricity by burning coal as fuel. A manufacturing 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 offsite steam.

**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 31.6%. 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) or otherwise originally externally-sourced. Includes offsite electricity, offsite steam, and offsite fuel (including byproduct fuel derived from feedstock).

**Offsite fuel –** the sum of purchased fuel, fuel transferred into the plant boundary, and byproduct fuel from externally-sourced feedstocks.

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

**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 D.1 for a listing of energy loss assumptions.

**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.

**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. Indirect emissions are distributed to direct end uses in the accompanying report. Excluded are $CO_2$ from biomass use and some carbon emissions from steel production, which are detailed in the emissions profile sections for the forest products, food and beverage, and iron and steel sectors

**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).

**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.

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

**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 plant.

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

**Primary energy use** – the sum of energy purchases (fuel, steam, and electricity), the offsite losses associated with these energy purchases (see above *offsite steam generation and transmission losses* and *offsite electricity generation and transmission losses*), byproduct energy produced and used onsite, and energy from renewables and biomass. <u>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</u>.

**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 chemicals 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 (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.

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

**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% – 40% [Hooper and Gillette 1999].[26] For this analysis, a value of 20% was used for onsite steam distribution losses.

**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 GHG combustion emissions –** the sum of offsite and onsite GHG combustion emissions.

[26] Hooper, Frederic A., and Ronald D. Gillette. 1999. "How Efficient is Your Steam Distribution System?" Steam Conservation Systems. www.swopnet.com/engr/stm/steam_dist_eff.html

# Appendix B. FOOTPRINTS SCOPE AND SECTOR DESCRIPTIONS

## Scope

The footprint analysis looks at a large subset of U.S. manufacturing, with the objective of capturing the bulk share of energy consumption and carbon emissions. Table B.1 lists the 15 manufacturing sectors selected for analysis; a sixteenth footprint has also been prepared for the entire manufacturing sector. Manufacturing sectors are listed by their respective NAICS (North American Industry Classification System) codes. NAICS descriptions of the specific products manufactured in each sector are provided below.

Manufacturing sectors were selected based on their relative energy intensities, contribution to the economy, and relative importance to energy efficiency programs. Energy consumption and emissions for all manufacturing sectors within NAICS 31–33 are included in the overall manufacturing energy and carbon footprint.

**Table B.1. Manufacturing sectors selected for analysis**

| | |
|---|---|
| **Food and beverage**<br>NAICS 311 Food<br>NAICS 312 Beverage and tobacco products | **Iron and steel**<br>NAICS 3311 Iron and steel mills and ferroalloys<br>NAICS 3312 Steel products |
| **Textiles**<br>NAICS 313 Textile mills<br>NAICS 314 Textile product mills<br>NAICS 315 Apparel<br>NAICS 316 Leather and allied products | **Alumina and aluminum**<br>NAICS 3313 |
| **Forest products**<br>NAICS 321 Wood products<br>NAICS 322 Paper | **Foundries**<br>NAICS 3315 |
| **Petroleum refining**<br>NAICS 324110 | **Fabricated metals**<br>NAICS 332 |
| **Chemicals**<br>NAICS 325 | **Machinery**<br>NAICS 333 |
| **Plastics and rubber products**<br>NAICS 326 | **Computers, electronics, electrical equipment, and electrical equipment**<br>NAICS 334 Computer and electronic products<br>NAICS 335 Electrical equipment, appliances, and components |
| **Glass and glass products**<br>NAICS 3272 Glass and glass products<br>NAICS 327993 Mineral wool | **Transportation equipment**<br>NAICS 336 |
| **Cement**<br>NAICS 327310 | |

*Source:* U.S. Census Bureau. 2007. "North American Industry Classification System (NAICS)." U.S. Census Bureau. http://www.census.gov/eos/www/naics/

## NAICS Descriptions

**311 – Food Manufacturing**

Industries in the food manufacturing subsector transform livestock and agricultural products into products for intermediate or final consumption. The food products manufactured in these establishments are typically sold to wholesalers or retailers for distribution to consumers, but establishments primarily engaged in retailing bakery and candy products made on the premises not for immediate consumption are included.

**312 – Beverage and Tobacco Product Manufacturing**

Industries in the beverage and tobacco product manufacturing subsector manufacture beverages and tobacco products. Beverage manufacturing includes three types of establishments: (1) those that manufacture nonalcoholic beverages, (2) those that manufacture alcoholic beverages through the fermentation process, and (3) those that produce distilled alcoholic beverages. Ice manufacturing is included with nonalcoholic beverage manufacturing because it uses the same production process as water purification. Tobacco manufacturing includes two types of establishments: (1) those engaged in re-drying and stemming tobacco and (2) those that manufacture tobacco products, such as cigarettes and cigars.

**313 – Textile Mills**

Industries in the textile mills subsector group transform a basic fiber (natural or synthetic) into a product, such as yarn or fabric that is further manufactured into usable items, such as apparel, sheets, towels, and textile bags for individual or industrial consumption. Further manufacturing may be performed in the same establishment and classified in this subsector, or it may be performed at a separate establishment and be classified elsewhere in manufacturing.

**314 – Textile Product Mills**

Industries in the textile product mills subsector group make textile products (except apparel). With a few exceptions, processes used in these industries are generally cut and sew (i.e., purchasing fabric and cutting and sewing to make non-apparel textile products, such as sheets and towels).

**315 – Apparel Manufacturing**

Industries in the apparel manufacturing subsector group have two distinct manufacturing processes: (1) cut and sew (i.e., purchasing fabric and cutting and sewing to make a garment) and (2) the manufacture of garments in establishments that first knit fabric and then cut and sew the fabric into a garment. The apparel manufacturing subsector includes a diverse range of establishments manufacturing full lines of ready-to-wear apparel and custom apparel. Knitting, when done alone, is classified in the Textile Mills subsector, but when knitting is combined with the production of complete garments, the activity is classified in apparel manufacturing.

**316 – Leather and Allied Product Manufacturing**

Establishments in the leather and allied product manufacturing subsector transform hides into leather by tanning or curing and fabricating the leather into products for final consumption. It also includes the manufacture of similar products from other materials, including products (except apparel) made from "leather substitutes," such as rubber, plastics, or textiles. Rubber footwear, textile luggage, and plastic purses or wallets are examples of "leather substitute" products included in this group. The products made from leather substitutes are included in this subsector because they are made in similar ways leather products are made (e.g., luggage). They are made in the same establishments, so it is not practical to separate them.

**321 – Wood Product Manufacturing**

Industries in the wood product manufacturing subsector manufacture wood products, such as lumber, plywood, veneers, wood containers, wood flooring, wood trusses, manufactured homes (i.e., mobile homes), and prefabricated wood buildings.

**322 – Paper Manufacturing**
Industries in the paper manufacturing subsector make pulp, paper, or converted paper products. The manufacturing of these products is grouped together because they constitute a series of vertically connected processes. More than one is often carried out in a single establishment.

**324110 – Petroleum Refineries**
This industry comprises establishments primarily engaged in refining crude petroleum into refined petroleum. Petroleum refining involves one or more of the following activities: (1) fractionation, (2) straight distillation of crude oil, and (3) cracking.

**325 – Chemicals Manufacturing**
The chemicals manufacturing subsector is based on the transformation of organic and inorganic raw materials by a chemical process and the formulation of products. This subsector distinguishes the production of basic chemicals that comprise the first industry group from the production of intermediate and end products produced by further processing of basic chemicals that make up the remaining industry groups.

**326 – Plastics and Rubber Products Manufacturing**
Industries in the plastics and rubber products manufacturing subsector make goods by processing plastics materials and raw rubber. Plastics and rubber are combined in the same subsector because plastics are increasingly being used as a substitute for rubber; however, the subsector is generally restricted to the production of products made of just one material, either solely plastics or rubber.

**3272 – Glass and Glass Product Manufacturing**
This industry comprises establishments primarily engaged in manufacturing glass and/or glass products. Establishments in this industry may manufacture glass and/or glass products by melting silica sand or cullet, or purchasing glass.

**327993 – Mineral Wool Manufacturing**
This industry comprises establishments primarily engaged in manufacturing mineral wool and mineral wool (i.e., fiberglass) insulation products made of such siliceous materials as rock, slag, and glass, or combinations thereof.

**327310 – Cement Manufacturing**
This industry comprises establishments primarily engaged in manufacturing portland, natural, masonry, pozzolanic, and other hydraulic cements. Cement manufacturing establishments may calcine earths or mine, quarry, manufacture, or purchase lime.

**3311 – Iron and Steel Mills and Ferroalloy Manufacturing**
This industry comprises establishments primarily engaged in one or more of the following: (1) direct reduction of iron ore, (2) manufacturing pig iron in molten or solid form, (3) converting pig iron into steel, (4) manufacturing ferroalloys,; (5) making steel, (6) making steel and manufacturing shapes (e.g., bar, plate, rod, sheet, strip, wire),; and (7) making steel and forming pipe and tube.

**3312 – Steel Product Manufacturing from Purchased Steel**
This industry group comprises establishments primarily engaged in manufacturing iron and steel tube and pipe, drawing steel wire, and rolling or drawing shapes from purchased iron or steel.

**3313 – Alumina and Aluminum Production and Processing**
This industry comprises establishments primarily engaged in one or more of the following: (1) refining alumina, (2) making (i.e., the primary production) aluminum from alumina,; (3) recovering aluminum from scrap or dross, (4) alloying purchased aluminum, and (5) manufacturing aluminum primary forms (e.g., bar, foil, pipe, plate, rod, sheet, tube, wire).

**3315 – Foundries**
This industry group comprises establishments primarily engaged in pouring molten metal into molds or dies to form castings. Foundries may perform operations, such as cleaning and deburring, on the castings they manufacture.

**332 – Fabricated Metal Product Manufacturing**
Industries in the fabricated metal product manufacturing subsector transform metal into intermediate or end products. Important fabricated metal processes are forging, stamping, bending, forming, and machining, used to shape individual pieces of metal; and other processes, such as welding and assembling, used to join separate parts together. Establishments in this subsector may use one of these processes or a combination of these processes.

**333 – Machinery Manufacturing**
Industries in the machinery manufacturing subsector create end products that apply mechanical force to perform work. Some important processes for the manufacture of machinery are forging, stamping, bending, forming, and machining that are used to shape individual pieces of metal. Processes such as welding and assembling are used to join separate parts together. Although these processes are similar to those used in metal fabricating establishments, machinery manufacturing is different because it typically employs multiple metal forming processes in manufacturing the various parts of the machine. Moreover, complex assembly operations are an inherent part of the production process.

**334 – Computer and Electronic Product Manufacturing**
Industries in the computer and electronic product manufacturing subsector group manufacture computers, computer peripherals, communications equipment, and similar electronic products, as well as the components for such products.

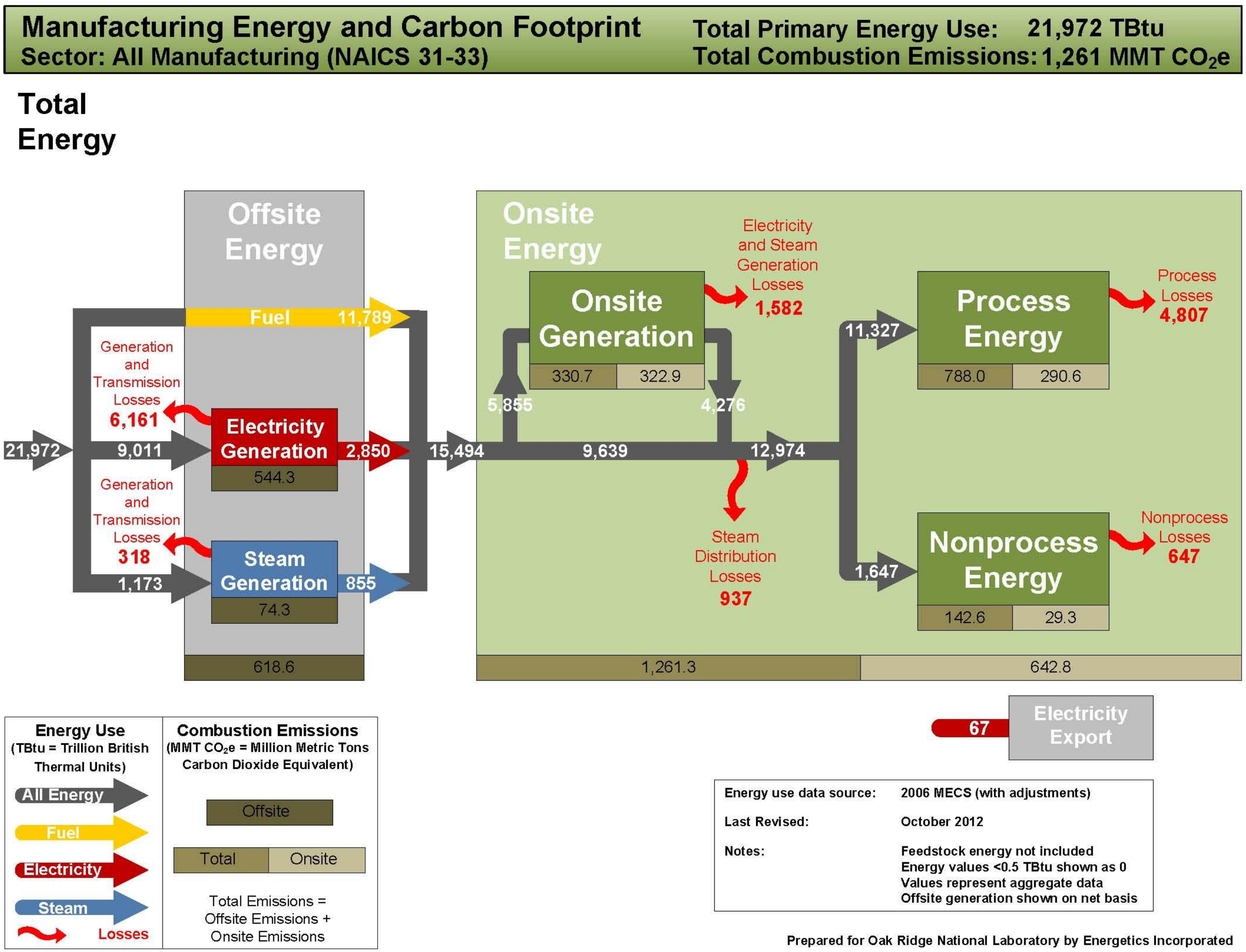
**335 – Electrical Equipment, Appliance, and Component Manufacturing**
Industries in the electrical equipment, appliance, and component Manufacturing subsector manufacture products that generate, distribute, and use electrical power. Electric lighting equipment manufacturing establishments produce electric lamp bulbs, lighting fixtures, and parts. Household appliance manufacturing establishments make both small and major electrical appliances and parts. Electrical equipment manufacturing establishments make goods, such as electric motors, generators, transformers, and switchgear apparatus. Other component manufacturing establishments make devices for storing electrical power (e.g., batteries) and for transmitting electricity (e.g., insulated wire), as well as wiring devices (e.g., electrical outlets, fuse boxes, and light switches).

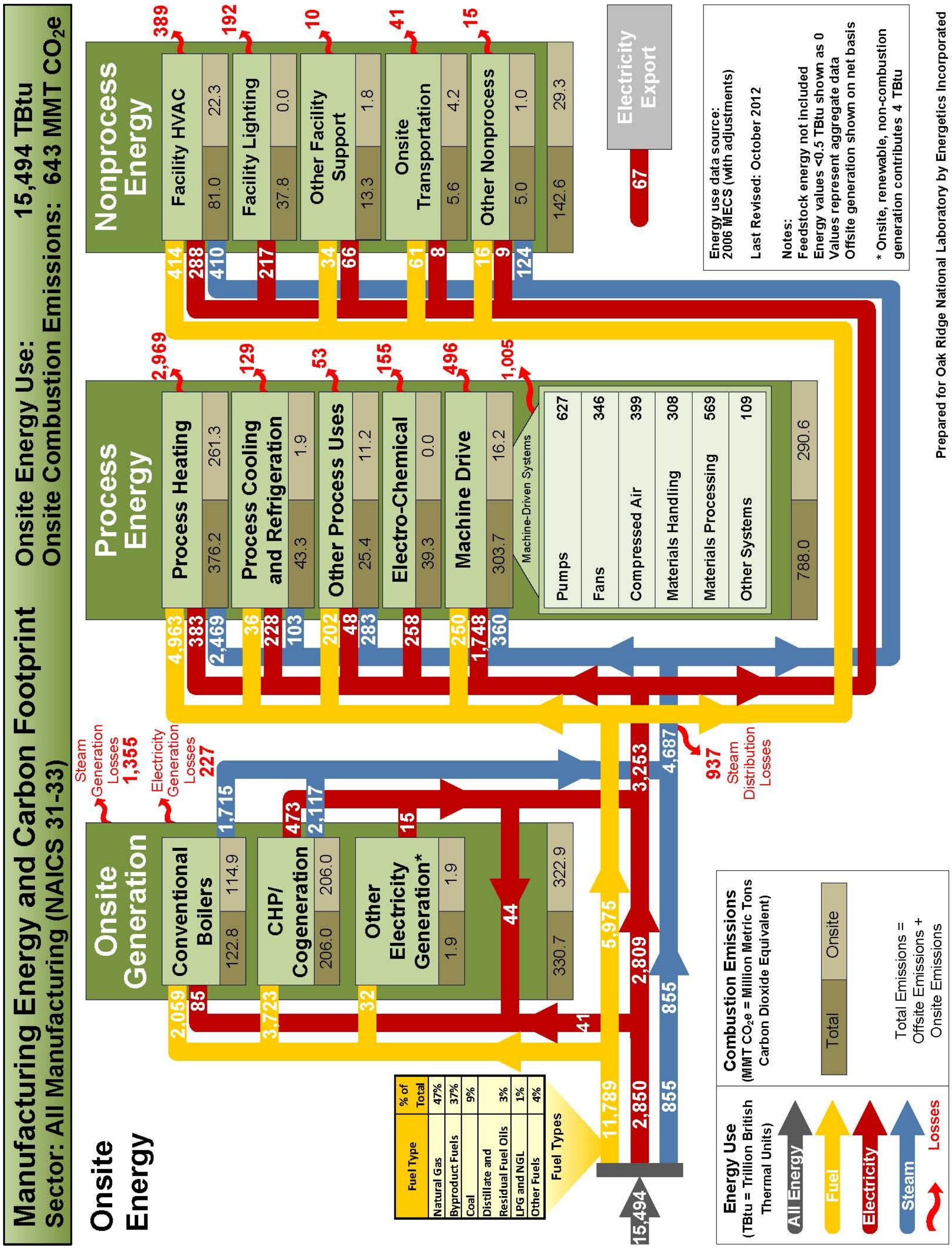
**336 – Transportation Equipment Manufacturing**
Industries in the transportation equipment manufacturing subsector produce equipment for transporting people and goods. Transportation equipment is a type of machinery. An entire subsector is devoted to this activity because of the significance of its economic size in all three North American countries.

## Appendix C. FOOTPRINTS BY SECTOR

Listed in this appendix are the manufacturing energy and carbon footprints by sector. Data is presented in two levels of detail for each sector. The first page provides a high level snapshot of the offsite and onsite energy flow; the second page shows the detail for onsite generation and end use of energy.

**Sector** **Page**

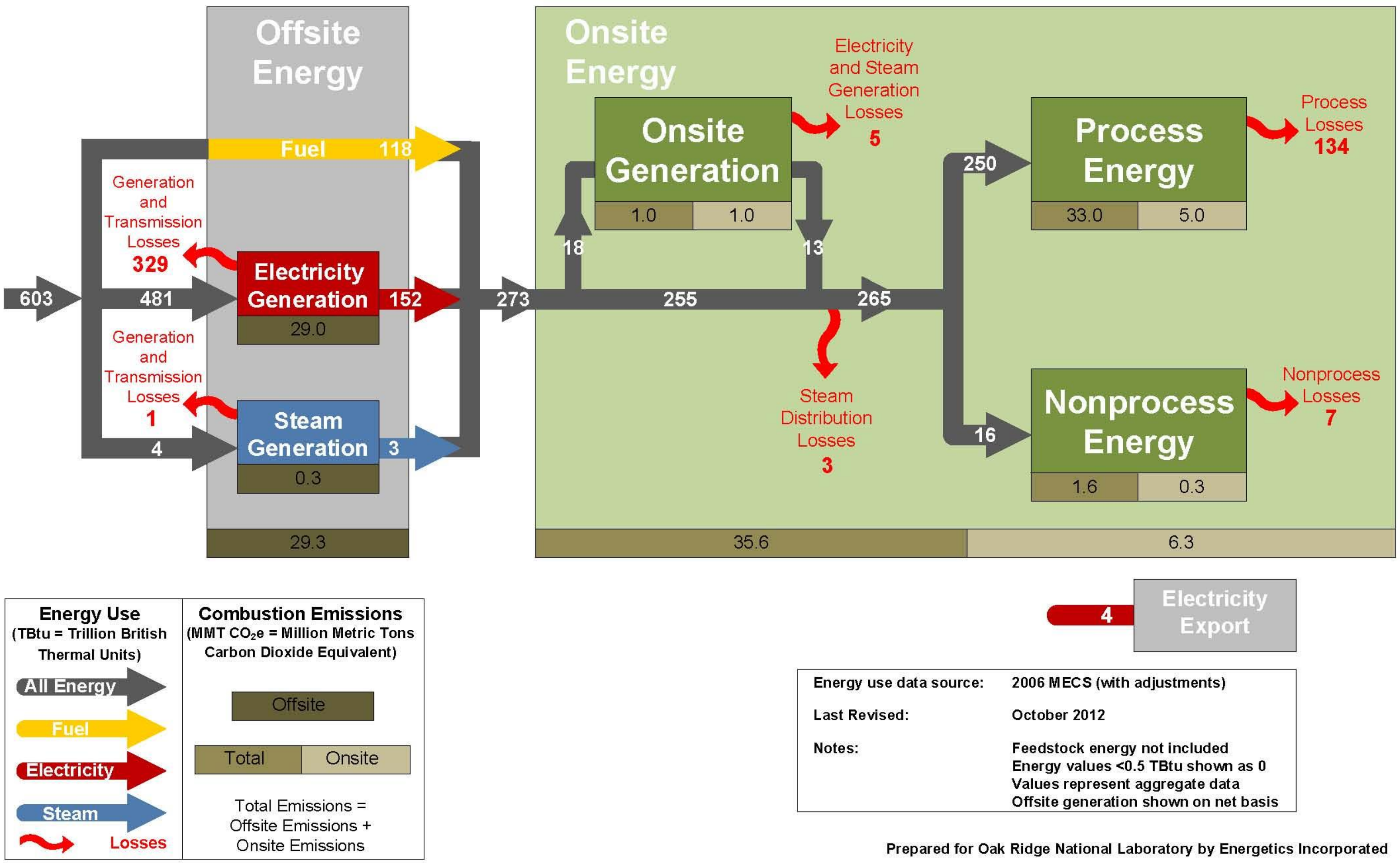

Manufacturing Energy and Carbon Footprint
Sector: All Manufacturing (NAICS 31-33)
Total Primary Energy Use: 21,972 TBtu
Total Combustion Emissions: 1,261 MMT $CO_2e$
Total Energy
Offsite Energy
Onsite Energy
21,972
Fuel 11,789
Generation and Transmission Losses 6,161
9,011
Electricity Generation
544.3
2,850
Generation and Transmission Losses 318
1,173
Steam Generation
74.3
855
618.6
15,494
5,855
Onsite Generation
330.7
322.9
Electricity and Steam Generation Losses 1,582
4,276
9,639
12,974
Steam Distribution Losses 937
11,327
1,647
Process Energy
788.0
290.6
Process Losses 4,807
Nonprocess Energy
142.6
29.3
Nonprocess Losses 647
1,261.3
642.8
67
Electricity Export
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Offsite
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes: Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
Prepared for Oak Ridge National Laboratory by Energetics Incorporated


Manufacturing Energy and Carbon Footprint
Sector: All Manufacturing (NAICS 31-33)
Onsite Energy Use: 15,494 TBtu
Onsite Combustion Emissions: 643 MMT CO2e
Onsite Energy
Fuel Type | % of Total
Natural Gas 47%
Byproduct Fuels 37%
Coal 9%
Distillate and Residual Fuel Oils 3%
LPG and NGL 1%
Other Fuels 4%
Fuel Types
15,494
11,789
2,850
855
Onsite Generation
Conventional Boilers
122.8
114.9
CHP/ Cogeneration
206.0
206.0
Other Electricity Generation*
1.9
1.9
330.7
322.9
2,059
85
3,723
32
41
44
5,975
2,809
855
1,715
473
2,117
15
Steam Generation Losses 1,355
Electricity Generation Losses 227
3,253
4,687
937 Steam Distribution Losses
Process Energy
Process Heating
376.2
261.3
Process Cooling and Refrigeration
43.3
1.9
Other Process Uses
25.4
11.2
Electro-Chemical
39.3
0.0
Machine Drive
303.7
16.2
Machine-Driven Systems
Pumps 627
Fans 346
Compressed Air 399
Materials Handling 308
Materials Processing 569
Other Systems 109
788.0
290.6
4,963
383
2,469
36
228
103
202
48
283
258
250
1,748
360
2,969
129
53
155
496
1,005
Nonprocess Energy
Facility HVAC
81.0
22.3
Facility Lighting
37.8
0.0
Other Facility Support
13.3
1.8
Onsite Transportation
5.6
4.2
Other Nonprocess
5.0
1.0
142.6
29.3
414
288
410
217
34
66
61
8
16
9
124
389
192
10
41
15
Electricity Export
67
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 4 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

# Manufacturing Energy and Carbon Footprint
**Sector: Alumina and Aluminum (NAICS 3313)**

Total Primary Energy Use: 603 TBtu
Total Combustion Emissions: 36 MMT $CO_2e$

## Total Energy




| | |
|---|---|
| Energy use data source: | 2006 MECS (with adjustments) |
| Last Revised: | October 2012 |
| Notes: | Feedstock energy not included<br>Energy values <0.5 TBtu shown as 0<br>Values represent aggregate data<br>Offsite generation shown on net basis |

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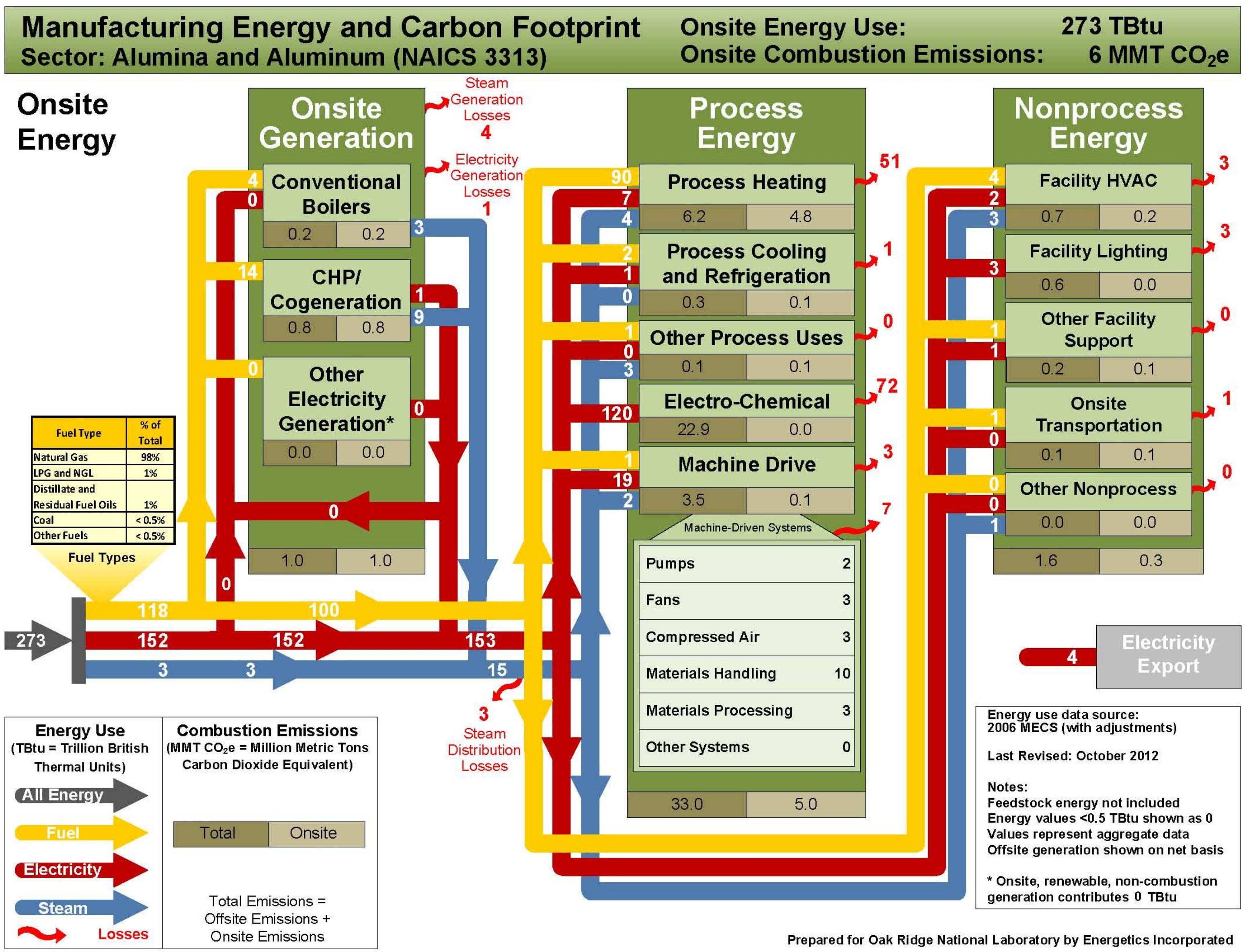
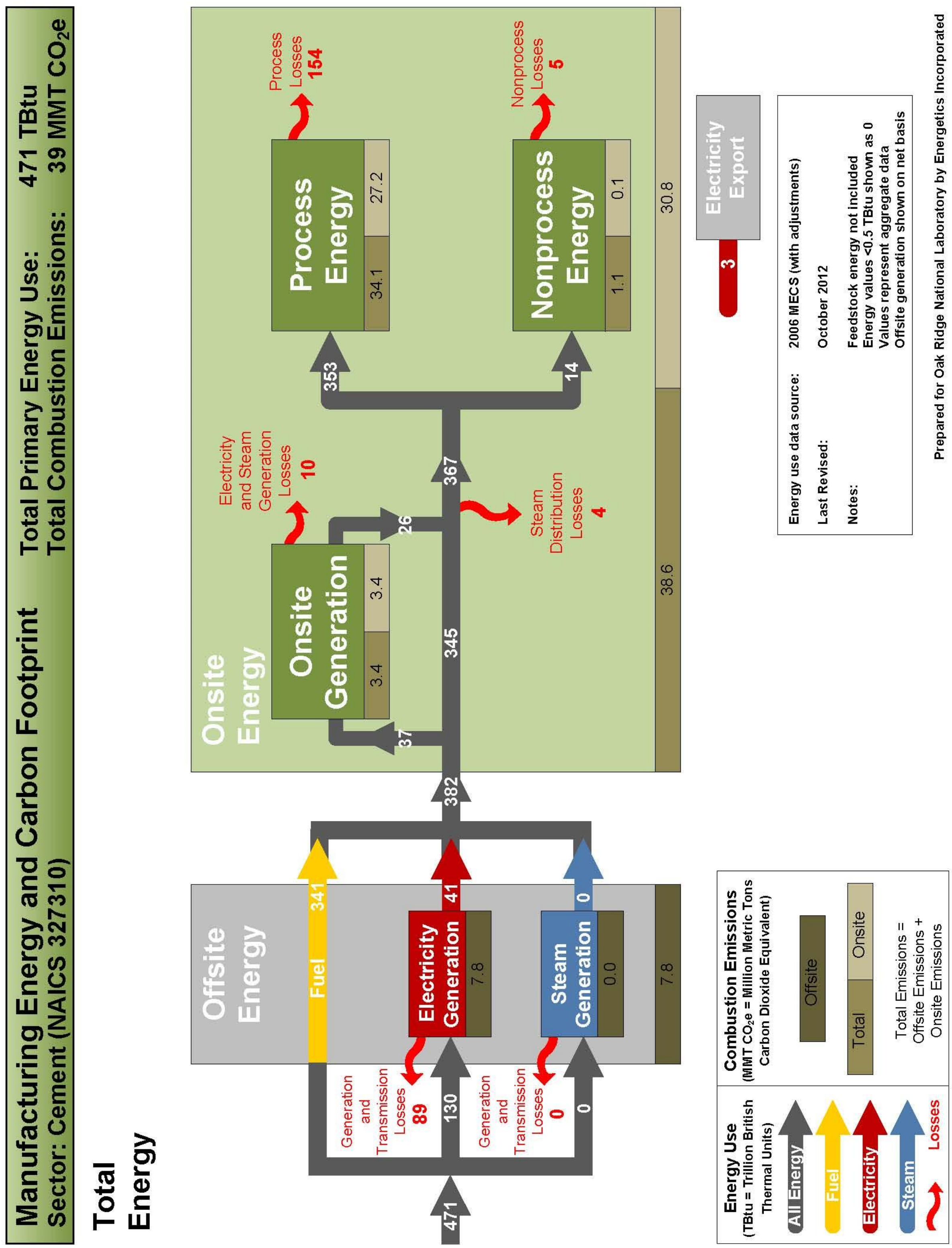
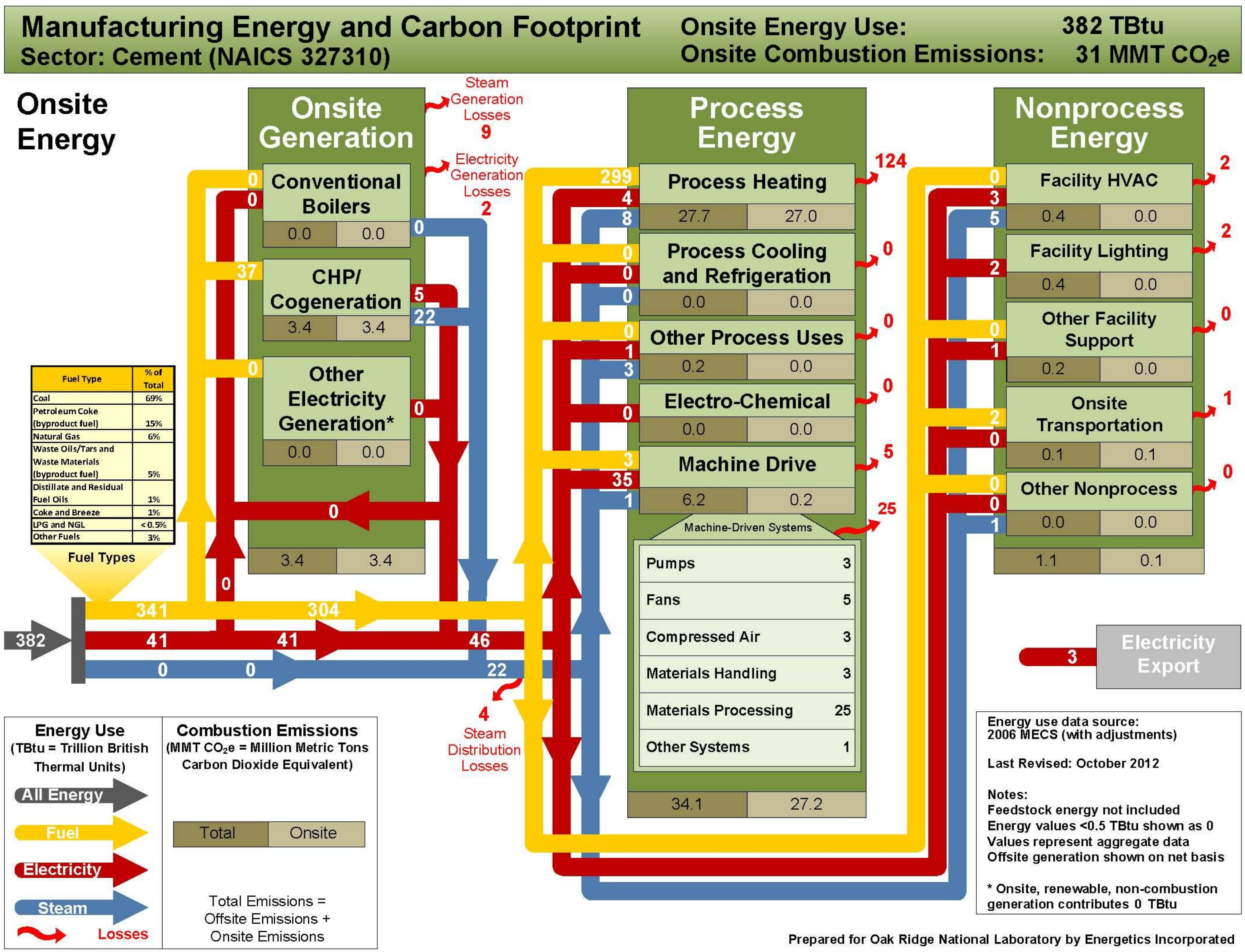
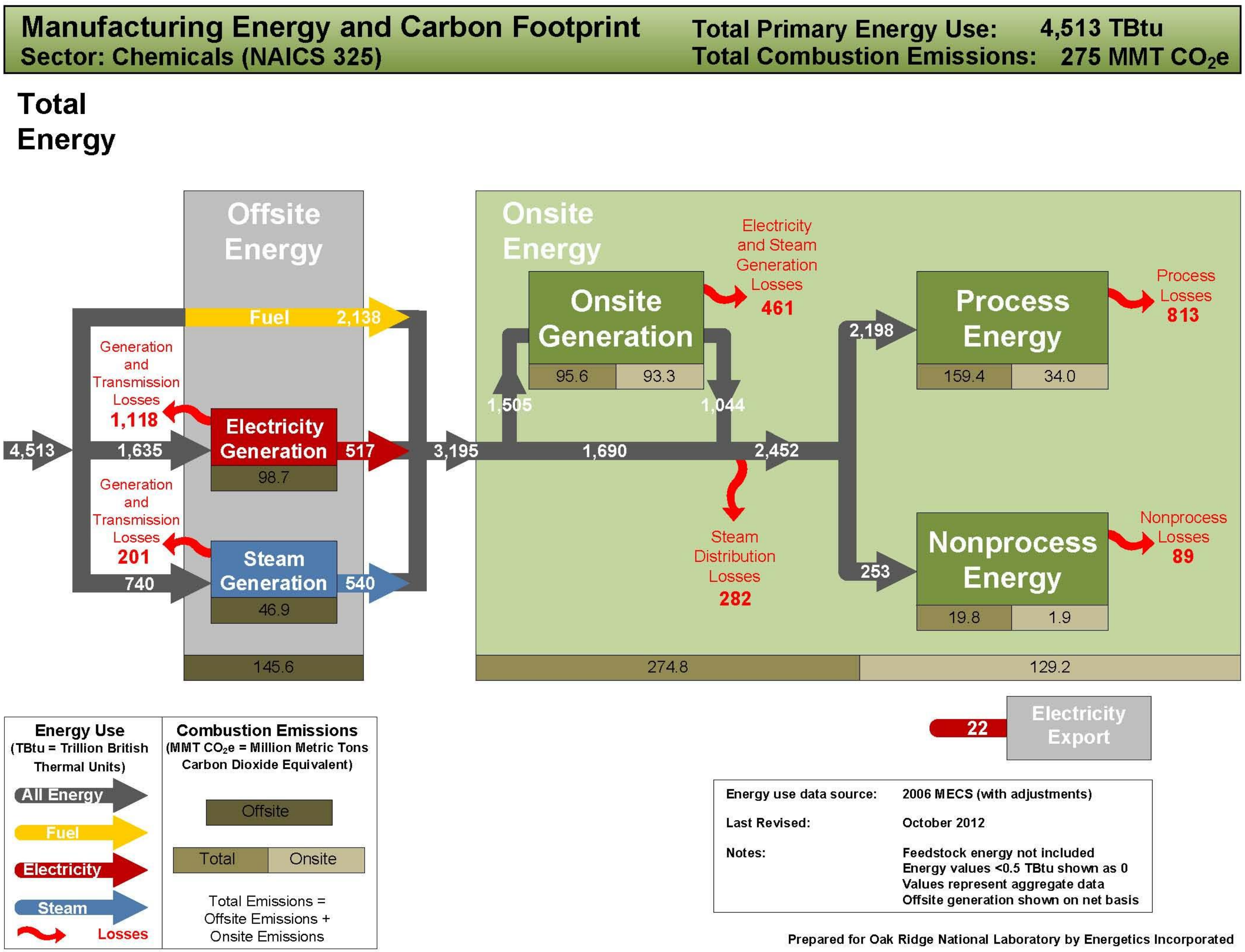
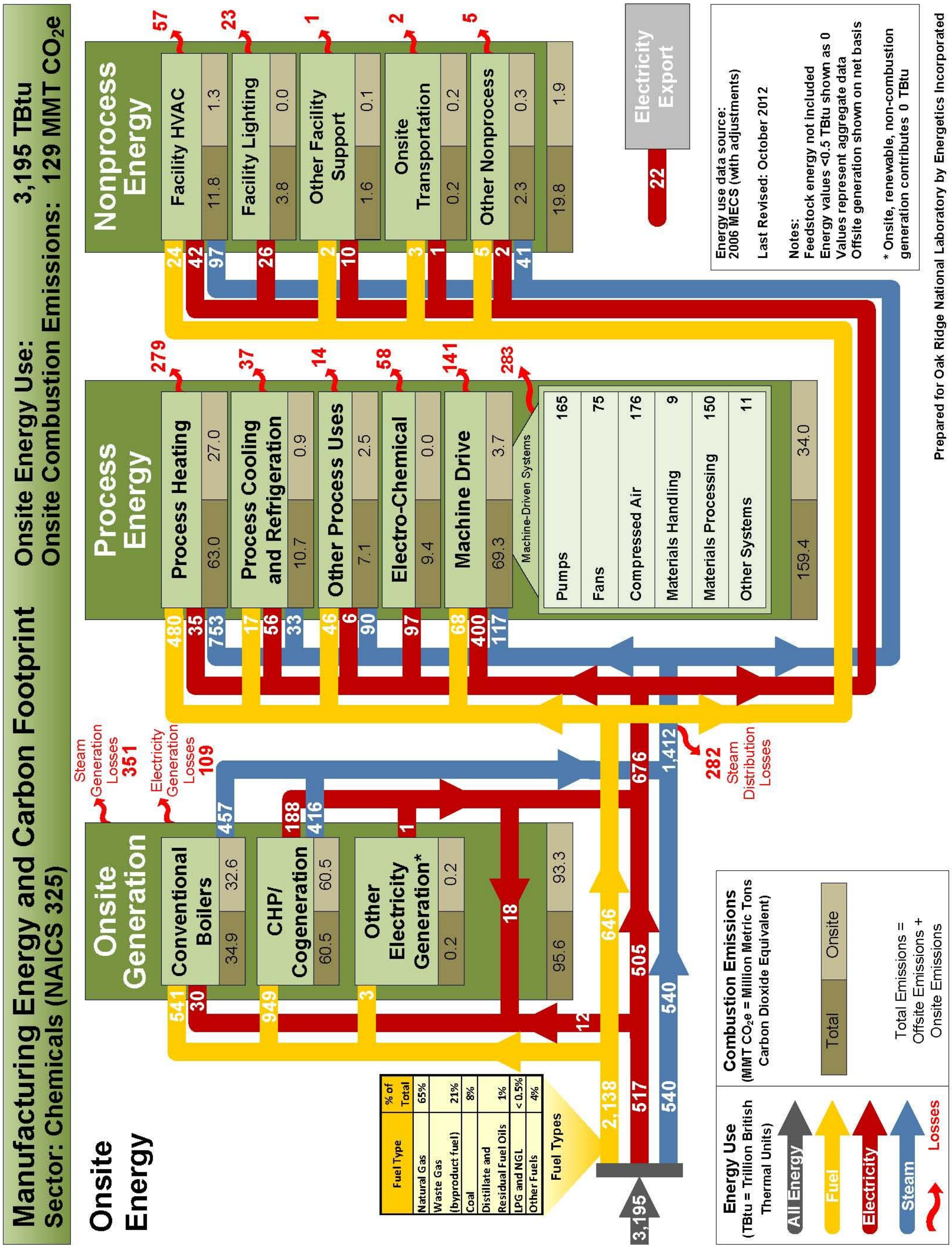

Manufacturing Energy and Carbon Footprint
Sector: Alumina and Aluminum (NAICS 3313)
Onsite Energy Use: 273 TBtu
Onsite Combustion Emissions: 6 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
0.2 0.2
CHP/ Cogeneration
0.8 0.8
Other Electricity Generation*
0.0 0.0
1.0 1.0
Steam Generation Losses 4
Electricity Generation Losses 1
Process Energy
Process Heating
6.2 4.8
Process Cooling and Refrigeration
0.3 0.1
Other Process Uses
0.1 0.1
Electro-Chemical
22.9 0.0
Machine Drive
3.5 0.1
Machine-Driven Systems
Pumps 2
Fans 3
Compressed Air 3
Materials Handling 10
Materials Processing 3
Other Systems 0
33.0 5.0
Nonprocess Energy
Facility HVAC
0.7 0.2
Facility Lighting
0.6 0.0
Other Facility Support
0.2 0.1
Onsite Transportation
0.1 0.1
Other Nonprocess
0.0 0.0
1.6 0.3
Electricity Export
4
273
118
152
3
100
152
3
153
15
3 Steam Distribution Losses
Fuel Type | % of Total
Natural Gas | 98%
LPG and NGL | 1%
Distillate and Residual Fuel Oils | 1%
Coal | < 0.5%
Other Fuels | < 0.5%
Fuel Types
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
($MMT\ CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source:
2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated


Manufacturing Energy and Carbon Footprint
Sector: Cement (NAICS 327310)
Total Primary Energy Use: 471 TBtu
Total Combustion Emissions: 39 MMT $CO_2e$
Total Energy
Offsite Energy
Fuel
341
Electricity Generation
7.8
41
Steam Generation
0.0
0
7.8
471
130
0
Generation and Transmission Losses 89
Generation and Transmission Losses 0
382
Onsite Energy
37
Onsite Generation
3.4
3.4
Electricity and Steam Generation Losses 10
26
345
367
Steam Distribution Losses 4
353
14
Process Energy
34.1
27.2
Process Losses 154
Nonprocess Energy
1.1
0.1
Nonprocess Losses 5
38.6
30.8
Electricity Export
3
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Offsite
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes: Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
Prepared for Oak Ridge National Laboratory by Energetics Incorporated



Manufacturing Energy and Carbon Footprint
Sector: Cement (NAICS 327310)
Onsite Energy Use: 382 TBtu
Onsite Combustion Emissions: 31 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
0.0 0.0
CHP/ Cogeneration
3.4 3.4
Other Electricity Generation*
0.0 0.0
3.4 3.4
Steam Generation Losses 9
Electricity Generation Losses 2
Process Energy
Process Heating
27.7 27.0
124
Process Cooling and Refrigeration
0.0 0.0
Other Process Uses
0.2 0.0
Electro-Chemical
0.0 0.0
Machine Drive
6.2 0.2
Machine-Driven Systems
Pumps 3
Fans 5
Compressed Air 3
Materials Handling 3
Materials Processing 25
Other Systems 1
34.1 27.2
Nonprocess Energy
Facility HVAC
0.4 0.0
Facility Lighting
0.4 0.0
Other Facility Support
0.2 0.0
Onsite Transportation
0.1 0.1
Other Nonprocess
0.0 0.0
1.1 0.1
Electricity Export
3
Fuel Type | % of Total
Coal 69%
Petroleum Coke (byproduct fuel) 15%
Natural Gas 6%
Waste Oils/Tars and Waste Materials (byproduct fuel) 5%
Distillate and Residual Fuel Oils 1%
Coke and Breeze 1%
LPG and NGL < 0.5%
Other Fuels 3%
Fuel Types
382
341
41
0
304
46
22
4
Steam Distribution Losses
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source:
2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated


Manufacturing Energy and Carbon Footprint
Sector: Chemicals (NAICS 325)
Total Primary Energy Use: 4,513 TBtu
Total Combustion Emissions: 275 MMT CO2e
Total Energy
Offsite Energy
Fuel
2,138
Generation and Transmission Losses
1,118
4,513
1,635
Electricity Generation
517
98.7
Generation and Transmission Losses
201
740
Steam Generation
540
46.9
145.6
3,195
Onsite Energy
Onsite Generation
95.6
93.3
Electricity and Steam Generation Losses
461
1,505
1,044
1,690
2,452
Steam Distribution Losses
282
2,198
Process Energy
159.4
34.0
Process Losses
813
253
Nonprocess Energy
19.8
1.9
Nonprocess Losses
89
274.8
129.2
22
Electricity Export
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Offsite
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes: Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
Prepared for Oak Ridge National Laboratory by Energetics Incorporated



Manufacturing Energy and Carbon Footprint
Sector: Chemicals (NAICS 325)
Onsite Energy Use: 3,195 TBtu
Onsite Combustion Emissions: 129 MMT CO2e
Onsite Energy
Fuel Types
Fuel Type | % of Total
Natural Gas 65%
Waste Gas (byproduct fuel) 21%
Coal 8%
Distillate and Residual Fuel Oils 1%
LPG and NGL < 0.5%
Other Fuels 4%
3,195
2,138
517
540
Onsite Generation
Conventional Boilers
34.9
32.6
CHP/ Cogeneration
60.5
60.5
Other Electricity Generation*
0.2
0.2
95.6
93.3
541
30
949
3
12
18
646
505
540
457
188
416
1
Steam Generation Losses 351
Electricity Generation Losses 109
676
1,412
282 Steam Distribution Losses
Process Energy
Process Heating
63.0
27.0
Process Cooling and Refrigeration
10.7
0.9
Other Process Uses
7.1
2.5
Electro-Chemical
9.4
0.0
Machine Drive
69.3
3.7
159.4
34.0
480
35
753
17
56
33
46
6
90
97
68
400
117
279
37
14
58
141
283
Machine-Driven Systems
Pumps 165
Fans 75
Compressed Air 176
Materials Handling 9
Materials Processing 150
Other Systems 11
Nonprocess Energy
Facility HVAC
11.8
1.3
Facility Lighting
3.8
0.0
Other Facility Support
1.6
0.1
Onsite Transportation
0.2
0.2
Other Nonprocess
2.3
0.3
19.8
1.9
24
42
97
26
2
10
3
1
5
2
41
57
23
1
2
5
Electricity Export
22
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

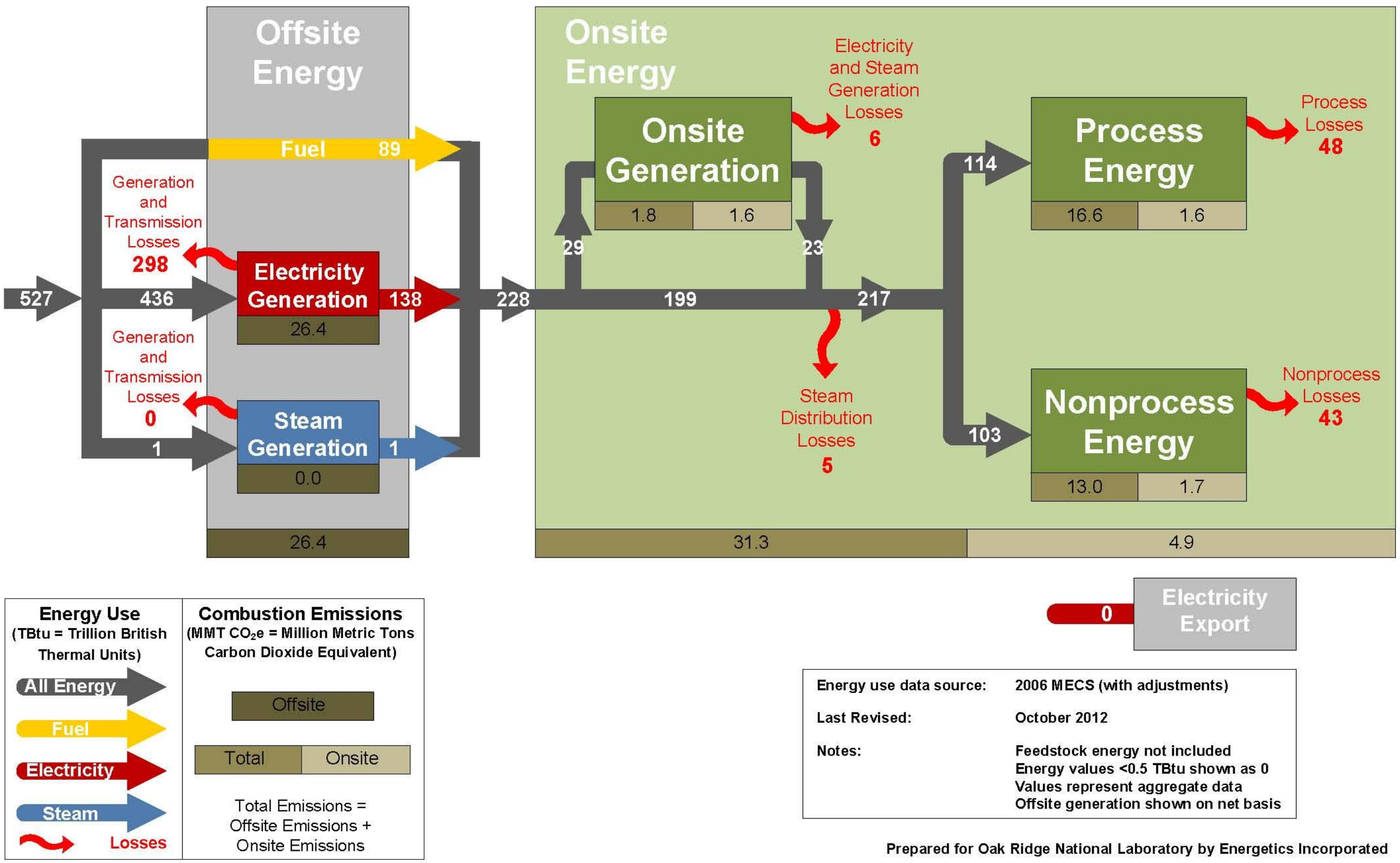
# Manufacturing Energy and Carbon Footprint

**Sector: Computers, Electronics and Electrical Equipment (NAICS 334,335)**

**Total Primary Energy Use: 527 TBtu**

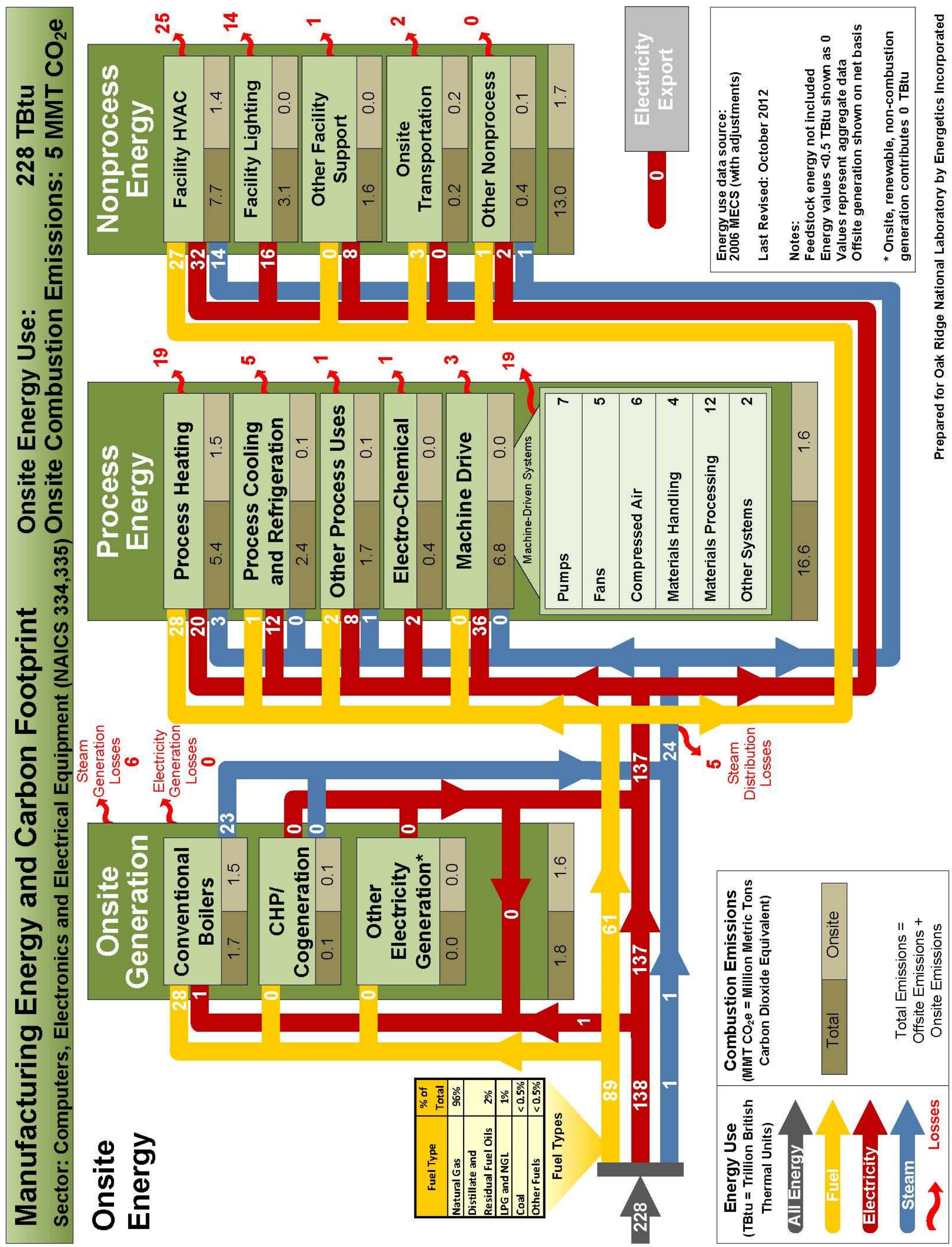
**Total Combustion Emissions: 31 MMT $CO_2e$**

## Total Energy




| | |
|---|---|
| Energy use data source: | 2006 MECS (with adjustments) |
| Last Revised: | October 2012 |
| Notes: | Feedstock energy not included<br>Energy values <0.5 TBtu shown as 0<br>Values represent aggregate data<br>Offsite generation shown on net basis |

Prepared for Oak Ridge National Laboratory by Energetics Incorporated



Manufacturing Energy and Carbon Footprint
Sector: Computers, Electronics and Electrical Equipment (NAICS 334,335)
Onsite Energy Use: 228 TBtu
Onsite Combustion Emissions: 5 MMT CO2e
Onsite Energy
228
Fuel Types
Fuel Type | % of Total
Natural Gas | 96%
Distillate and Residual Fuel Oils | 2%
LPG and NGL | 1%
Coal | < 0.5%
Other Fuels | < 0.5%
89
138
1
Onsite Generation
Conventional Boilers
1.7
1.5
CHP/ Cogeneration
0.1
0.1
Other Electricity Generation*
0.0
0.0
1.8
1.6
Steam Generation Losses
6
Electricity Generation Losses
0
Steam Distribution Losses
5
61
137
24
23
Process Energy
Process Heating
5.4
1.5
Process Cooling and Refrigeration
2.4
0.1
Other Process Uses
1.7
0.1
Electro-Chemical
0.4
0.0
Machine Drive
6.8
0.0
16.6
1.6
Machine-Driven Systems
Pumps 7
Fans 5
Compressed Air 6
Materials Handling 4
Materials Processing 12
Other Systems 2
19
5
1
1
3
19
Nonprocess Energy
Facility HVAC
7.7
1.4
Facility Lighting
3.1
0.0
Other Facility Support
1.6
0.0
Onsite Transportation
0.2
0.2
Other Nonprocess
0.4
0.1
13.0
1.7
25
14
1
2
0
Electricity Export
0
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
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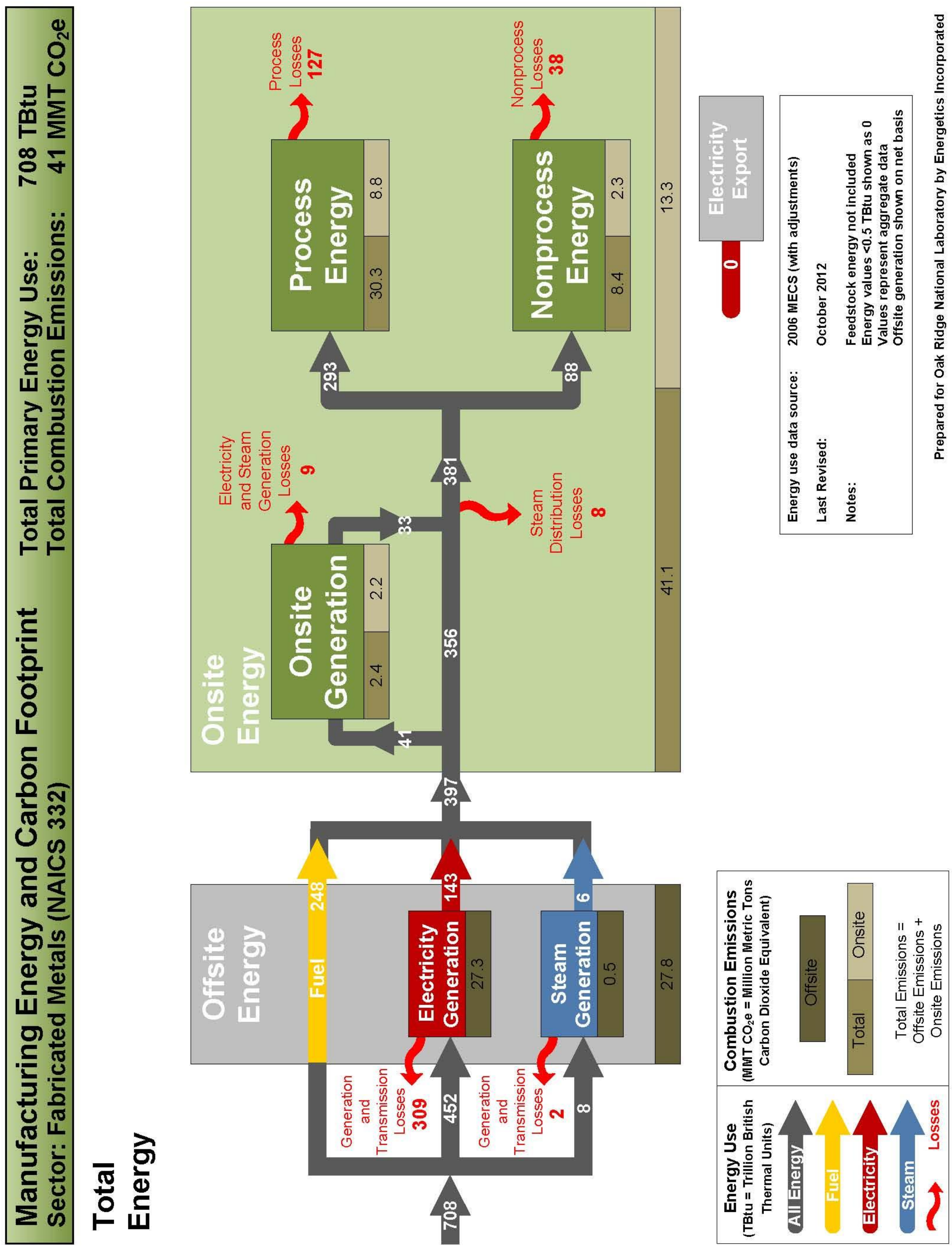

Manufacturing Energy and Carbon Footprint
Sector: Fabricated Metals (NAICS 332)
Total Primary Energy Use: 708 TBtu
Total Combustion Emissions: 41 MMT $CO_2e$
Total Energy
Offsite Energy
Onsite Energy
708
452
8
Generation and Transmission Losses 309
Generation and Transmission Losses 2
Fuel
248
Electricity Generation
27.3
143
Steam Generation
0.5
6
27.8
397
41
Onsite Generation
2.4
2.2
Electricity and Steam Generation Losses 9
33
356
381
Steam Distribution Losses 8
293
88
Process Energy
30.3
8.8
Process Losses 127
Nonprocess Energy
8.4
2.3
Nonprocess Losses 38
41.1
13.3
0
Electricity Export
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Offsite
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes: Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
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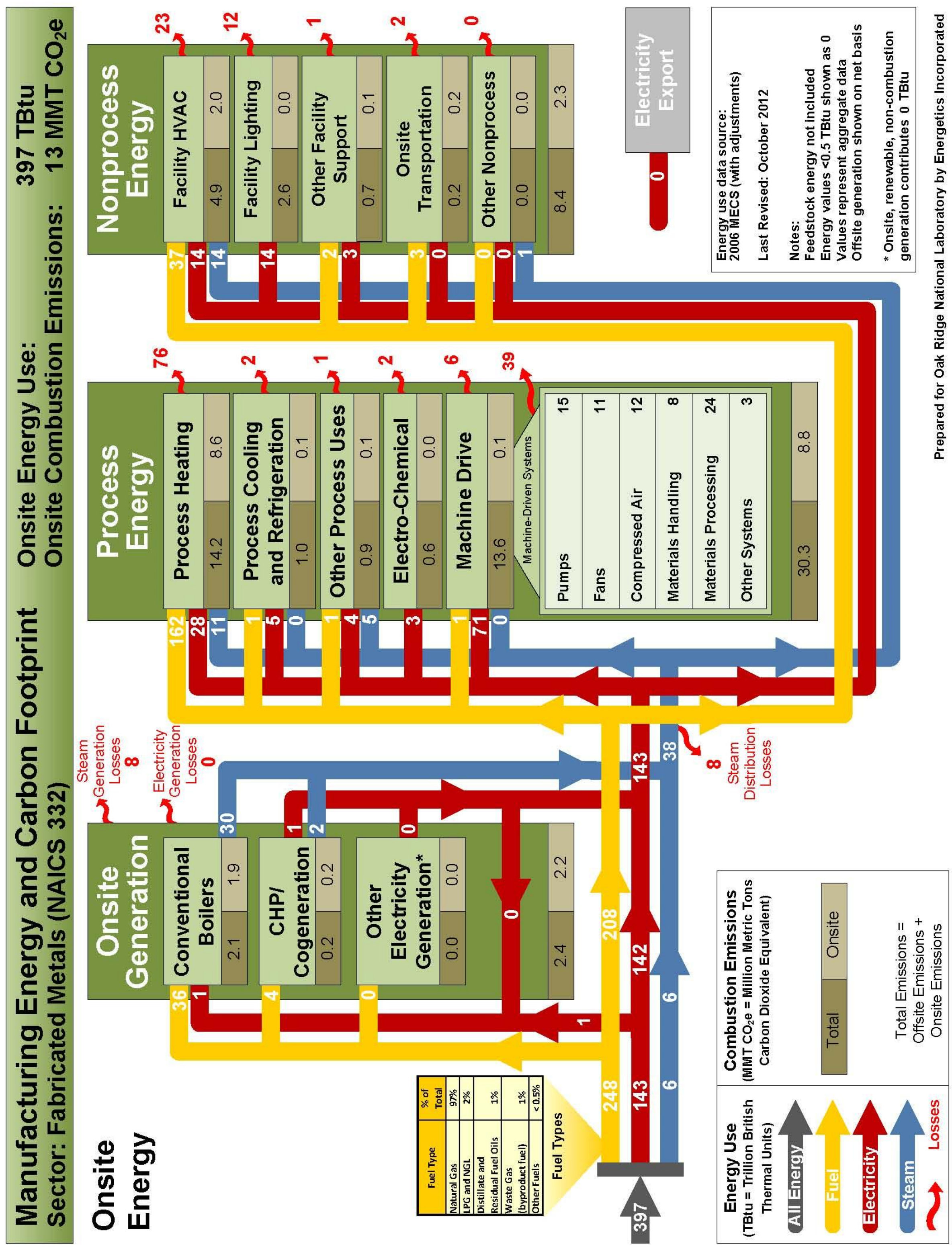
Manufacturing Energy and Carbon Footprint
Sector: Fabricated Metals (NAICS 332)
Onsite Energy Use: 397 TBtu
Onsite Combustion Emissions: 13 MMT CO2e
Onsite Energy
Onsite Generation
Conventional Boilers
2.1
1.9
CHP/ Cogeneration
0.2
0.2
Other Electricity Generation*
0.0
0.0
2.4
2.2
Steam Generation Losses
8
Electricity Generation Losses
0
Steam Distribution Losses
8
Process Energy
Process Heating
14.2
8.6
76
Process Cooling and Refrigeration
1.0
0.1
2
Other Process Uses
0.9
0.1
1
Electro-Chemical
0.6
0.0
2
Machine Drive
13.6
0.1
6
39
Machine-Driven Systems
Pumps
15
Fans
11
Compressed Air
12
Materials Handling
8
Materials Processing
24
Other Systems
3
30.3
8.8
Nonprocess Energy
Facility HVAC
4.9
2.0
23
Facility Lighting
2.6
0.0
12
Other Facility Support
0.7
0.1
1
Onsite Transportation
0.2
0.2
2
Other Nonprocess
0.0
0.0
0
8.4
2.3
Electricity Export
0
Fuel Types
Fuel Type | % of Total
Natural Gas | 97%
LPG and NGL | 2%
Distillate and Residual Fuel Oils | 1%
Waste Gas (byproduct fuel) | 1%
Other Fuels | < 0.5%
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
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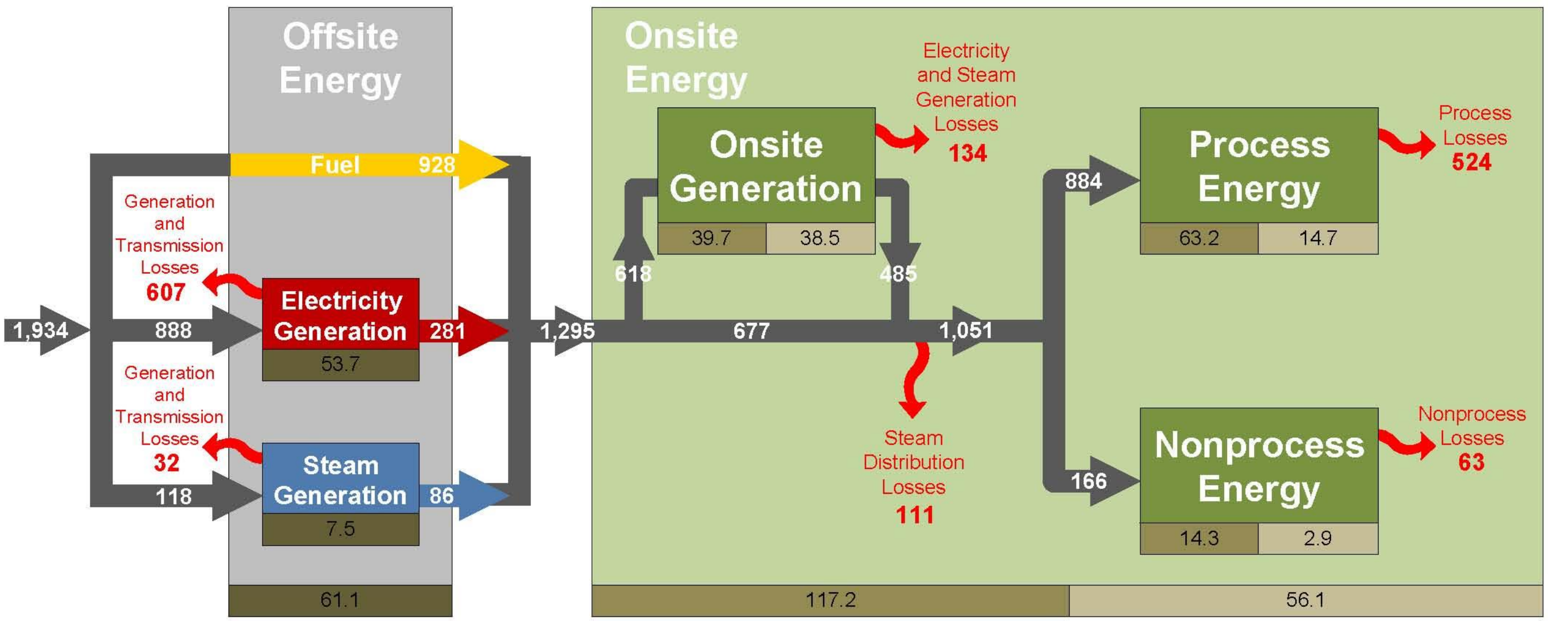
## Manufacturing Energy and Carbon Footprint
## Sector: Food and Beverage (NAICS 311, 312)

**Total Primary Energy Use:** 1,934 TBtu
**Total Combustion Emissions:** 117 MMT $CO_2e$

### Total Energy




0 Electricity Export

**Energy Use** (TBtu = Trillion British Thermal Units)
- All Energy
- Fuel
- Electricity
- Steam
- Losses

**Combustion Emissions** ($MMT\ CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
- Offsite
- Total | Onsite

Total Emissions = Offsite Emissions + Onsite Emissions

| | |
|---|---|
| Energy use data source: | 2006 MECS (with adjustments) |
| Last Revised: | October 2012 |
| Notes: | Feedstock energy not included<br>Energy values <0.5 TBtu shown as 0<br>Values represent aggregate data<br>Offsite generation shown on net basis |

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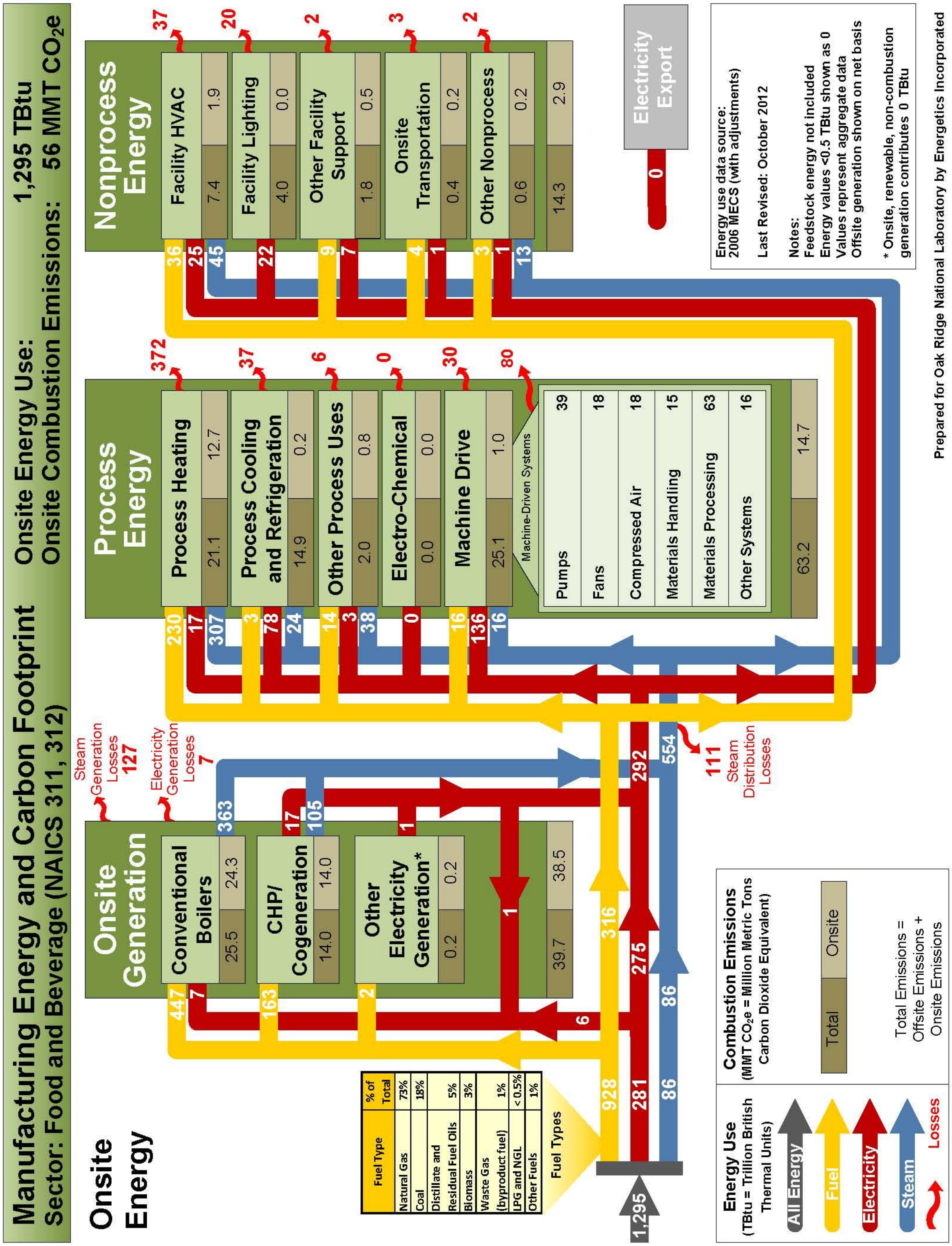
Manufacturing Energy and Carbon Footprint
Sector: Food and Beverage (NAICS 311, 312)
Onsite Energy Use: 1,295 TBtu
Onsite Combustion Emissions: 56 MMT CO2e
Onsite Energy
Fuel Type
% of Total
Natural Gas 73%
Coal 18%
Distillate and Residual Fuel Oils 5%
Biomass 3%
Waste Gas (byproduct fuel) 1%
LPG and NGL < 0.5%
Other Fuels 1%
Fuel Types
1,295
928
281
86
Onsite Generation
Conventional Boilers
25.5
24.3
CHP/ Cogeneration
14.0
14.0
Other Electricity Generation*
0.2
0.2
39.7
38.5
447
7
163
2
6
1
1
316
275
86
363
17
105
Steam Generation Losses 127
Electricity Generation Losses 7
292
554
111 Steam Distribution Losses
Process Energy
Process Heating
21.1
12.7
Process Cooling and Refrigeration
14.9
0.2
Other Process Uses
2.0
0.8
Electro-Chemical
0.0
0.0
Machine Drive
25.1
1.0
63.2
14.7
372
37
6
0
30
80
230
17
307
3
78
24
14
3
38
0
16
136
16
Machine-Driven Systems
Pumps 39
Fans 18
Compressed Air 18
Materials Handling 15
Materials Processing 63
Other Systems 16
Nonprocess Energy
Facility HVAC
7.4
1.9
Facility Lighting
4.0
0.0
Other Facility Support
1.8
0.5
Onsite Transportation
0.4
0.2
Other Nonprocess
0.6
0.2
14.3
2.9
37
20
2
3
2
36
25
45
22
9
7
4
1
3
1
13
Electricity Export
0
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
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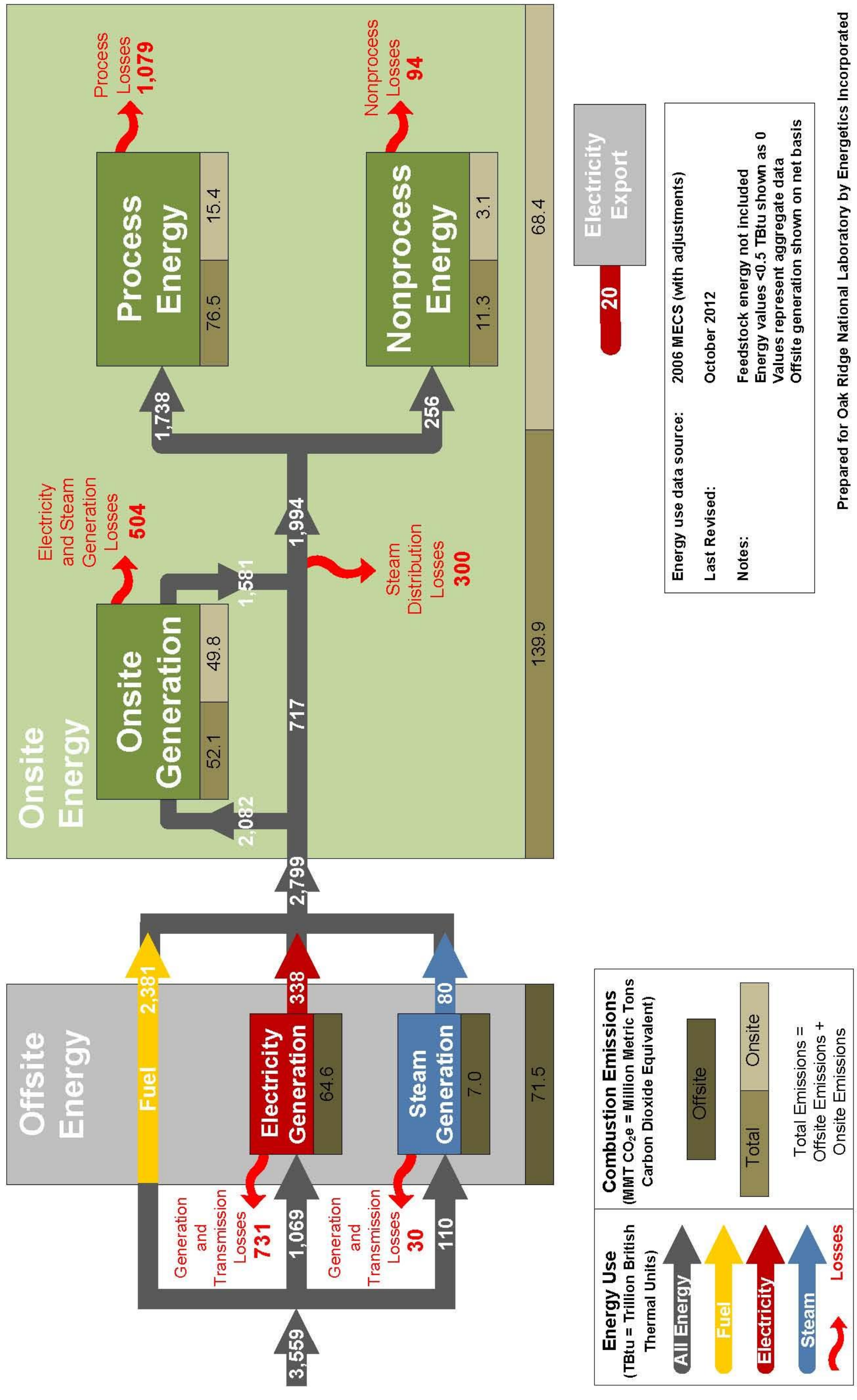
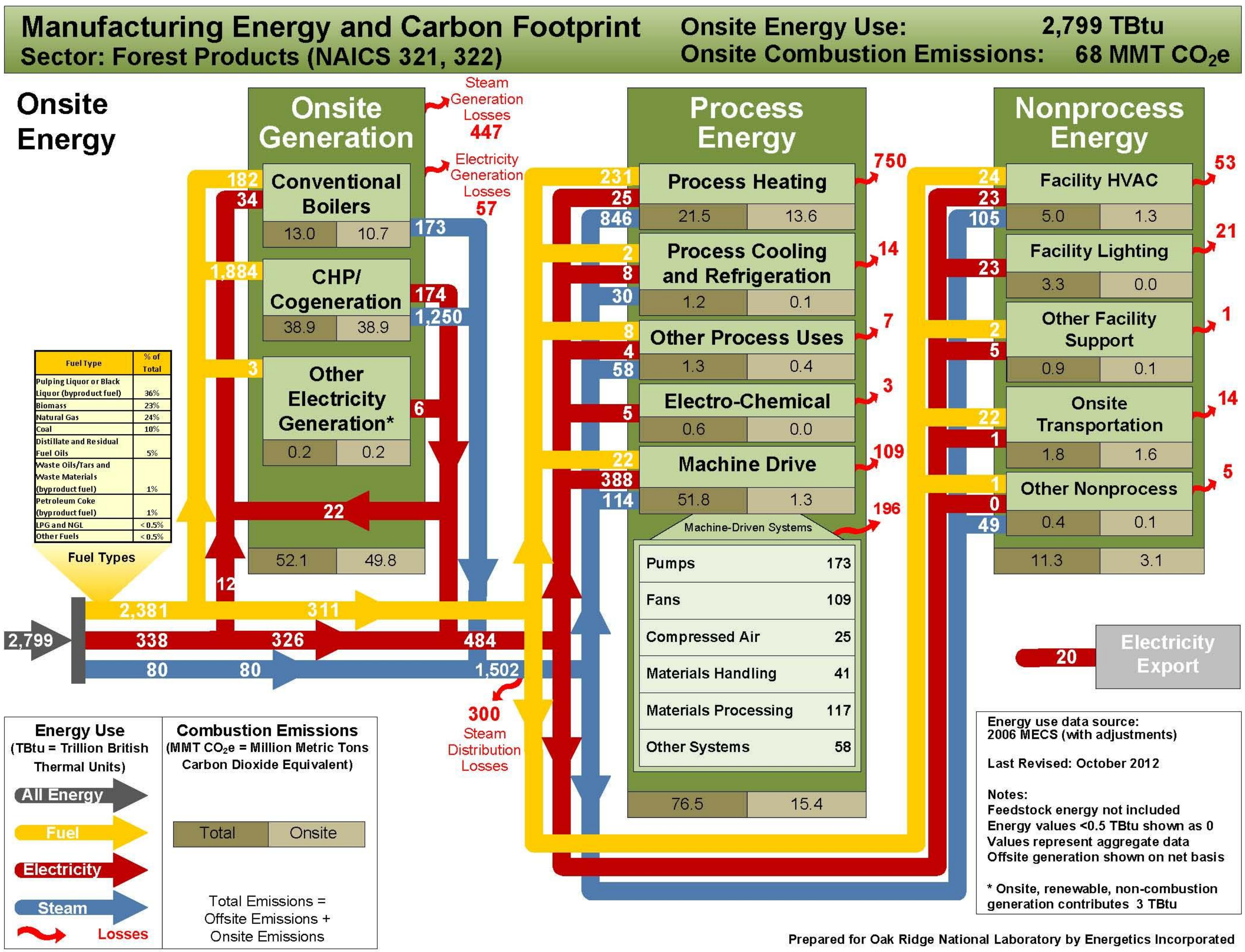
## Manufacturing Energy and Carbon Footprint
## Sector: Forest Products (NAICS 321, 322)

Total Primary Energy Use: 3,559 TBtu
Total Combustion Emissions: 140 MMT $CO_2e$

### Total Energy




Manufacturing Energy and Carbon Footprint
Sector: Forest Products (NAICS 321, 322)
Onsite Energy Use: 2,799 TBtu
Onsite Combustion Emissions: 68 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
13.0
10.7
CHP/ Cogeneration
38.9
38.9
Other Electricity Generation*
0.2
0.2
52.1
49.8
Steam Generation Losses
447
Electricity Generation Losses
57
Process Energy
Process Heating
21.5
13.6
750
Process Cooling and Refrigeration
1.2
0.1
14
Other Process Uses
1.3
0.4
7
Electro-Chemical
0.6
0.0
3
Machine Drive
51.8
1.3
109
Machine-Driven Systems
196
Pumps 173
Fans 109
Compressed Air 25
Materials Handling 41
Materials Processing 117
Other Systems 58
76.5
15.4
Nonprocess Energy
Facility HVAC
5.0
1.3
53
Facility Lighting
3.3
0.0
21
Other Facility Support
0.9
0.1
1
Onsite Transportation
1.8
1.6
14
Other Nonprocess
0.4
0.1
5
11.3
3.1
Electricity Export
20
Fuel Types
Fuel Type | % of Total
Pulping Liquor or Black Liquor (byproduct fuel) 36%
Biomass 23%
Natural Gas 24%
Coal 10%
Distillate and Residual Fuel Oils 5%
Waste Oils/Tars and Waste Materials (byproduct fuel) 1%
Petroleum Coke (byproduct fuel) 1%
LPG and NGL <0.5%
Other Fuels <0.5%
2,799
2,381
338
80
311
326
80
484
1,502
182
34
1,884
3
12
22
173
174
1,250
6
300
Steam Distribution Losses
231
25
846
2
8
30
8
4
58
5
22
388
114
24
23
105
23
2
5
22
1
1
0
49
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source:
2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 3 TBtu
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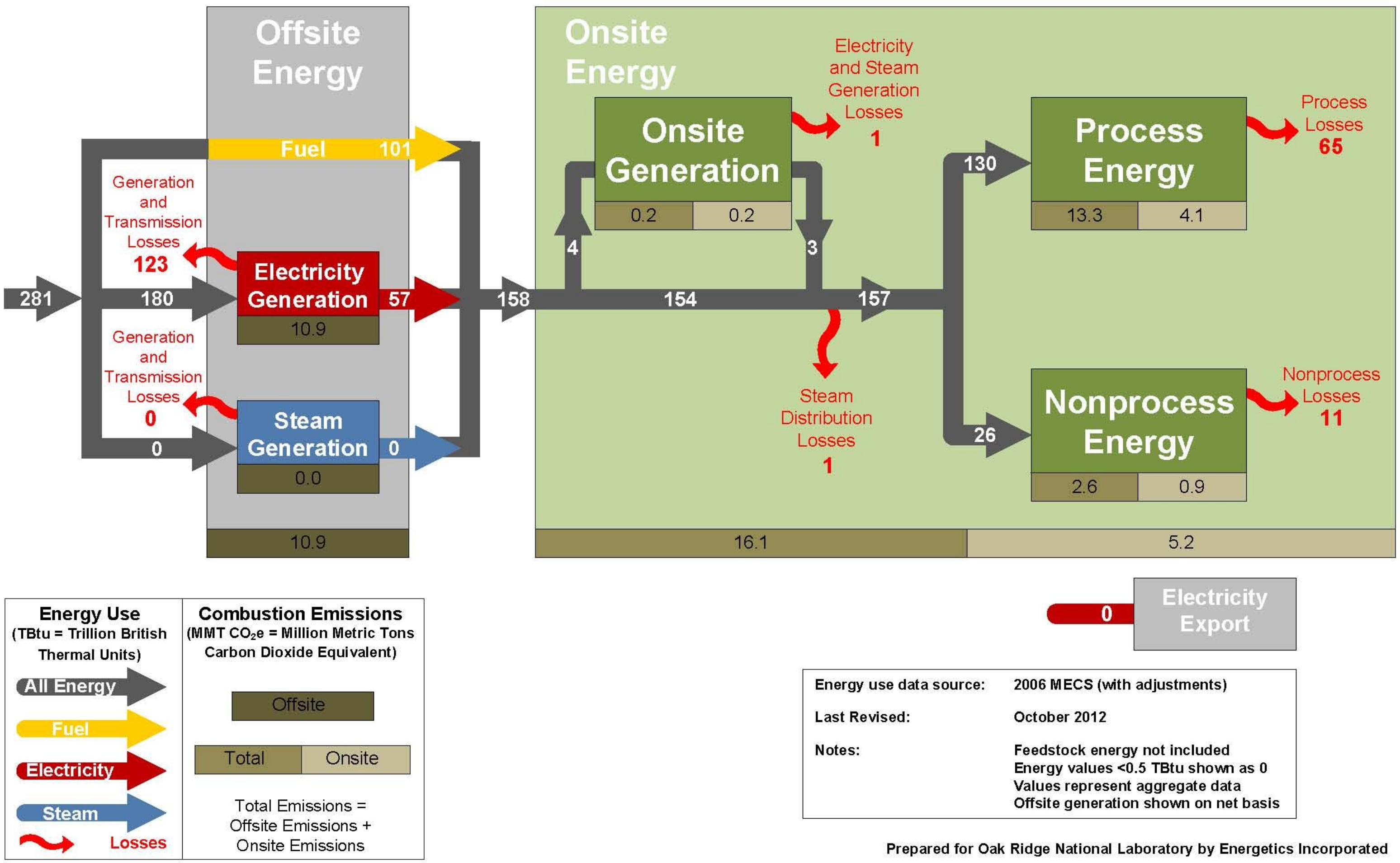
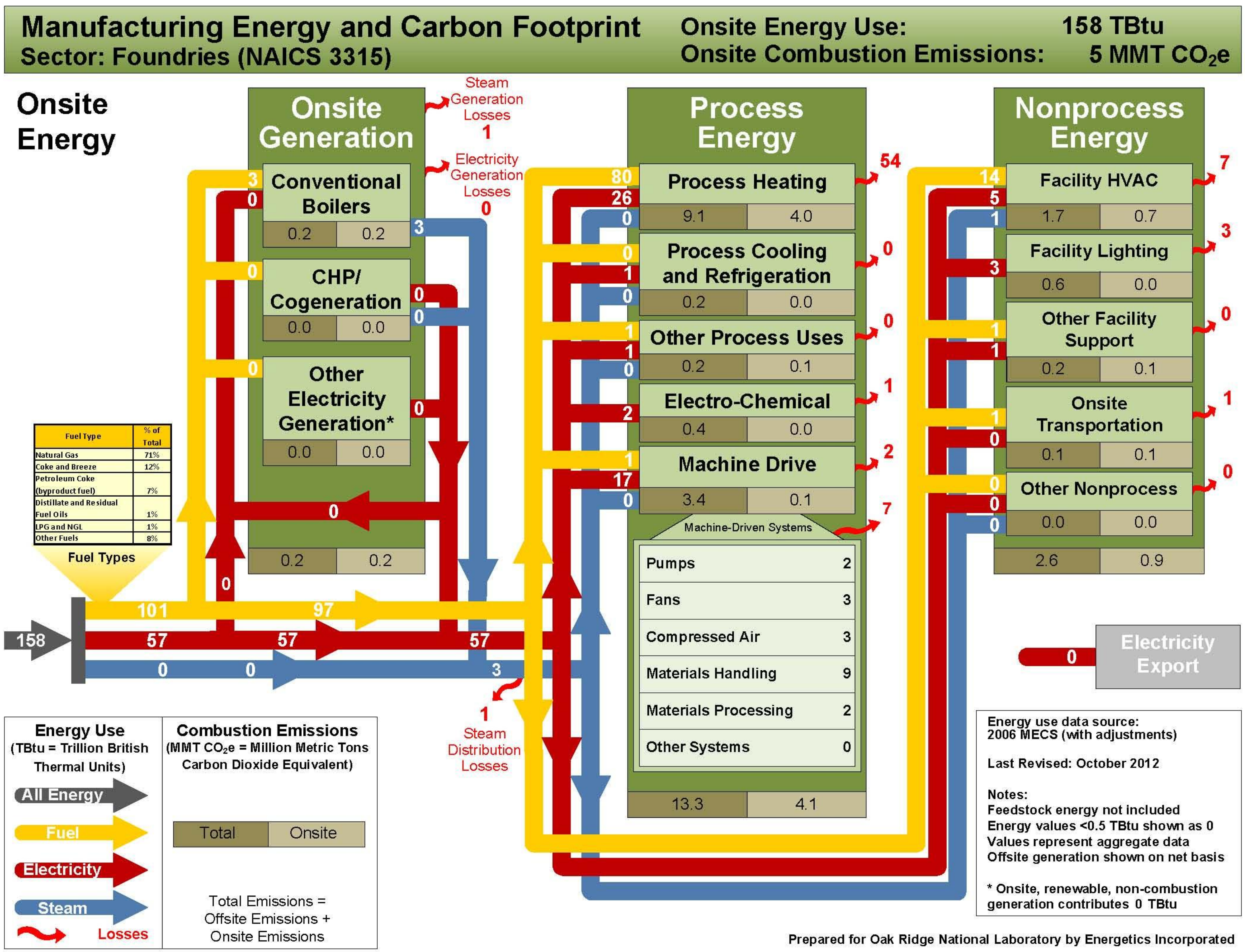
# Manufacturing Energy and Carbon Footprint
## Sector: Foundries (NAICS 3315)

**Total Primary Energy Use:** 281 TBtu
**Total Combustion Emissions:** 16 MMT $CO_2e$

## Total Energy




Manufacturing Energy and Carbon Footprint
Sector: Foundries (NAICS 3315)
Onsite Energy Use: 158 TBtu
Onsite Combustion Emissions: 5 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
CHP/ Cogeneration
Other Electricity Generation*
Steam Generation Losses 1
Electricity Generation Losses 0
Steam Distribution Losses 1
Process Energy
Process Heating
Process Cooling and Refrigeration
Other Process Uses
Electro-Chemical
Machine Drive
Machine-Driven Systems
Pumps 2
Fans 3
Compressed Air 3
Materials Handling 9
Materials Processing 2
Other Systems 0
Nonprocess Energy
Facility HVAC
Facility Lighting
Other Facility Support
Onsite Transportation
Other Nonprocess
Electricity Export
Fuel Type
% of Total
Natural Gas 71%
Coke and Breeze 12%
Petroleum Coke (byproduct fuel) 7%
Distillate and Residual Fuel Oils 1%
LPG and NGL 1%
Other Fuels 8%
Fuel Types
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
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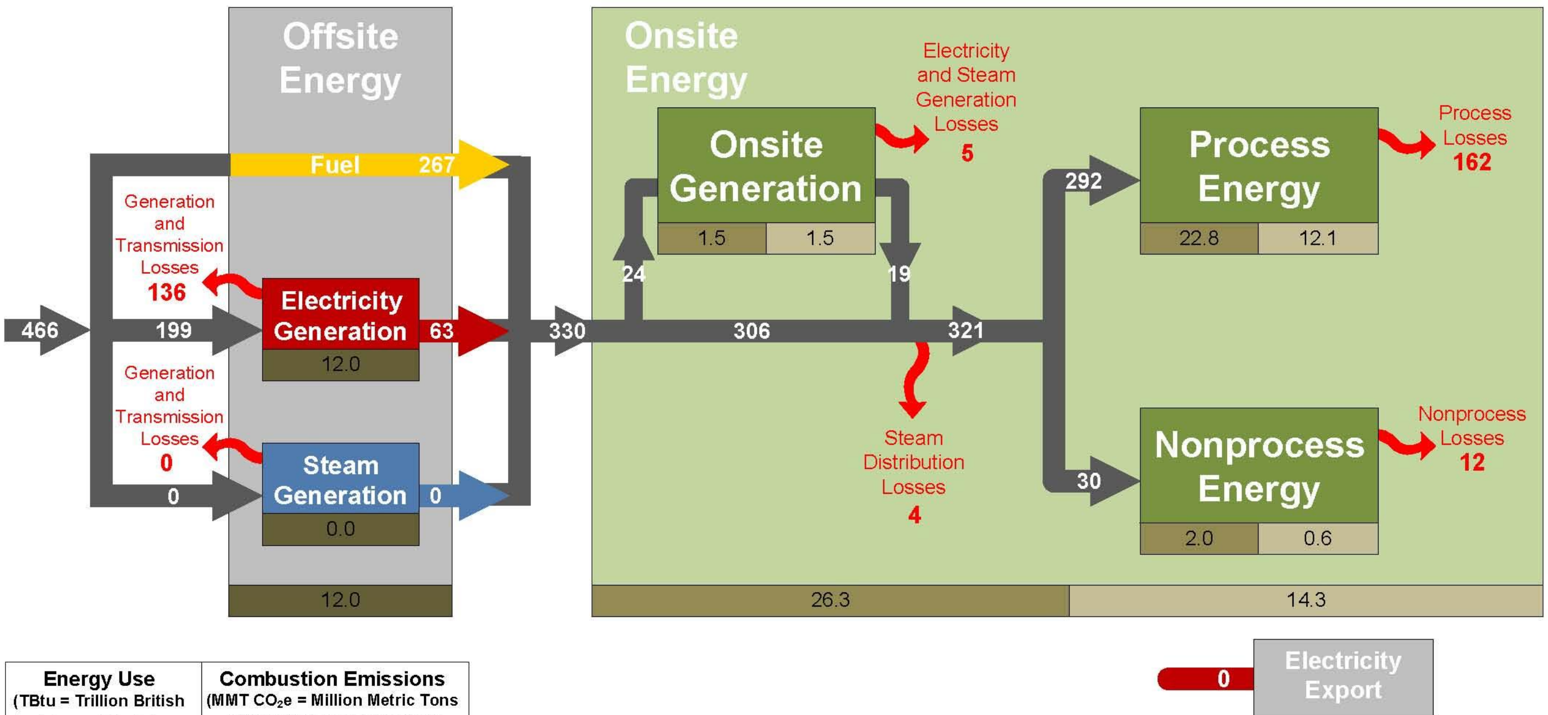
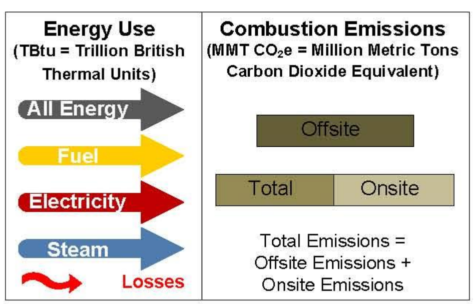
## Manufacturing Energy and Carbon Footprint
**Sector: Glass (NAICS 3272, 327993)**

**Total Primary Energy Use:** 466 TBtu
**Total Combustion Emissions:** 26 MMT $CO_2e$

# Total Energy




| | |
|---|---|
| Energy use data source: | 2006 MECS (with adjustments) |
| Last Revised: | October 2012 |
| Notes: | Feedstock energy not included<br>Energy values <0.5 TBtu shown as 0<br>Values represent aggregate data<br>Offsite generation shown on net basis |

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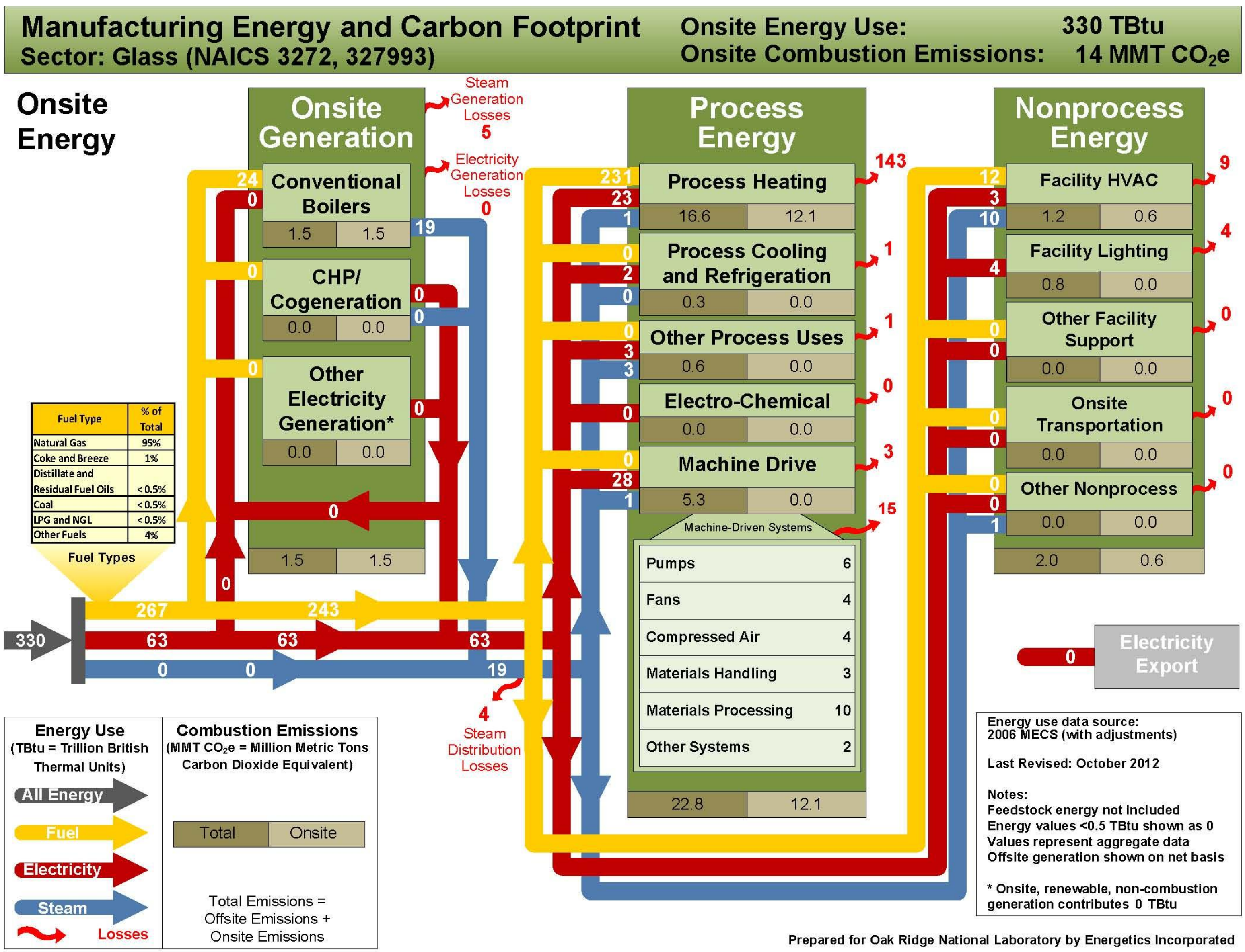
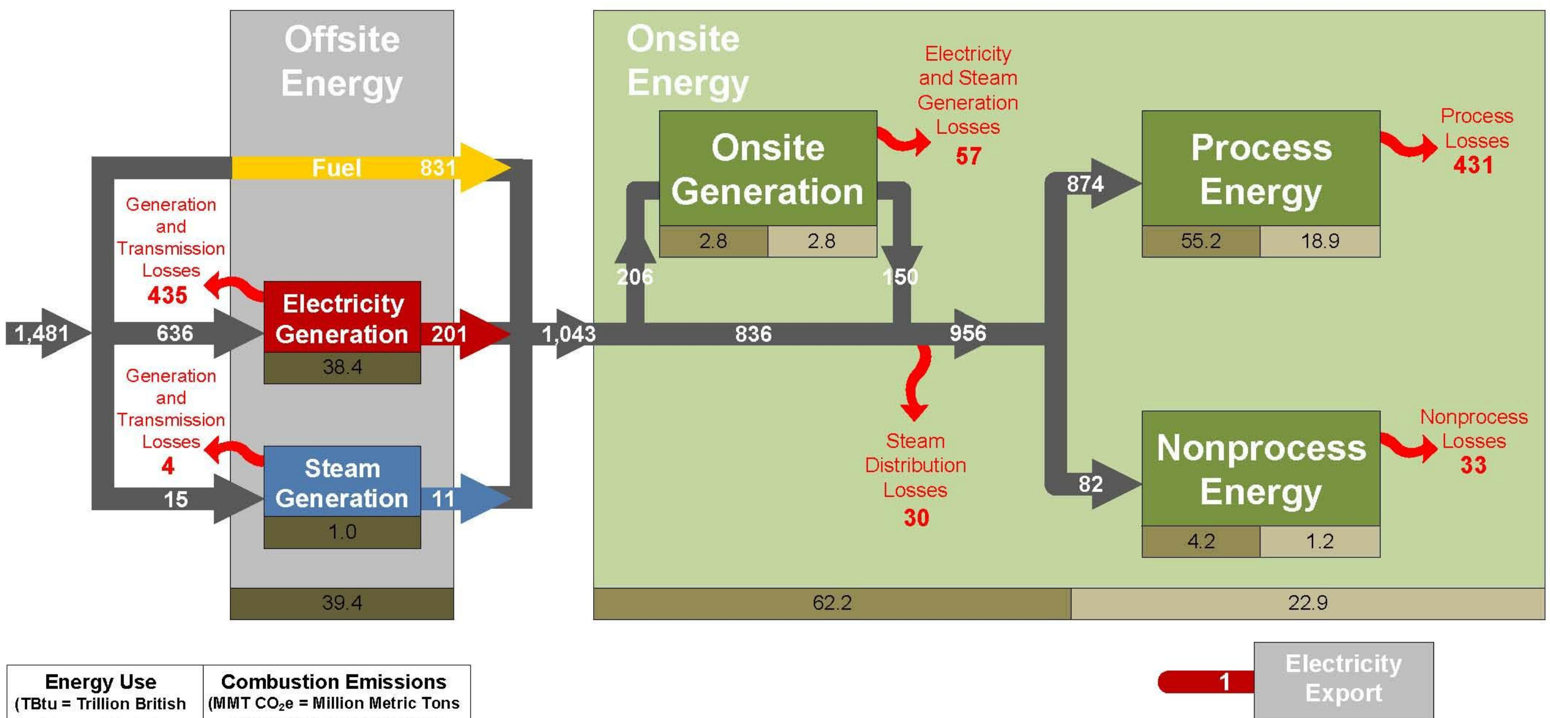


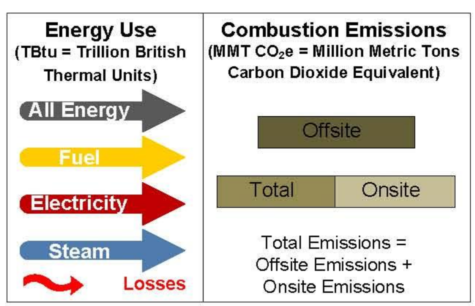
Manufacturing Energy and Carbon Footprint
Sector: Glass (NAICS 3272, 327993)
Onsite Energy Use: 330 TBtu
Onsite Combustion Emissions: 14 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
1.5 1.5
CHP/ Cogeneration
0.0 0.0
Other Electricity Generation*
0.0 0.0
1.5 1.5
Steam Generation Losses 5
Electricity Generation Losses 0
Steam Distribution Losses 4
Process Energy
Process Heating
16.6 12.1
Process Cooling and Refrigeration
0.3 0.0
Other Process Uses
0.6 0.0
Electro-Chemical
0.0 0.0
Machine Drive
5.3 0.0
Machine-Driven Systems
Pumps 6
Fans 4
Compressed Air 4
Materials Handling 3
Materials Processing 10
Other Systems 2
22.8 12.1
143
1
1
0
3
15
Nonprocess Energy
Facility HVAC
1.2 0.6
Facility Lighting
0.8 0.0
Other Facility Support
0.0 0.0
Onsite Transportation
0.0 0.0
Other Nonprocess
0.0 0.0
2.0 0.6
9
4
0
0
0
Electricity Export
0
330
267
243
63
63
63
0
0
19
24
0
0
0
19
0
0
0
0
231
23
1
0
2
0
0
3
3
0
0
28
1
12
3
10
4
0
0
0
0
0
0
1
Fuel Type | % of Total
Natural Gas 95%
Coke and Breeze 1%
Distillate and Residual Fuel Oils < 0.5%
Coal < 0.5%
LPG and NGL < 0.5%
Other Fuels 4%
Fuel Types
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source:
2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

# Manufacturing Energy and Carbon Footprint
## Sector: Iron and Steel (NAICS 3311,3312)

**Total Primary Energy Use: 1,481 TBtu**
**Total Combustion Emissions: 62 MMT $CO_2e$**

## Total Energy




| | |
|---|---|
| Energy use data source: | 2006 MECS (with adjustments) |
| Last Revised: | October 2012 |
| Notes: | Feedstock energy not included<br>Energy values <0.5 TBtu shown as 0<br>Values represent aggregate data<br>Offsite generation shown on net basis |

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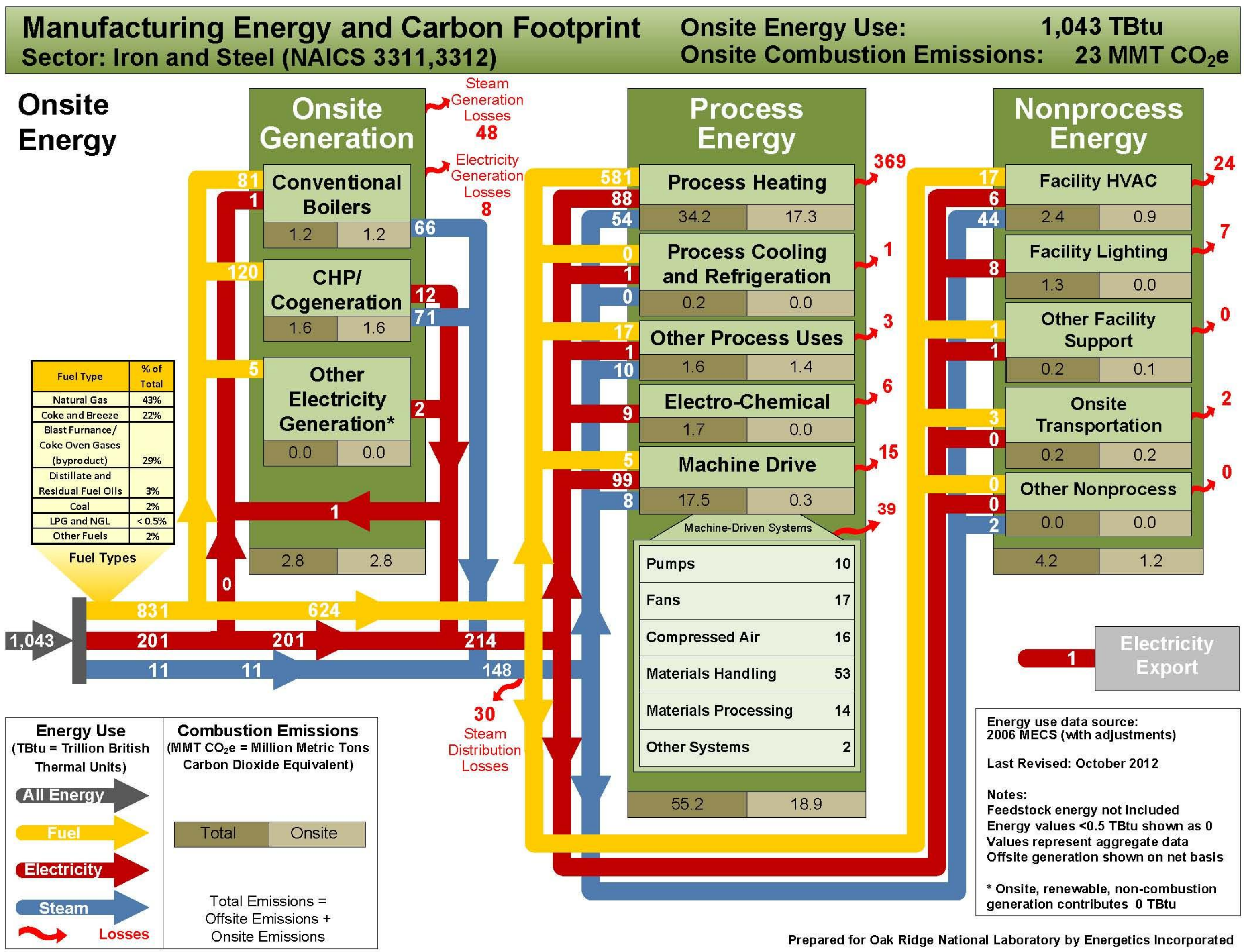
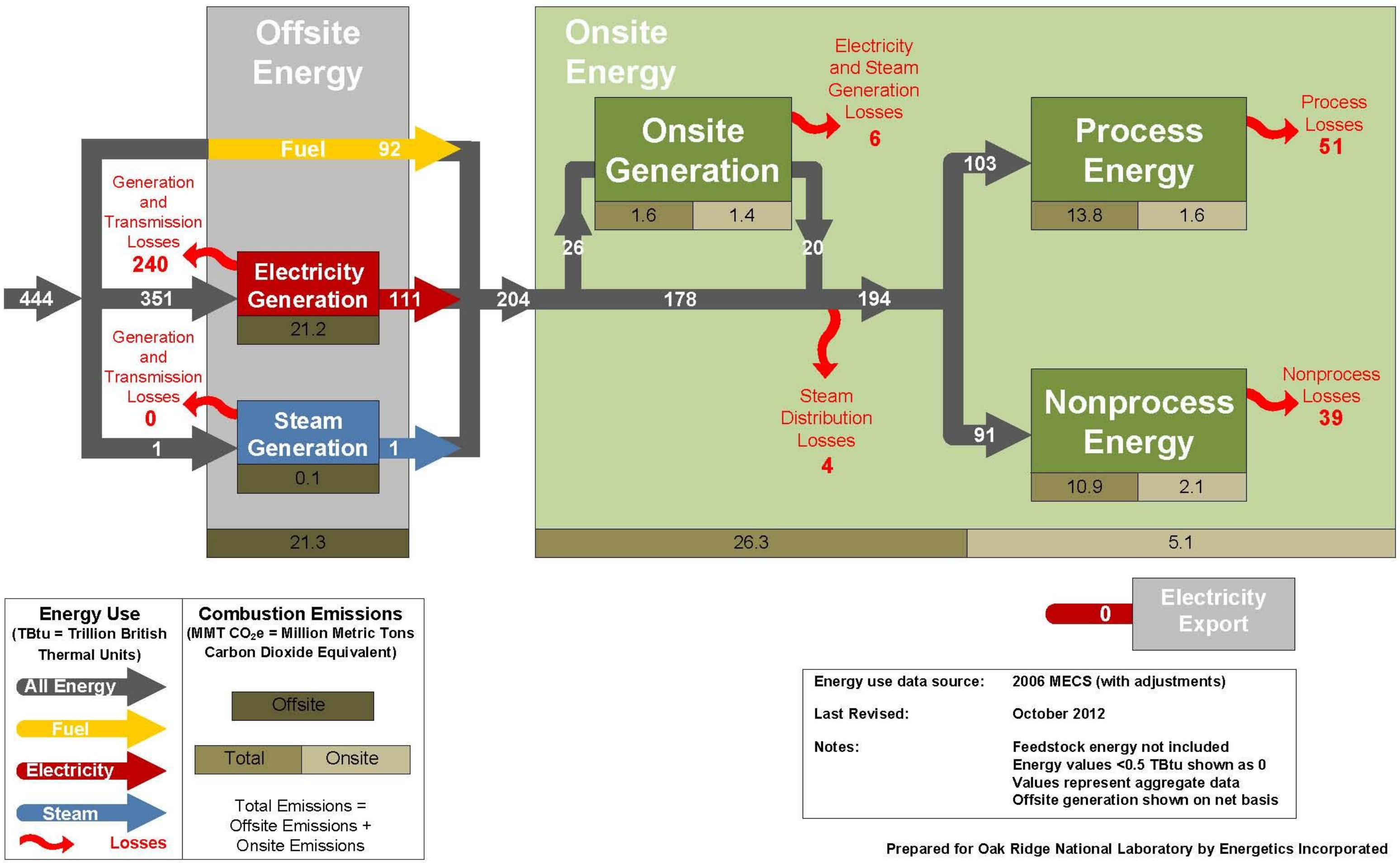


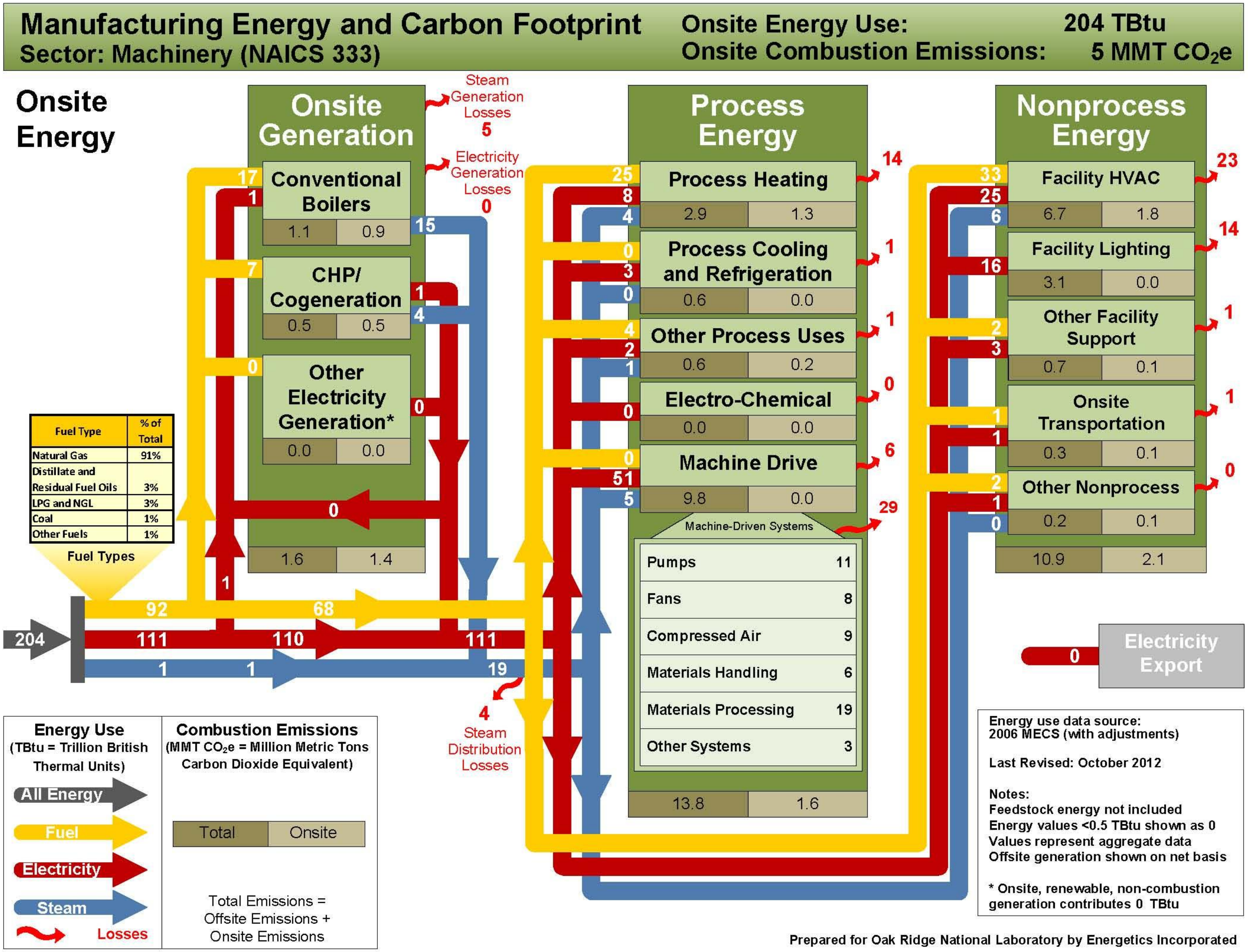
Manufacturing Energy and Carbon Footprint
Sector: Iron and Steel (NAICS 3311,3312)
Onsite Energy Use: 1,043 TBtu
Onsite Combustion Emissions: 23 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
1.2
1.2
CHP/ Cogeneration
1.6
1.6
Other Electricity Generation*
0.0
0.0
2.8
2.8
Steam Generation Losses 48
Electricity Generation Losses 8
Process Energy
Process Heating
34.2
17.3
369
Process Cooling and Refrigeration
0.2
0.0
1
Other Process Uses
1.6
1.4
3
Electro-Chemical
1.7
0.0
6
Machine Drive
17.5
0.3
15
Machine-Driven Systems
39
Pumps 10
Fans 17
Compressed Air 16
Materials Handling 53
Materials Processing 14
Other Systems 2
55.2
18.9
Nonprocess Energy
Facility HVAC
2.4
0.9
24
Facility Lighting
1.3
0.0
7
Other Facility Support
0.2
0.1
0
Onsite Transportation
0.2
0.2
2
Other Nonprocess
0.0
0.0
0
4.2
1.2
Electricity Export
1
Fuel Type
% of Total
Natural Gas 43%
Coke and Breeze 22%
Blast Furnance/ Coke Oven Gases (byproduct) 29%
Distillate and Residual Fuel Oils 3%
Coal 2%
LPG and NGL < 0.5%
Other Fuels 2%
Fuel Types
1,043
831
201
11
624
201
11
214
148
81
1
120
5
66
12
71
2
1
0
581
88
54
0
1
0
17
1
10
9
5
99
8
17
6
44
8
1
1
3
0
0
0
2
30 Steam Distribution Losses
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

# Manufacturing Energy and Carbon Footprint
## Sector: Machinery (NAICS 333)

**Total Primary Energy Use:** 444 TBtu
**Total Combustion Emissions:** 26 MMT $CO_2e$

### Total Energy



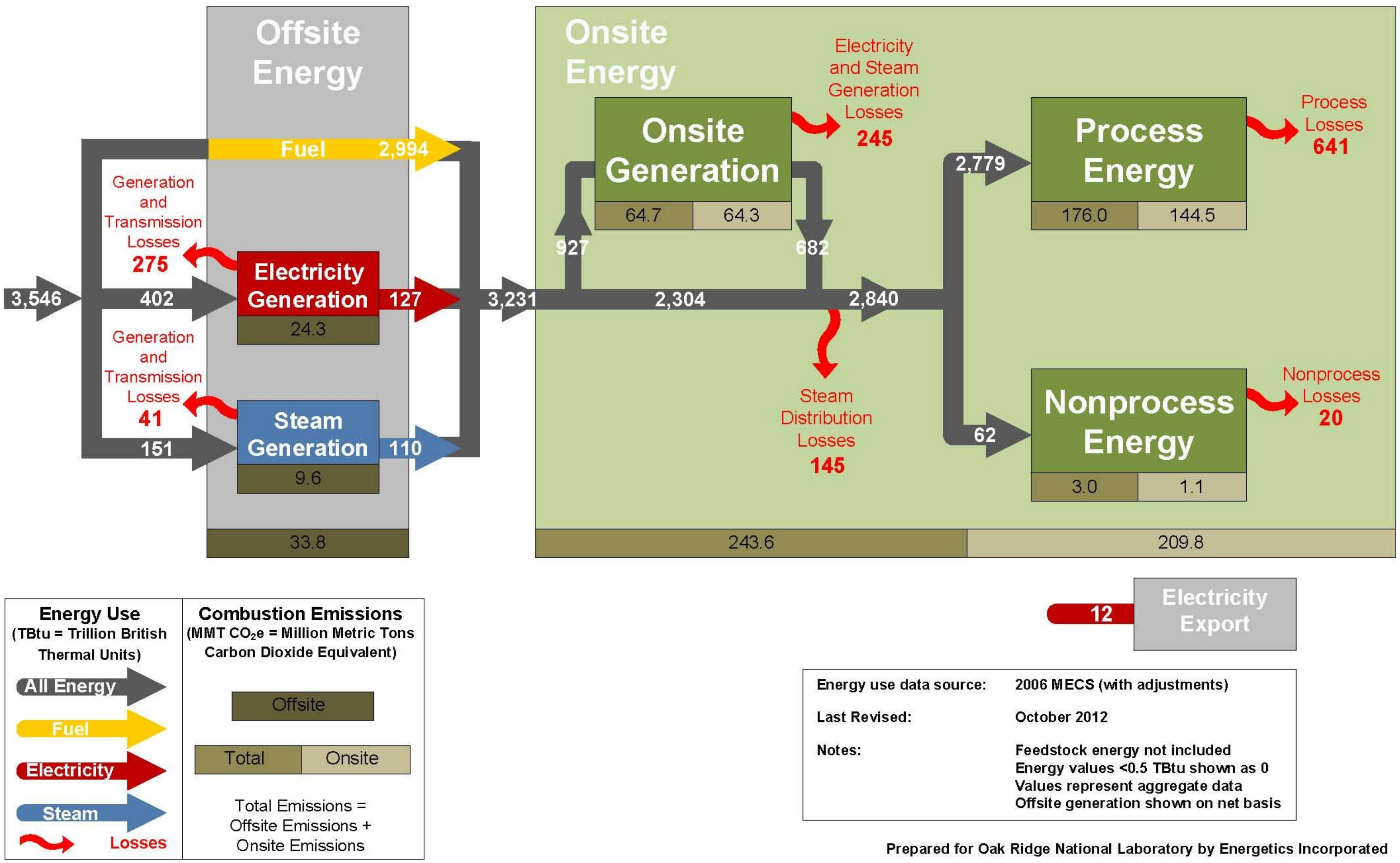


Manufacturing Energy and Carbon Footprint
Sector: Machinery (NAICS 333)
Onsite Energy Use: 204 TBtu
Onsite Combustion Emissions: 5 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
1.1 0.9
CHP/ Cogeneration
0.5 0.5
Other Electricity Generation*
0.0 0.0
1.6 1.4
Steam Generation Losses 5
Electricity Generation Losses 0
Steam Distribution Losses 4
Process Energy
Process Heating 2.9 1.3
Process Cooling and Refrigeration 0.6 0.0
Other Process Uses 0.6 0.2
Electro-Chemical 0.0 0.0
Machine Drive 9.8 0.0
Machine-Driven Systems
Pumps 11
Fans 8
Compressed Air 9
Materials Handling 6
Materials Processing 19
Other Systems 3
13.8 1.6
Nonprocess Energy
Facility HVAC 6.7 1.8
Facility Lighting 3.1 0.0
Other Facility Support 0.7 0.1
Onsite Transportation 0.3 0.1
Other Nonprocess 0.2 0.1
10.9 2.1
Electricity Export 0
Fuel Type | % of Total
Natural Gas 91%
Distillate and Residual Fuel Oils 3%
LPG and NGL 3%
Coal 1%
Other Fuels 1%
Fuel Types
204
92 68
111 110 111
1 1 19
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions ($MMT CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

## Manufacturing Energy and Carbon Footprint
## Sector: Petroleum Refining (NAICS 324110)

**Total Primary Energy Use:** 3,546 TBtu
**Total Combustion Emissions:** 244 MMT $CO_2e$

# Total Energy

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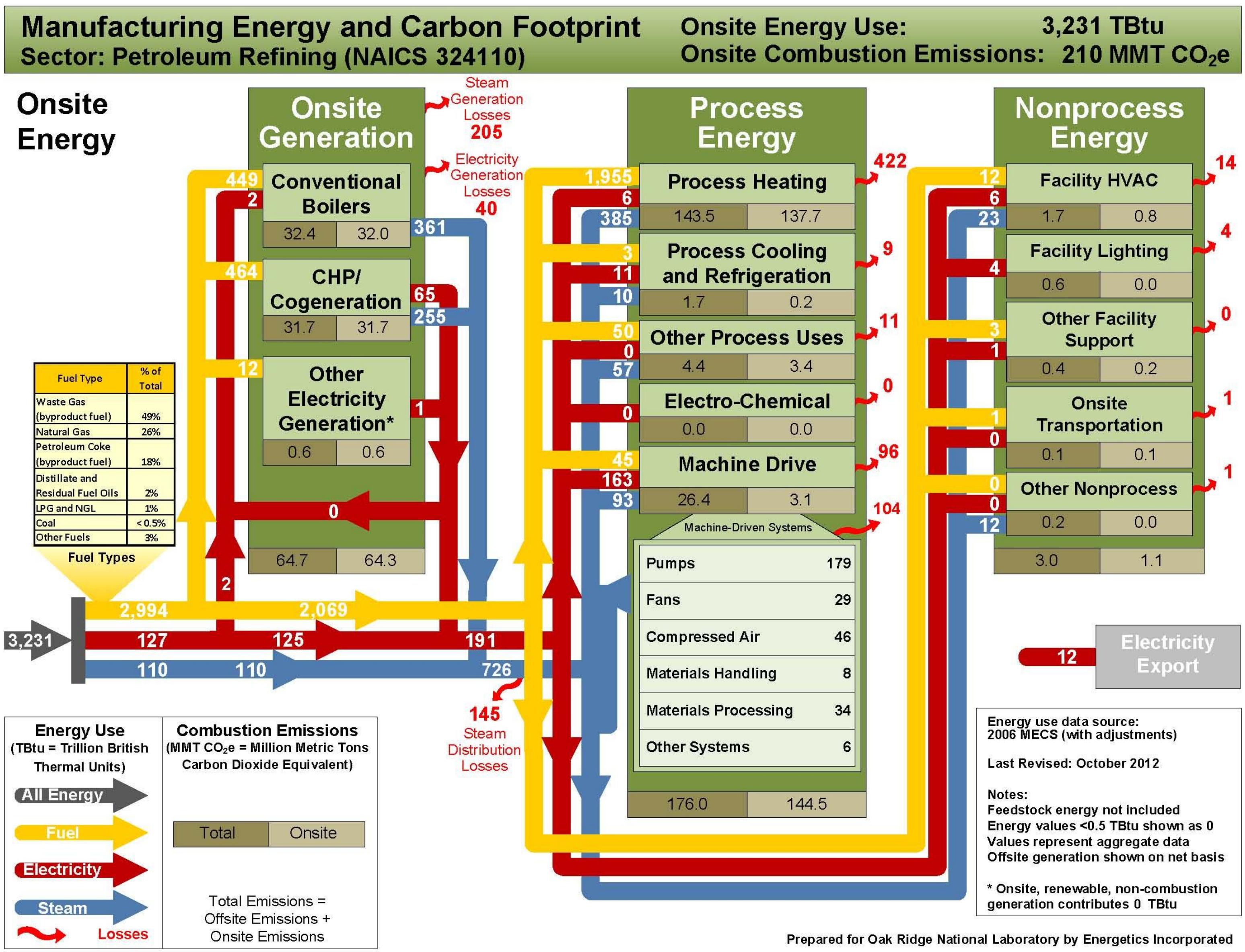
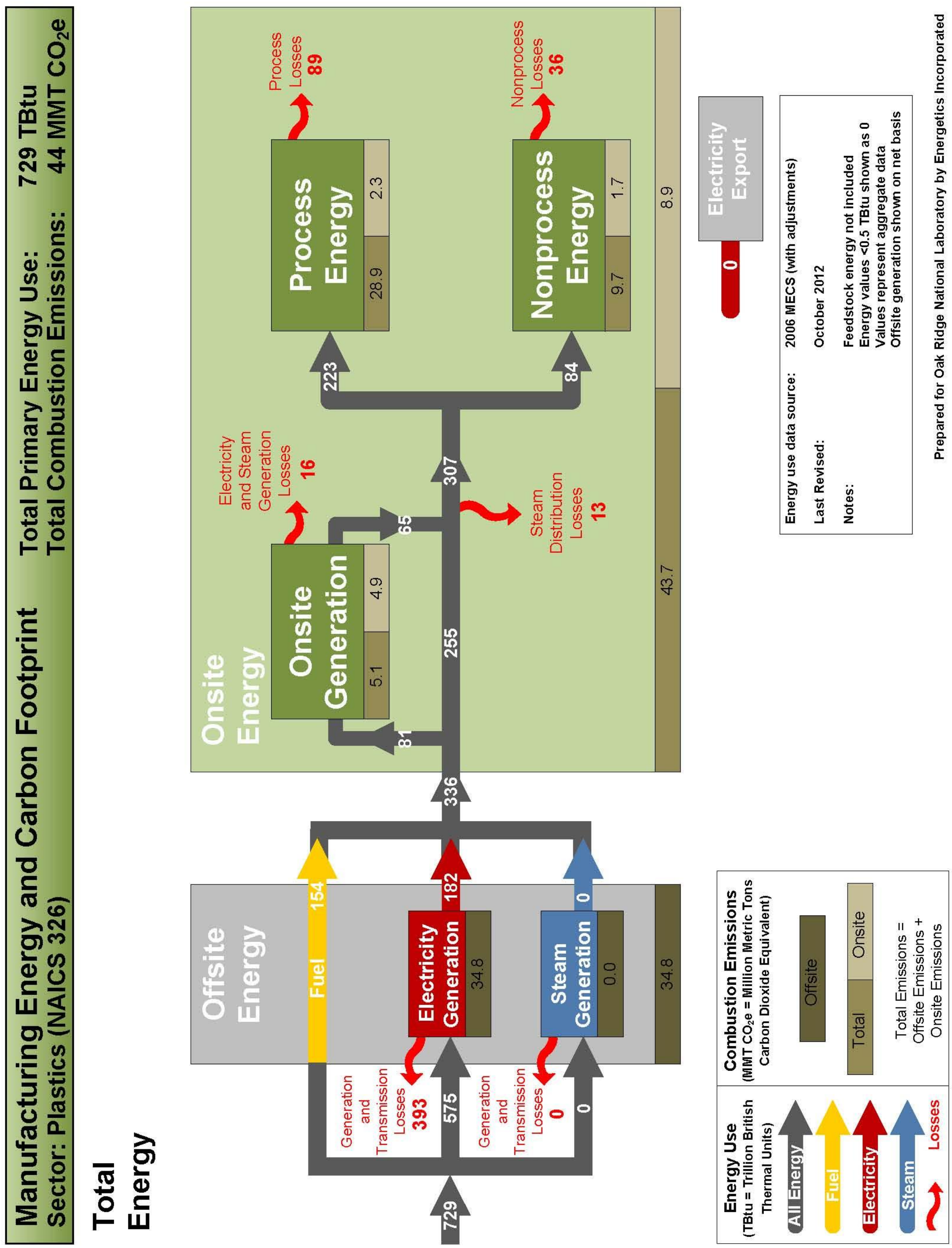
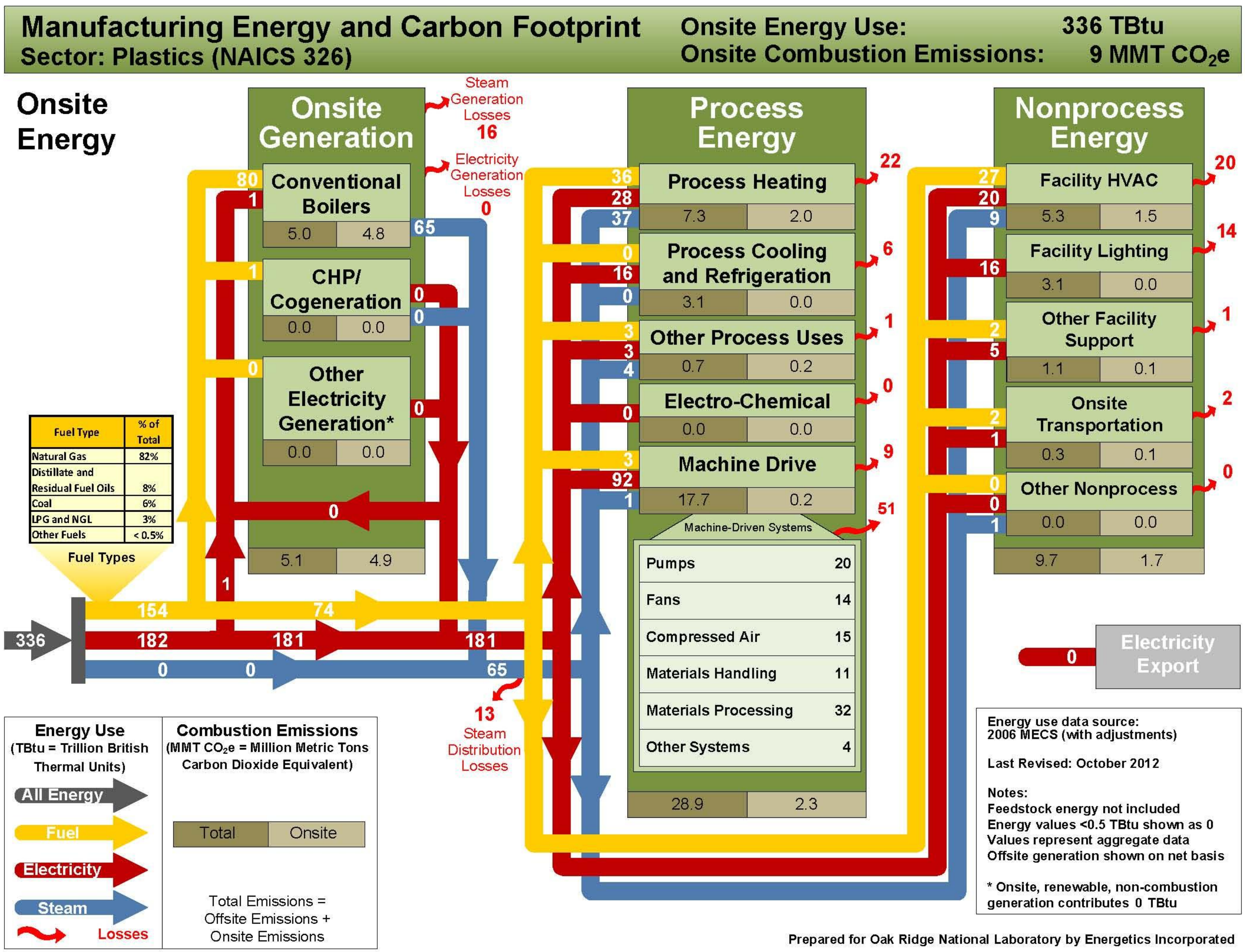

Manufacturing Energy and Carbon Footprint
Sector: Petroleum Refining (NAICS 324110)
Onsite Energy Use: 3,231 TBtu
Onsite Combustion Emissions: 210 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
32.4
32.0
CHP/ Cogeneration
31.7
31.7
Other Electricity Generation*
0.6
0.6
64.7
64.3
Steam Generation Losses
205
Electricity Generation Losses
40
Process Energy
Process Heating
143.5
137.7
422
Process Cooling and Refrigeration
1.7
0.2
9
Other Process Uses
4.4
3.4
11
Electro-Chemical
0.0
0.0
0
Machine Drive
26.4
3.1
96
104
Machine-Driven Systems
Pumps 179
Fans 29
Compressed Air 46
Materials Handling 8
Materials Processing 34
Other Systems 6
176.0
144.5
Nonprocess Energy
Facility HVAC
1.7
0.8
14
Facility Lighting
0.6
0.0
4
Other Facility Support
0.4
0.2
0
Onsite Transportation
0.1
0.1
1
Other Nonprocess
0.2
0.0
1
3.0
1.1
Electricity Export
12
3,231
2,994
127
110
2,069
125
110
191
726
449
2
464
12
361
65
255
1
0
2
1,955
6
385
3
11
10
50
0
57
0
45
163
93
12
6
23
4
3
1
1
0
0
0
12
145
Steam Distribution Losses
Fuel Type
% of Total
Waste Gas (byproduct fuel) 49%
Natural Gas 26%
Petroleum Coke (byproduct fuel) 18%
Distillate and Residual Fuel Oils 2%
LPG and NGL 1%
Coal < 0.5%
Other Fuels 3%
Fuel Types
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source:
2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

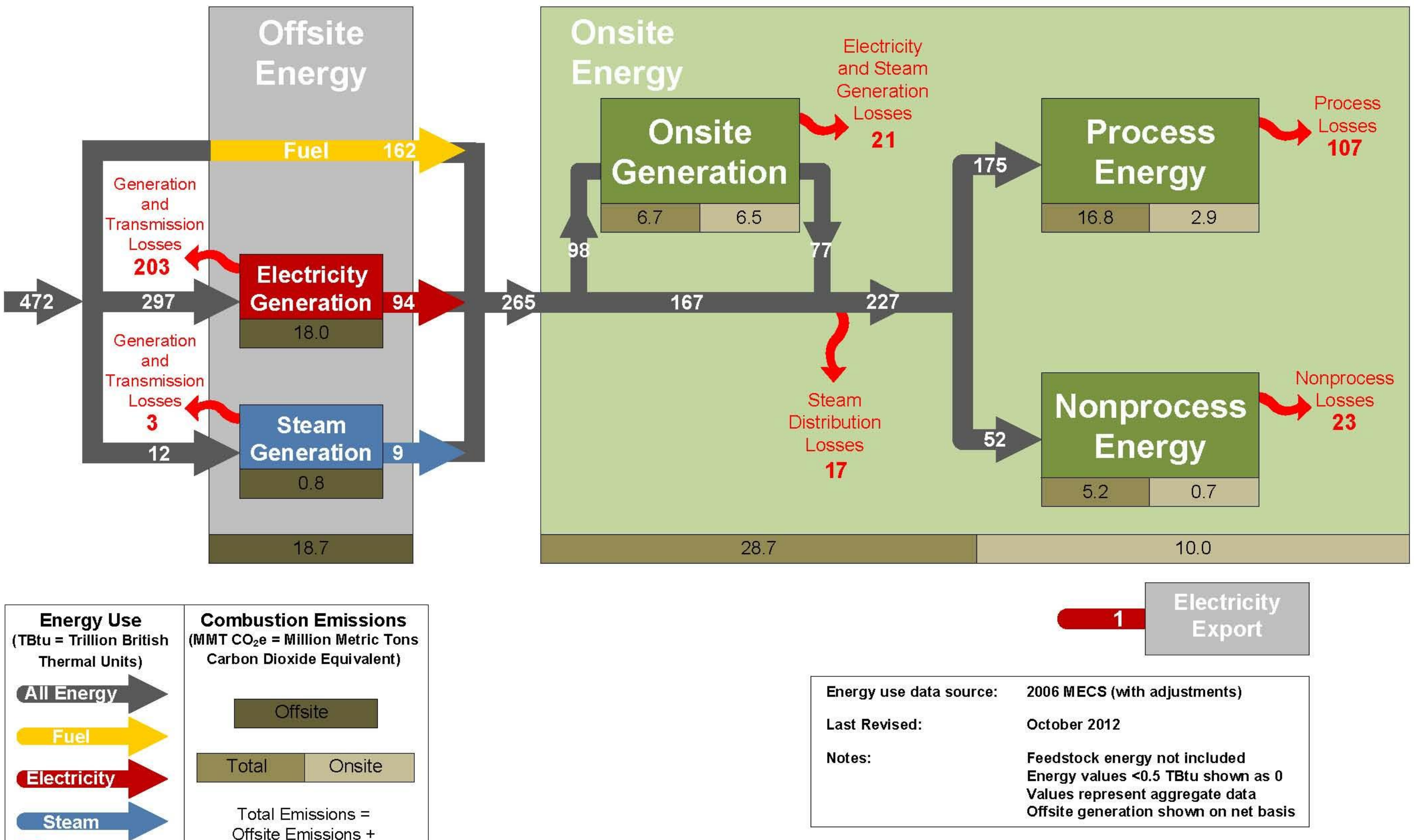

Manufacturing Energy and Carbon Footprint
Sector: Plastics (NAICS 326)
Total Primary Energy Use: 729 TBtu
Total Combustion Emissions: 44 MMT $CO_2e$
Total Energy
Offsite Energy
Fuel
154
Electricity Generation
34.8
182
Steam Generation
0.0
0
34.8
729
575
0
Generation and Transmission Losses
393
Generation and Transmission Losses
0
336
Onsite Energy
81
Onsite Generation
5.1
4.9
255
65
Electricity and Steam Generation Losses
16
Steam Distribution Losses
13
307
223
84
Process Energy
28.9
2.3
Process Losses
89
Nonprocess Energy
9.7
1.7
Nonprocess Losses
36
43.7
8.9
Electricity Export
0
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Offsite
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes: Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
Prepared for Oak Ridge National Laboratory by Energetics Incorporated



Manufacturing Energy and Carbon Footprint
Sector: Plastics (NAICS 326)
Onsite Energy Use: 336 TBtu
Onsite Combustion Emissions: 9 MMT CO2e
Onsite Energy
Onsite Generation
Conventional Boilers
5.0 4.8
CHP/ Cogeneration
0.0 0.0
Other Electricity Generation*
0.0 0.0
5.1 4.9
Steam Generation Losses 16
Electricity Generation Losses 0
Process Energy
Process Heating
7.3 2.0
Process Cooling and Refrigeration
3.1 0.0
Other Process Uses
0.7 0.2
Electro-Chemical
0.0 0.0
Machine Drive
17.7 0.2
Machine-Driven Systems
Pumps 20
Fans 14
Compressed Air 15
Materials Handling 11
Materials Processing 32
Other Systems 4
28.9 2.3
Nonprocess Energy
Facility HVAC
5.3 1.5
Facility Lighting
3.1 0.0
Other Facility Support
1.1 0.1
Onsite Transportation
0.3 0.1
Other Nonprocess
0.0 0.0
9.7 1.7
Electricity Export
0
Fuel Type | % of Total
Natural Gas 82%
Distillate and Residual Fuel Oils 8%
Coal 6%
LPG and NGL 3%
Other Fuels < 0.5%
Fuel Types
336
154
182
0
74
181
0
181
65
13 Steam Distribution Losses
22
6
1
0
9
51
20
14
1
2
0
Energy Use
(TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions
(MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

## Manufacturing Energy and Carbon Footprint — Total Primary Energy Use: 472 TBtu
## Sector: Textiles (NAICS 313-316) — Total Combustion Emissions: 29 MMT $CO_2e$

# Total Energy

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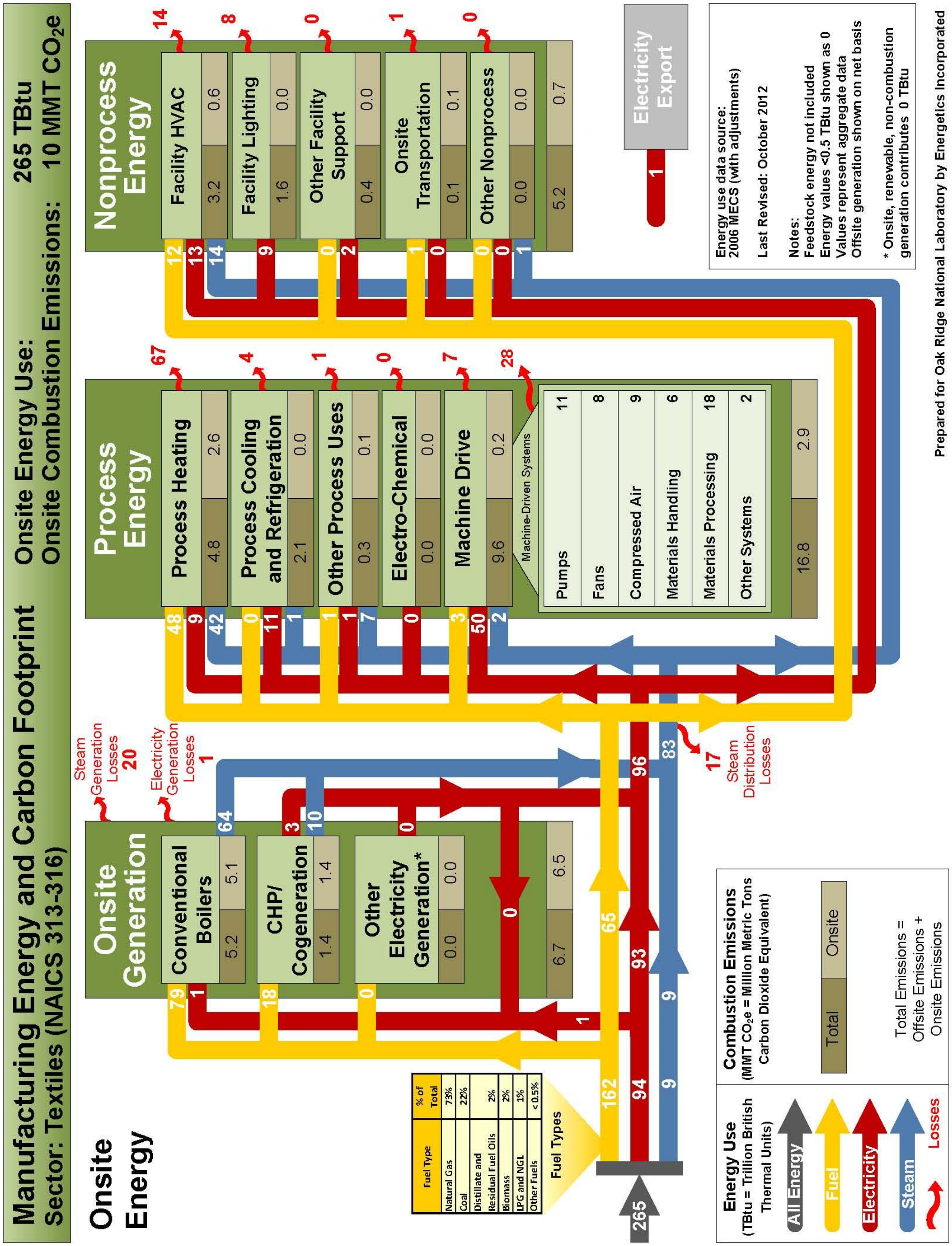
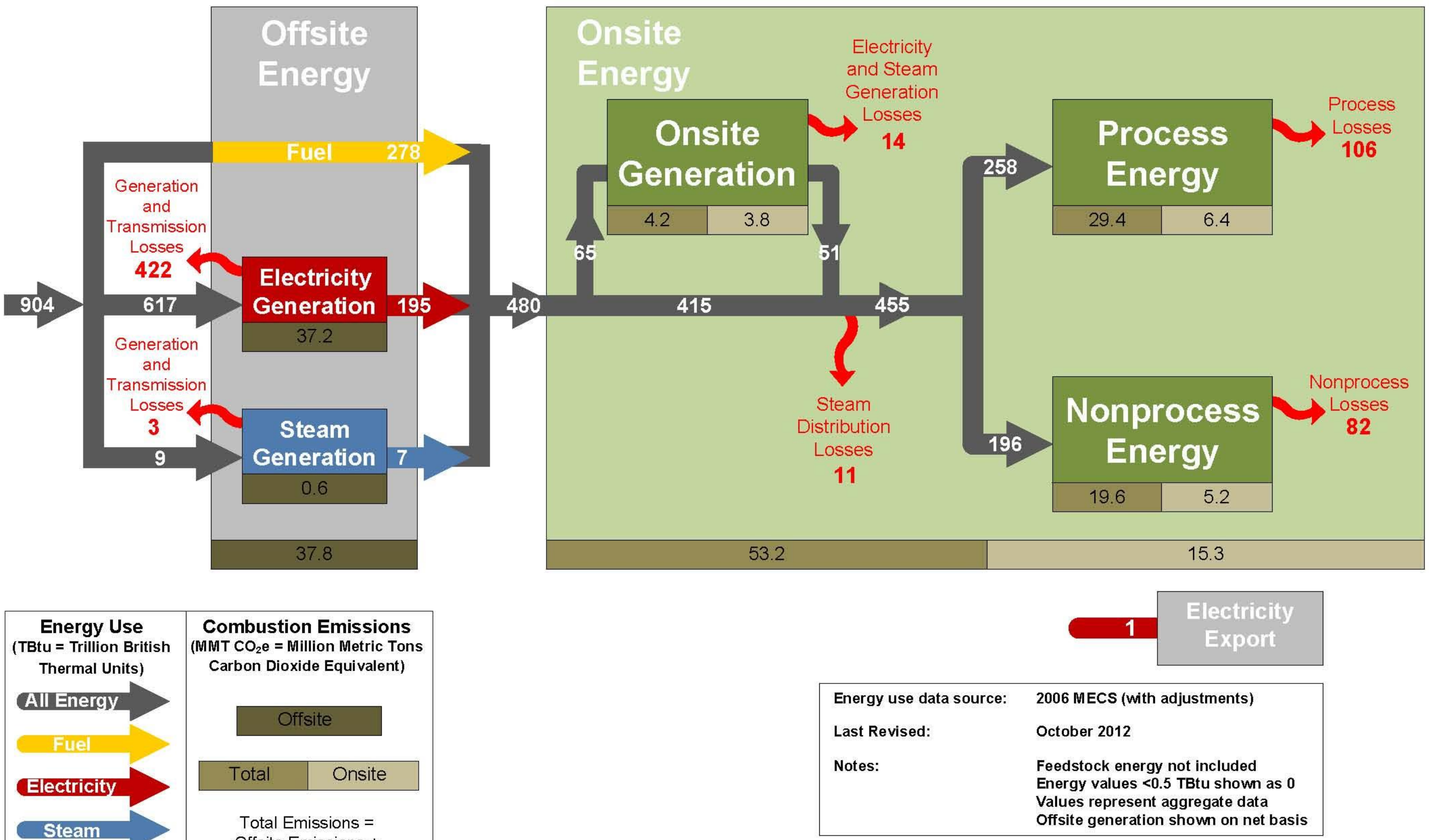


Manufacturing Energy and Carbon Footprint
Sector: Textiles (NAICS 313-316)
Onsite Energy Use: 265 TBtu
Onsite Combustion Emissions: 10 MMT CO2e
Onsite Energy
Onsite Generation
Conventional Boilers
CHP/ Cogeneration
Other Electricity Generation*
Process Energy
Process Heating
Process Cooling and Refrigeration
Other Process Uses
Electro-Chemical
Machine Drive
Machine-Driven Systems
Pumps 11
Fans 8
Compressed Air 9
Materials Handling 6
Materials Processing 18
Other Systems 2
Nonprocess Energy
Facility HVAC
Facility Lighting
Other Facility Support
Onsite Transportation
Other Nonprocess
Electricity Export
Steam Generation Losses 20
Electricity Generation Losses 1
Steam Distribution Losses 17
Fuel Types
Fuel Type | % of Total
Natural Gas 73%
Coal 22%
Distillate and Residual Fuel Oils 2%
Biomass 2%
LPG and NGL 1%
Other Fuels <0.5%
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT CO2e = Million Metric Tons Carbon Dioxide Equivalent)
Total
Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

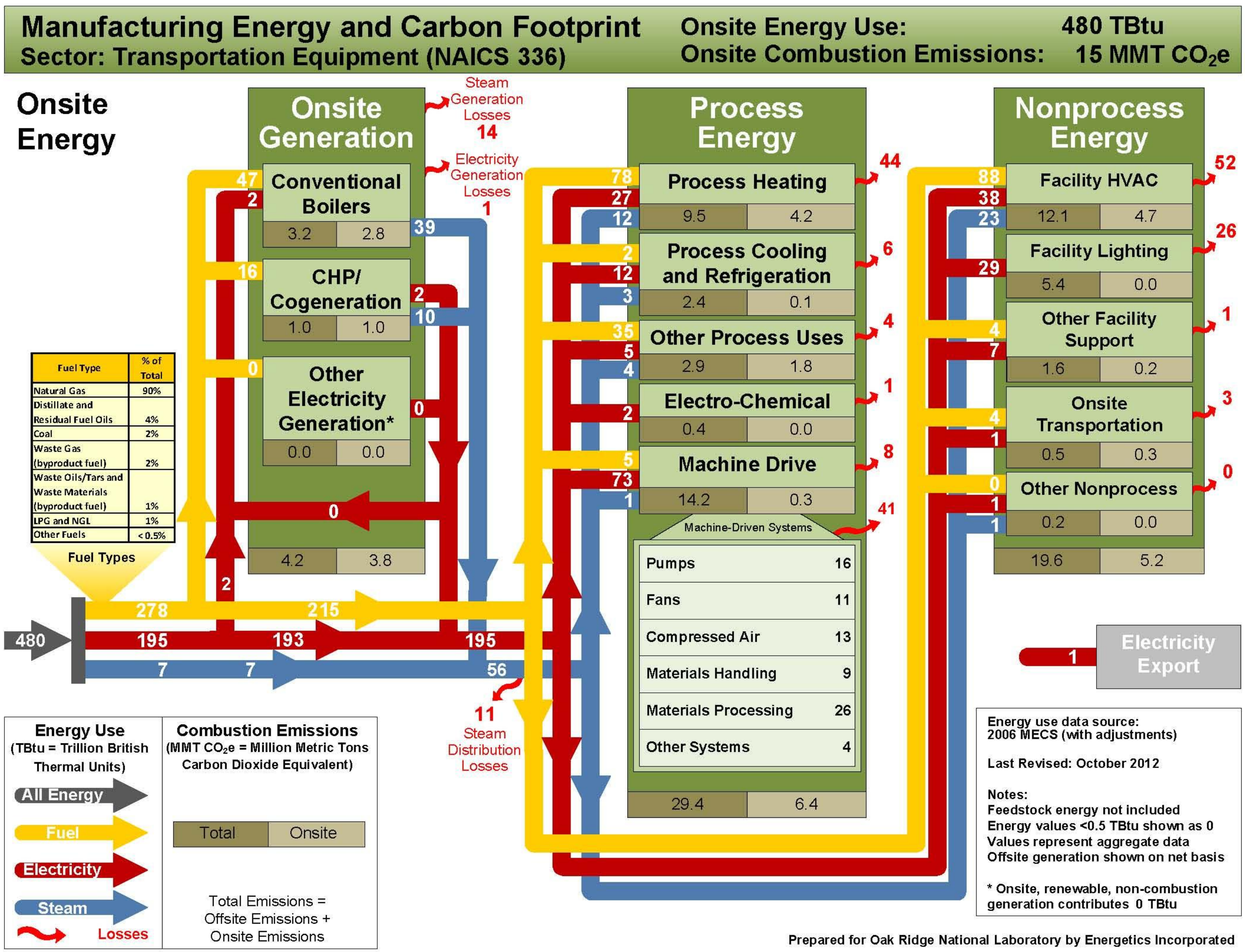
**Manufacturing Energy and Carbon Footprint**
**Sector: Transportation Equipment (NAICS 336)**

**Total Primary Energy Use: 904 TBtu**
**Total Combustion Emissions: 53 MMT $CO_2e$**

# Total Energy




Prepared for Oak Ridge National Laboratory by Energetics Incorporated



Manufacturing Energy and Carbon Footprint
Sector: Transportation Equipment (NAICS 336)
Onsite Energy Use: 480 TBtu
Onsite Combustion Emissions: 15 MMT $CO_2e$
Onsite Energy
Onsite Generation
Conventional Boilers
3.2 2.8
CHP/ Cogeneration
1.0 1.0
Other Electricity Generation*
0.0 0.0
4.2 3.8
Steam Generation Losses 14
Electricity Generation Losses 1
Process Energy
Process Heating
9.5 4.2
Process Cooling and Refrigeration
2.4 0.1
Other Process Uses
2.9 1.8
Electro-Chemical
0.4 0.0
Machine Drive
14.2 0.3
Machine-Driven Systems
Pumps 16
Fans 11
Compressed Air 13
Materials Handling 9
Materials Processing 26
Other Systems 4
29.4 6.4
Nonprocess Energy
Facility HVAC
12.1 4.7
Facility Lighting
5.4 0.0
Other Facility Support
1.6 0.2
Onsite Transportation
0.5 0.3
Other Nonprocess
0.2 0.0
19.6 5.2
Electricity Export
Fuel Type | % of Total
Natural Gas 90%
Distillate and Residual Fuel Oils 4%
Coal 2%
Waste Gas (byproduct fuel) 2%
Waste Oils/Tars and Waste Materials (byproduct fuel) 1%
LPG and NGL 1%
Other Fuels < 0.5%
Fuel Types
480
278 215
195 193 195
7 7 56
47 2 16 0 2 0 39 2 10 0
78 27 12 2 12 3 35 5 4 2 5 73 1
88 38 23 29 4 7 4 1 0 1 1
44 6 4 1 8 41
52 26 1 3 0
1
11 Steam Distribution Losses
Energy Use (TBtu = Trillion British Thermal Units)
All Energy
Fuel
Electricity
Steam
Losses
Combustion Emissions (MMT $CO_2e$ = Million Metric Tons Carbon Dioxide Equivalent)
Total Onsite
Total Emissions = Offsite Emissions + Onsite Emissions
Energy use data source: 2006 MECS (with adjustments)
Last Revised: October 2012
Notes:
Feedstock energy not included
Energy values <0.5 TBtu shown as 0
Values represent aggregate data
Offsite generation shown on net basis
* Onsite, renewable, non-combustion generation contributes 0 TBtu
Prepared for Oak Ridge National Laboratory by Energetics Incorporated

## Appendix D. FOOTPRINT ASSUMPTIONS AND DATA ADJUSTMENTS

The U.S. manufacturing energy use and greenhouse gas emissions analysis relies primarily on 2006 EIA Manufacturing Energy Consumption Survey (MECS) data, along with estimated loss assumptions for energy-consuming operations. Key efficiency and loss assumptions are provided in Tables D.1 to D.4. Greenhouse gas emission factors are provided in Table D.5. Data adjustments and assumptions were necessary in the analysis to address rounding errors, double-counting, withheld values, and to ascertain use of energy where end use was not reported. Further data adjustments were made to delineate the composition and use of the MECS "Other Fuels" category reported in MECS Tables 3.2 and 5.2. Adjustments and assumptions of necessary data were determined for each sector based on other EIA data sets, other published sources, and discussions with industry professionals and EIA staff.

**Table D.1. Manufacturing energy footprint loss assumptions**

| Energy system | Percent energy lost |
|---|---|
| **Energy generation, transmission, and distribution losses** | |
| Offsite generation | Offsite electricity generation and transmission (grid) – 68.4%<br>Offsite steam generation – 19%<br>Offsite steam transmission – 10% |
| Onsite generation | Onsite steam generation (conventional boiler) – 20%<br>Onsite CHP/cogeneration – 24.4% – 36.3%, see Table D.2<br>Onsite steam distribution – 20% |
| **Onsite process and nonprocess losses** | |
| Process energy | Process heating – 18% – 68%, see Table D.3<br>Process cooling and refrigeration – 35%<br>Electro-chemical – 60%<br>Other processes – 10%<br>Machine drive (shaft energy) – electric 7%, fuel 60%, steam 50%<br>Machine driven systems<br>    Pumps – 40%<br>    Fans – 40%<br>    Compressed air – 80%<br>    Materials handling – 5%<br>    Materials processing (e.g., grinders) – 90%<br>    Other systems – 5% |
| Nonprocess energy | Facility HVAC – 35%<br>Facility lighting – 88%<br>Other facility support – 10%<br>Onsite transportation – 60%<br>Other nonprocesses – 10% |

*Note:* The values in this table are gross assumptions used to generate order-of-magnitude energy loss estimates. Energy generation and transmission loss assumptions are based on EIA data. Process and nonprocess loss assumptions are drawn from discussion with industry and process experts and have been substantiated where possible with review of relevant studies. In practice, these losses (energy generation, process, and nonprocess) are highly dependent on specific operating equipment and conditions and vary greatly within and across manufacturing sectors.

**Table D.2. CHP efficiency by sector**

| Sector | CHP efficiency |
|---|---|
| Chemicals | 63.7% |
| Food and beverage | 74.5% |
| Forest products | 75.6% |
| Petroleum refining | 69.0% |
| Iron and steel | 69.0% |
| All manufacturing weighted average<br>*also used for the following sectors where there is insufficient data:*<br>cement; textiles; transportation equipment; aluminum; machinery; fabricated metals; plastics and rubber products; computers, electronics, and electrical equipment[a]; foundries [a]; glass and fiberglass [a]. | 69.5% |

*Source:* EIA (U.S. Energy Information Administration). 2006. "Form EIA-906, EIA-920, and EIA-923 Databases." U.S. Department of Energy. http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html

[a] CHP energy use shown to be 0 TBtu, so CHP Efficiency is not applicable in the energy footprint.

**Table D.3. Process heating loss assumptions by sector**

| Sector | Percent of process heating lost |
|---|---|
| Chemicals; plastics and rubber products | 22% |
| Food and beverage; textiles | 68% |
| Forest products | 68% |
| Petroleum refining | 18% |
| Iron and steel; aluminum; foundries | 51% |
| Glass | 56% |
| Cement | 40% |
| All manufacturing average<br><br>*(also used for the following sectors where there is insufficient data: transportation equipment; machinery; fabricated metals; computers, electronics, and electrical equipment.)* | 38% |

*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 Table D.3 above. More methodology details are available in Appendix F.

**Table D.4. Steam allocation assumptions by sector**

| Sector | Steam end use allocation | | | | | |
|---|---|---|---|---|---|---|
| | Process heating | Machine drive | Process cooling/ 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 | 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 | 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% |

*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 Table 4 above. Methodology details are available in Appendix E.

**Table D.5. Fuel GHG combustion emission factors (kg $CO_2$e 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 coal) | 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 [a] | 0.80 | 1.25 | 2.05 | [a] |
| Agricultural byproducts | 118.17 [a] | 0.80 | 1.25 | 2.05 | [a] |
| Pulping liquor/black liquor | 94.40 [a] | 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] |

[a] $CO_2$ 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 (U.S. Environmental Protection Agency). 2007. "Emissions and Generation Resource Integrated Database (eGRID), eGRID2007 Version 1.1." U.S. Environmental Protection Agency. Last modified May 10. http://www.epa.gov/cleanenergy/egrid (adjusted to reflect transmission losses)

**Appendix E. ALLOCATION OF STEAM TO PROCESS AND NONPROCESS END USES MANUFACTURING ENERGY AND CARBON FOOTPRINT PEER REVIEW RESULTS**

SABINE BRUESKE
ENERGETICS INCORPORATED

CAROLINE KRAMER
ENERGETICS INCORPORATED

**ABSTRACT**

During 2011, the Manufacturing Steam End Use Working Group was formed to support analysis conducted for the United States Department of Energy Advanced Manufacturing Office (DOE/AMO). The working group provided industry peer review and contribution to the Manufacturing Energy and Carbon Footprints, an energy use analysis project conducted by Energetics Incorporated. Analysts and decision-makers utilize the energy footprints to better understand the distribution of energy use in manufacturing and the accompanying energy losses. The footprints provide a benchmark from which to justify the benefits of improving energy efficiency and for prioritizing opportunity analysis.

Comparative steam use by sector for the process and nonprocess end uses defined in the footprint is not readily available by sector through literature search. A peer review group was formed to contribute to this important piece of the footprint analysis. 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 have been incorporated into the energy footprint model and updated footprints have been republished on the DOE/AMO website.

MANUFACTURING ENERGY USE FOOTPRINT ANALYSIS

The Manufacturing Energy and Carbon Footprints serve as a map of manufacturing energy use and loss and associated greenhouse gas emissions for fuel, electricity, and steam use in the United States. Each footprint consists of two pages: one that provides an overview of the sector's total primary energy flow including offsite energy and losses (Fig. E.1) and one that provides a more detailed breakdown of the onsite energy by end use (Fig. E.2). Sixteen sector footprints have been published; detail on which sectors were studied is described later (see Table E.4).

The energy and carbon values portrayed in the footprint diagrams are the result of a complex analysis effort. Energy use statistics were primarily obtained from DOE, Energy Information Administration (EIA)-published 2006 Manufacturing Energy Consumption Survey (MECS) results. In order to complete an accurate balance of manufacturing energy use, some adjustments and assumptions were applied.

The topic of this paper (and the findings of the working group discussed herein)—the allocation of steam to process and nonprocess end uses—is a subset of the footprint analysis effort. After an extensive technical review of the footprints, two areas of analysis were identified as needing further industry peer review: *estimation of steam allocation to process and nonprocess end uses* and *energy loss in process heating*. The second peer review topic addressing energy loss in process heating end use is detailed in a separate white paper (see Appendix F).

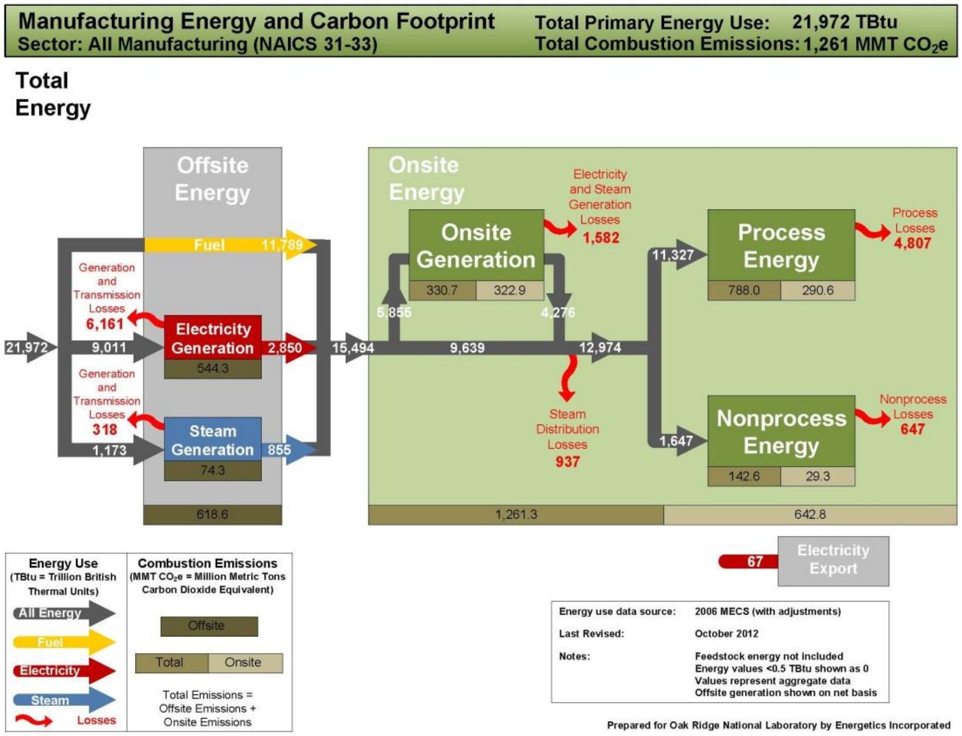



**Fig. E.1. Manufacturing energy and carbon footprint for U.S. manufacturing - total energy**

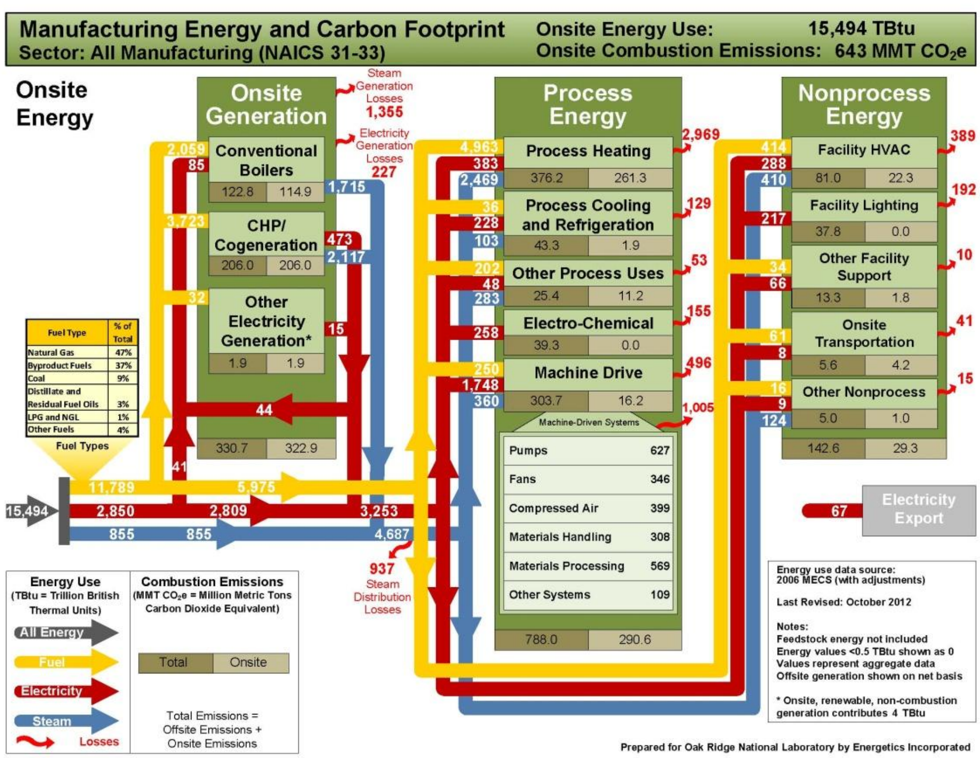



**Fig. E.2. Manufacturing energy and carbon footprint for U.S. manufacturing - onsite energy**

STEAM ALLOCATION PEER REVIEW

The purpose of the Manufacturing Steam End Use Working Group was to provide industry peer review and contribution to a U.S. Department of Energy (DOE) manufacturing energy analysis project, the Manufacturing Energy and Carbon Footprints. The footprint analysis project was conducted by Energetics Incorporated under contract with Oak Ridge National Laboratory (ORNL) for the DOE Advanced Manufacturing Office (AMO).

A working group comprised of representatives from seven industrial organizations was convened in 2011 to perform a short-term, focused peer review effort. Organizations voluntarily participated in the working group meetings are shown in Table E.1.

**Table E.1. Steam end use working group organizations**

| |
|---|
| Armstrong International |
| Council of Industrial Boiler Owners (CIBO) |
| Dow Chemical Company |
| Energetics Incorporated |
| U.S. Energy Information Administration (EIA) |
| Kumana and Associates |
| Oak Ridge National Laboratory |
| Spirax Sarco |

The steam end use values that were evaluated by the working group are highlighted in yellow in Fig. E.3.

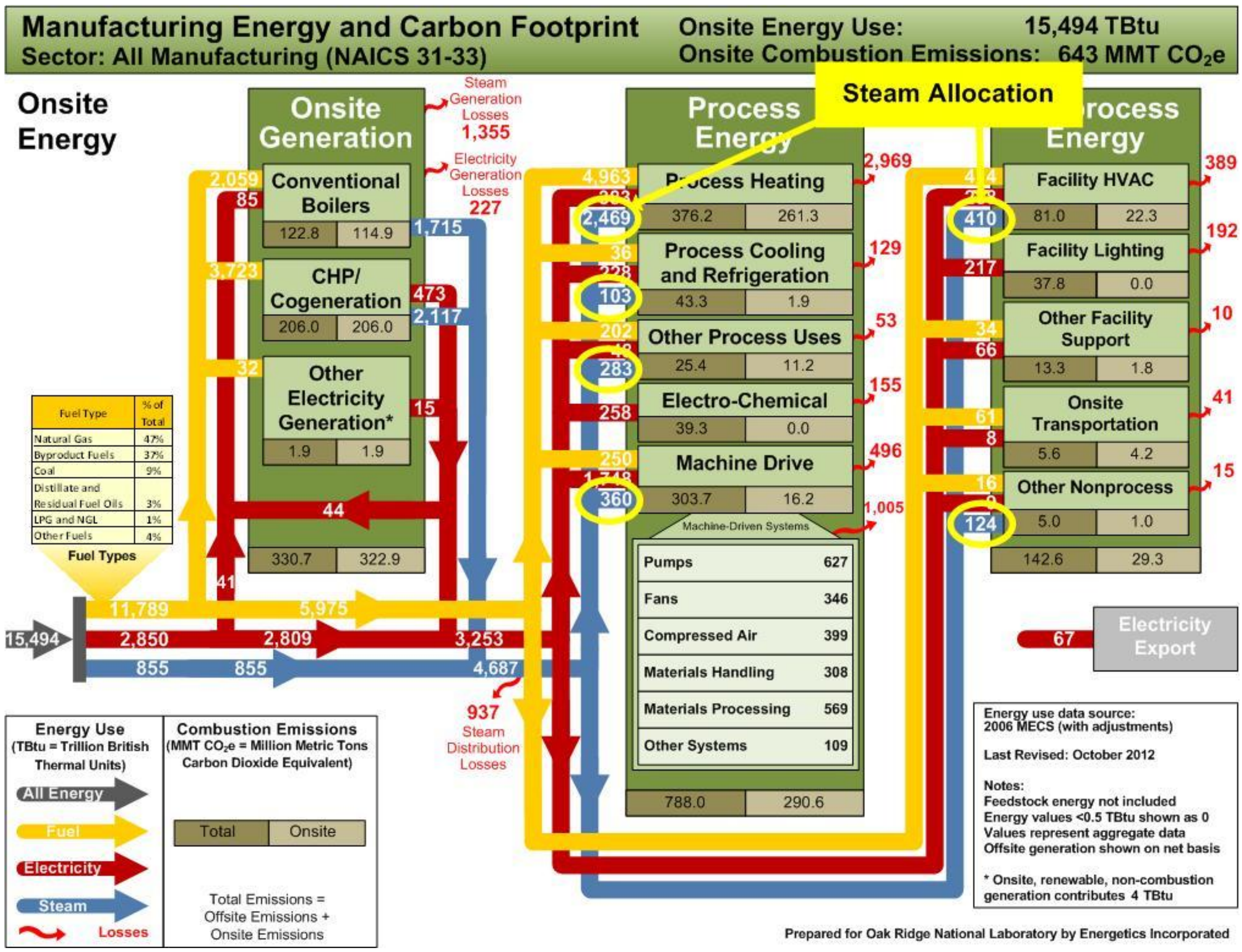



**Fig. E.3. Steam end use values evaluated by steam working group**

In the Manufacturing Energy and Carbon Footprints there are two sources for steam end use – offsite supply (purchased and transferred in) and onsite generation. Estimation of onsite utility steam generation is based upon the amount of energy used by and efficiency of steam-producing equipment (such as combined heat and power (CHP systems) and boilers). Calculations associated with steam supply and generation was not considered by the steam end use working group as these were outside the working group scope.

In the MECS data set, end use of fuel and electricity is reported by sector; steam end use, however, is not reported. For this reason, steam end use allocation must be assumed in the energy footprint model. The goal of the working group was to agree upon an acceptable approach for estimating steam allocation to six MECS-defined manufacturing process and nonprocess end uses: process heating, machine drive, process cooling and refrigeration, other process uses, facility heating, ventilation, and air conditioning (HVAC), and other nonprocess uses. Steam allocation results were needed for the following 15 individual sectors (listed in alphabetical order) and a weighted average of steam allocation for all of U.S. manufacturing: alumina and aluminum; cement; chemicals; computers, electronics, and electrical equipment; fabricated metals; food and beverage; forest products; foundries; glass; iron and steel; machinery; petroleum refining; plastics; textiles; and transportation equipment.

TIMELINE AND APPROACH

The Manufacturing Steam End Use Working Group was a two month peer review effort. The working group met on four separate occasions in December 2011 and January 2012 and conducted additional analysis between meetings.

During the first meeting, the working group reviewed the topic and discussed methods of improving the original steam end use estimates. After considering various options, the working group agreed that the best approach to determining realistic sector-wide steam allocation results would be to allow steam experts the opportunity to provide their site-based knowledge. It was agreed that the survey contributors should be given the opportunity to provide input on all of the 15 sectors.

The Manufacturing Steam End Use Working Group conducted an online survey using the survey software SurveyMonkey. Survey results were kept anonymous and categorized by employer category only. Energetics Incorporated assisted the working group with creating the survey content and language. The survey was issued by a representative from Spirax Sarco on behalf of the whole working group and was distributed to over 225 recipients including industrial steam experts, qualified steam system evaluation specialists, steam equipment providers, and others. CIBO distributed the survey to its Energy and Technical Committees. A total of 67 industry individuals responded and provided input to the manufacturing steam end use survey. The distribution of survey respondents by their employer category can be seen in Fig. E-4.

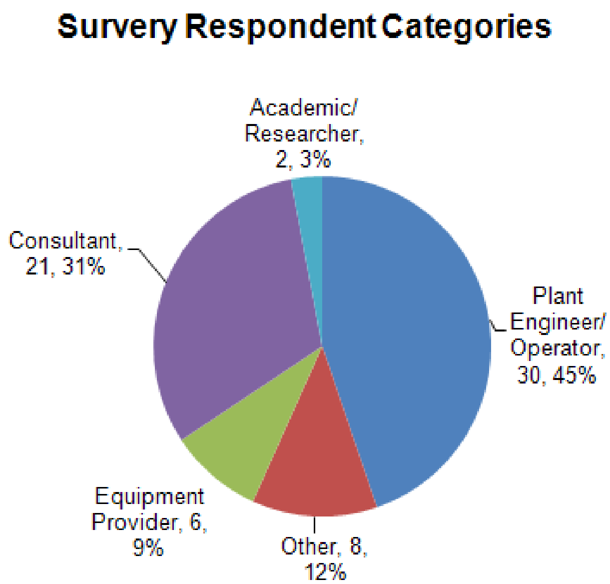



**Fig. E.4. Survey respondents by employer category**

Each survey participant had the opportunity to enter percentage steam use allocations across the six end use categories for 15 individual manufacturing sectors. Respondents were prompted to provide their site-based level of knowledge (significant, moderate, minimal, or none) for each sector; respondents were not required to enter steam end use allocations for every sector.

During the third and fourth meetings, the working group reviewed the data from the survey and discussed any outstanding issues such as whether or not to weigh the responses based upon site-based knowledge level. Also, a few of the manufacturing sectors did not have as many respondents as was deemed necessary for accuracy so the working group agreed to re-open the survey for an additional week and elicit further requests for input in those sectors.

To account for the different levels of survey respondent self-indicated site-based knowledge, the working group agreed that the survey responses should be weighted as outlined in Table E-2.

**Table E.2. Weighting of survey responses**

| Respondent knowledge level | Weight of response |
|---|---|
| Significant | 10 |
| Moderate | 5 |
| Minimal | 2 |
| None | 0 |

Working Group members agreed to eliminate the responses of participants who listed “none” as the site-based level of knowledge on steam end use allocation in any particular sector in order to ensure the most accurate results. The total number of survey respondents (excluding those with a knowledge level of “none”) for the 15 individual manufacturing sectors is shown in Fig. E.5.

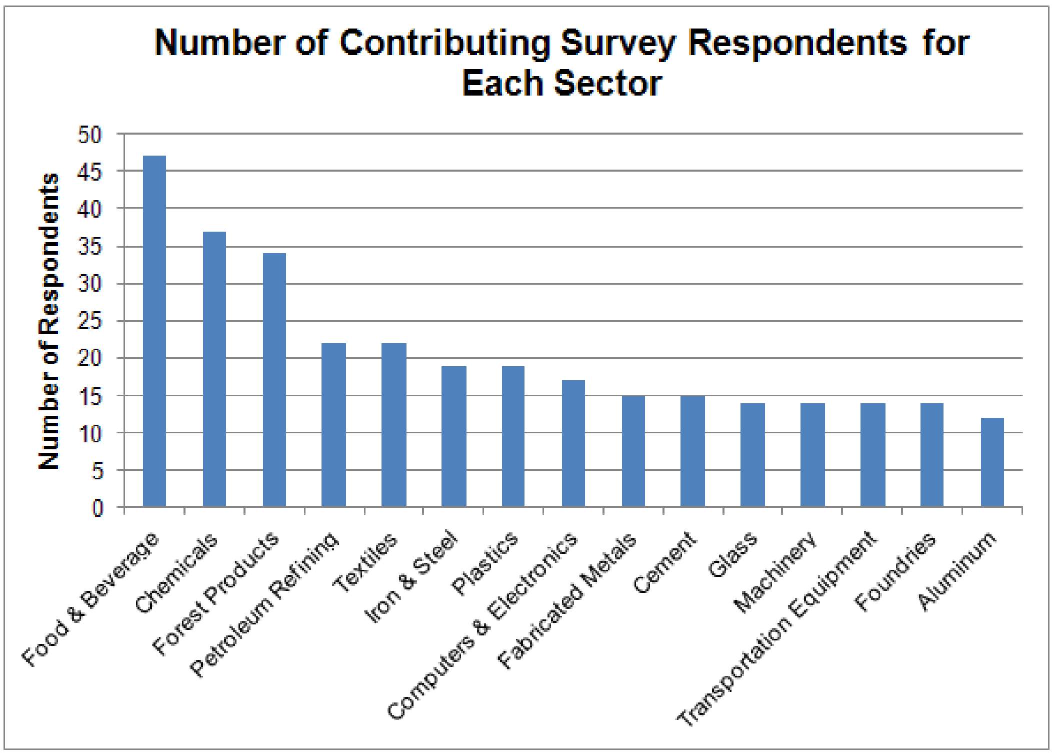



**Fig. E.5. Number of survey respondents for 15 individual sectors**

By the fourth and final meeting, the Manufacturing Steam End Use Working Group reached consensus on the results of steam allocation by sector.

RESULTS

The Manufacturing Steam End Use Working Group used the results from the manufacturing steam end use survey to determine the final end use allocations of steam in the 15 individual manufacturing sectors as well as an average for all of U.S. manufacturing. A complete summary of the working group's final results of are given in Table E.3.

**Table E.3. Results for steam allocation from the manufacturing steam end use working group**

| Sector | Steam end use | | | | | |
|---|---|---|---|---|---|---|
| | Process heating | Machine drive | Process cooling/ refrigeration | Other process uses | Facility HVAC | Other nonprocess uses |
| **All manufacturing** | 66% | 10% | 3% | 8% | 11% | 3% |
| **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** | 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** | 71% | 1% | 0% | 7% | 18% | 3% |
| **Textiles** | 63% | 2% | 2% | 10% | 21% | 2% |
| **Transportation equipment** | 27% | 2% | 7% | 9% | 53% | 2% |

The six process and nonprocess end uses where steam is consumed are defined by EIA in the MECS survey as follows:

1. **Process heating**: the direct process end use in which energy is used to raise the temperature of substances involved in the manufacturing process (e.g., kilns, ovens, furnaces, strip heaters). Examples of process heating 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.
2. **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.

3. **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 chemicals industry.
4. **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. Examples include steam tracing, stripping, vacuum, purging, humidification, and fuel oil atomization.
5. **Facility HVAC**: the direct nonprocess end use that includes energy used to provide heating, ventilation, and air conditioning for building envelopes within the plant boundary.
6. **Other nonprocess uses**: the direct nonprocess end use that includes energy used for nonprocess uses other than the defined nonprocess energy categories. Examples include cleaning and hot water heating.

The all manufacturing steam end use allocation was calculated as a weighted average based upon the net steam and steam allocation for each sector. The values of net steam use for each sector are the sum of offsite steam (obtained from MECS 2006 data) and onsite steam (obtained using input fuel data and the estimated efficiencies of steam-producing equipment). Steam allocation for all U.S. manufacturing is heavily dependent on the sectors that have a higher net steam use. The forest products, chemicals, petroleum refining, and food and beverage sectors represent 88% of all manufacturing net steam use. The weighted average steam end use allocation for all of U.S. manufacturing as shown in Table E.3 was found to be 66% to process heating, 11% to facility HVAC, 10% to machine driven equipment, 8% to other process uses, 3% to process cooling and refrigeration, and 3% to other nonprocess uses.

APPLICATION OF RESULTS

The Manufacturing Steam End Use Working Group was created at the request of DOE and ORNL to obtain industry expert input that could be applied to the Manufacturing Energy and Carbon Footprints. The Manufacturing Energy and Carbon Footprints (published on the AMO website) serve as a useful reference for industrial energy use characteristics and allow for comparisons of energy consumption across and within sectors.

The 16 individual footprints map energy consumption, energy losses, and greenhouse gas emissions from fuel, electricity, and steam use for the respective sector. Manufacturing and energy footprints are available for the following individual manufacturing sectors (listed in alphabetical order): alumina and aluminum; cement; chemicals; computers, electronics, and electrical equipment; fabricated metals; food and beverage; forest products; foundries; glass; iron and steel; machinery; petroleum refining; plastics; textiles; and transportation equipment. The sectors are defined by North American Industrial Classification System (NAICS) code, as shown in Table E.4.

The net steam use for each of the 15 sectors can also be found in Table E.4. The net steam use by sector is calculated using 2006 MECS offsite steam numbers and input fuel data for conventional boilers and combined heat and power (CHP) systems (and associated assumptions of boiler and CHP efficiency) to calculate the total amount of steam produced in each industry.

**Table E.4. Manufacturing sector NAICS codes and net steam use**

| Sector | NAICS code | Sector net steam* (TBtu) |
|---|---|---|
| **All manufacturing** | 31-33 | 3,810 |
| **Aluminum and alumina** | 3313 | 12 |
| **Cement** | 327310 | 18 |
| **Chemicals** | 325 | 1,134 |
| **Computers, electronics, and electrical equipment** | 334-335 | 19 |
| **Fabricated metals** | 332 | 26 |
| **Food and beverage** | 311-312 | 443 |
| **Forest products** | 321-322 | 1,198 |
| **Foundries** | 3315 | 2 |
| **Glass** | 272, 32799 | 15 |
| **Iron and steel** | 3311-3312 | 118 |
| **Machinery** | 333 | 15 |
| **Petroleum refining** | 324110 | 581 |
| **Plastics** | 326 | 52 |
| **Textiles** | 313-316 | 66 |
| **Transportation equipment** | 336 | 45 |

*The net steam use (in units of Trillion British Thermal Units or TBtu) by sector numbers are calculated by using EIA MECS offsite steam numbers and input fuel data for conventional boilers and combined heat and power (CHP) systems (and associated assumptions of boiler and CHP efficiency) to calculate the total amount of steam produced in each industry. EIA MECS does not allocate this steam to different end uses.

The Manufacturing Energy and Carbon Footprints have undergone multiple rounds of review in the finalization process including review and input from DOE AMO, ORNL, EIA, and representatives from various industry organizations and associations. The results from the Manufacturing Steam End Use Working Group have been incorporated in to the Energetics energy footprint model and updated energy footprints were posted on the DOE website.

The results from the Manufacturing Steam End Use Working Group have been significant in improving and updating the Manufacturing Energy and Carbon Footprints.

The final survey and working group results helped to refine the previous estimates for steam allocation by sector.

CONCLUSION

The final steam allocation results for all of U.S. manufacturing was based upon the results from the 15 individual sectors but was heavily weighted by the four sectors that represent 88% of all manufacturing net steam use: forest products (31%), chemicals (30%), petroleum refining (15%), and food and beverage (12%). Average steam allocation for all of U.S. manufacturing was largely process heating (66%) as expected. However, facility HVAC (11%) and machine drive (10%) are also significant contributors to steam use in manufacturing.

This small, focused working group was successful in meeting the peer review objectives in the short timeframe allotted. The working group results improved the accuracy of the Manufacturing Energy and Carbon Footprints. The authors of this paper wish to express our gratitude for the leadership of the working group members in this effort and the contribution of all of those who responded to the survey.

**Appendix F. ESTIMATION OF PROCESS HEATING ENERGY LOSS MANUFACTURING ENERGY AND CARBON FOOTPRINT PEER REVIEW RESULTS**

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**ABSTRACT**

In January 2012, the Manufacturing Process Heating Energy Loss Working Group was formed to support analysis conducted for the U.S. Department of Energy (DOE) Advanced Manufacturing Office (AMO). The working group provided industry peer review and contribution to the Manufacturing Energy and Carbon Footprints, an energy use analysis tool developed by Energetics Incorporated. Analysts and decision-makers utilize the energy footprints to better understand the distribution of energy use in energy-intensive industries and the accompanying energy losses; including, as described in this white paper, process heating losses. The footprints provide a benchmark from which to justify the benefits of improving energy efficiency and for prioritizing opportunity analysis.

The working group considered 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. A peer review 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. Results from the peer review have been incorporated into the energy footprint model and updated footprints have been republished on the AMO website.

MANUFACTURING ENERG USE FOOTPRINT ANALYSIS

The Manufacturing Energy and Carbon Footprints serve as a map of manufacturing energy use and loss and associated greenhouse gas emissions for fuel, electricity, and steam use in the United States. Each footprint consists of two pages: one that provides an overview of the sector's total primary energy flow including offsite energy and associated generation and transmission losses (Fig. F.1) and one that provides a more detailed breakdown of the onsite energy by end use (Fig F.2). Sixteen sector footprints have been published; detail on which sectors were studied is discussed later (see Table F.5). The footprints are heavily referenced by private and public sector analysts and decision makers alike. They serve as a helpful reference in understanding the U.S. manufacturing energy use profile and are used in answering questions such as:

| | |
|---|---|
| *How much energy is consumed (source vs. site)?* | *What are the associated carbon emissions?* |
| *From where?* | *Where is it used?* |
| *What form?* | *How much is lost and where?* |

The energy and carbon values portrayed in the footprint diagrams are the result of a complex analysis effort. Energy use statistics were primarily obtained from the Energy Information Administration (EIA) 2006 Manufacturing Energy Consumption Survey (MECS) results. In order to complete an accurate balance of manufacturing energy use, some adjustments and assumptions were applied.

The topic of this paper (and the findings of the working group discussed herein) is a subset of the footprint analysis effort. After an extensive technical review of the footprints, two areas of analysis were identified as needing further industry peer review: *estimation of steam allocation to process and nonprocess end uses* and *energy loss in process heating*. The first peer review topic addressing steam allocation is detailed in a separate white paper (see Appendix E).

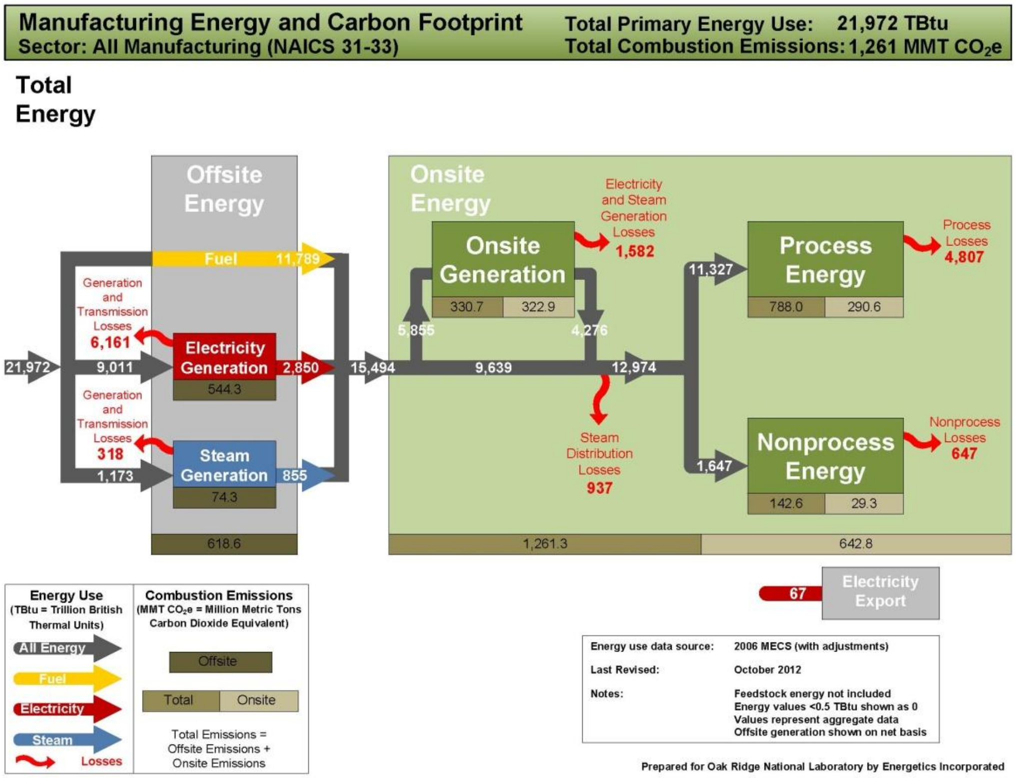


**Fig. F.1. Manufacturing energy and carbon footprint for U.S. manufacturing - total energy**

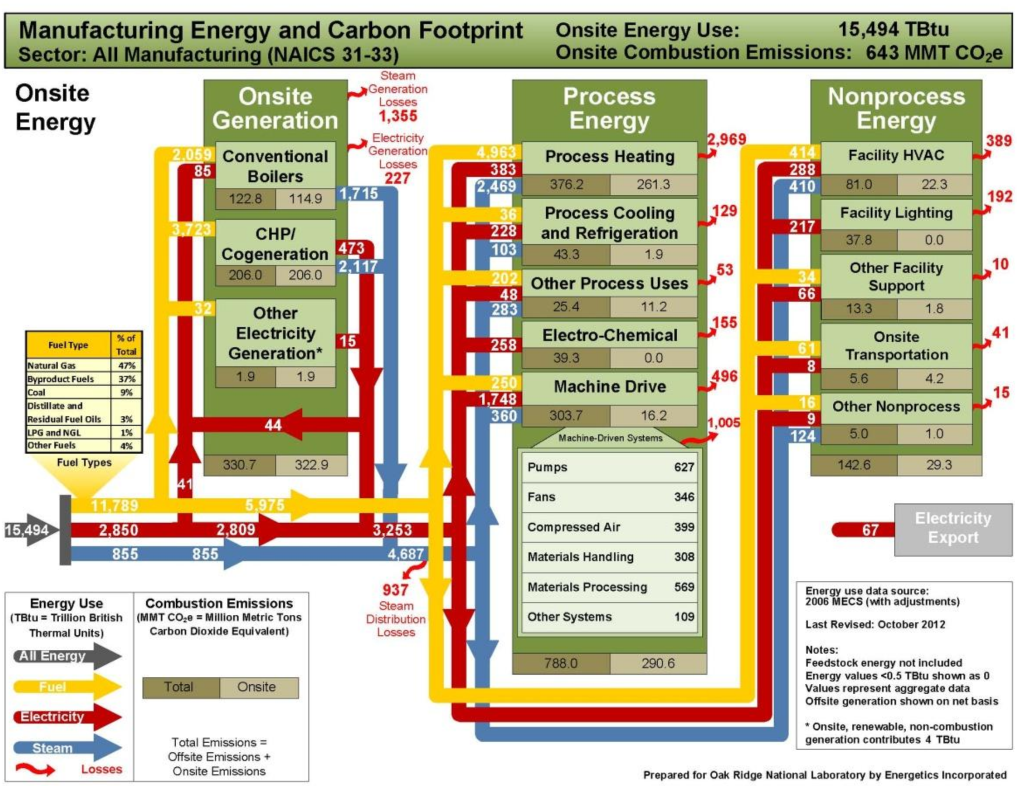


**Fig. F.2. Manufacturing energy and carbon footprint for U.S. manufacturing - onsite energy**

PROCESS HEATING ENERGY LOSS PEER REVIEW

The purpose of the Manufacturing Process Heating Energy Loss Working Group was to provide industry peer review and contribution to an AMO manufacturing energy analysis project, the Manufacturing Energy and Carbon Footprints. The footprint analysis project was conducted by Energetics Incorporated under contract with Oak Ridge National Laboratory (ORNL) for AMO.

A working group was convened in January 2012 to perform a short-term, focused peer review effort. Organizations that voluntarily participated in at least one of the working group meetings are listed below in Table F.1.

**Table F.1. Process heating energy loss working group organizations**

| | |
|---|---|
| Advanced Energy * | Eclipse, Inc. |
| Alcoa Inc. * | Energetics Incorporated *, ^ |
| Alzeta Corporation * | U.S. Energy Information Administration * |
| Briggs and Stratton Corporation *, ^ | Fives North American Combustion, Inc. |
| CHT Analytics *, ^ | Hauck Manufacturing Company * |
| Diamond Engineering * | Invensys Eurotherm *, ^ |
| The Dow Chemical Company * | Karl Dungs Inc. * |
| Duke Energy Corporation *, ^ | Lawrence Berkeley National Laboratory * |
| E3M, Inc. *, ^ | Oak Ridge National Laboratory *, ^ |
| Emerging Technology Application Center | Southern Company *, ^ |
| Organizations that participated in more than one working group meeting are noted with (*) symbol in the list, organizations that participated in the final consensus meeting are noted with (^) symbol in the list. | |

Organizations that participated in more than one working group meeting are noted with (*) symbol in the list, organizations that participated in the final consensus meeting are noted with ^ symbol in the list. The process heating energy loss value that was evaluated by the working group is highlighted in yellow Fig. F.3 (2,969 TBtu for All Manufacturing).

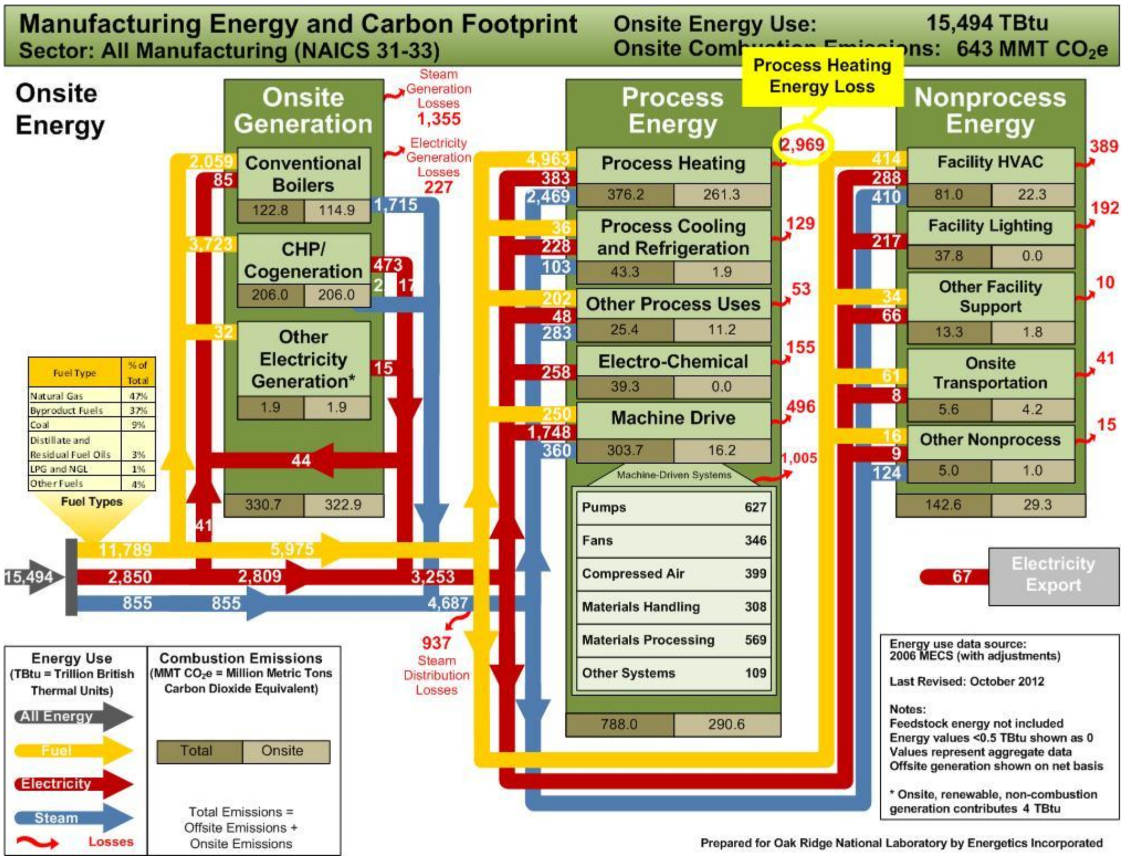


**Fig. F.3. Process heating energy loss value evaluated by the process heating working group**

Process heating is defined by EIA in the MECS survey as follows:

**Process heating**: the direct process end use in which energy is used to raise the temperature of substances involved in the manufacturing process (e.g., kilns, ovens, furnaces, strip heaters). Examples of process heating include the use of heat to melt scrap for electric-arc furnaces in steelmaking, to separate components of crude oil in petroleum refining, to dry paint in automobile manufacturing, and to cook packaged foods.

The term *direct* end use in the definition deserves explanation, as there were questions on this subject from working group participants. An obvious assumption is that the term Process Heating includes boilers, which is not the case.

The onsite energy footprint shows both indirect and direct end use of energy. Indirect energy use is shown on the footprint as Onsite Generation, this is primarily fuel used for boilers and combined heat and power (CHP) units. The indirect energy input is converted to steam and power to be used onsite. Direct energy, on the other hand, refers to process and nonprocess end uses such as process heating, machine drive, and lighting. The working group was tasked to consider energy losses from direct process heating end use only.

In the MECS data set, direct process heating end use of fuel and electricity is reported by sector; steam end use, however, is not reported. A steam working group was formed to help with estimating steam allocation to process and nonprocess end uses. Process heating energy use (fuel, electricity, and steam) is known for each of the manufacturing sectors studied. The goal of the working group was to agree upon an acceptable approach for estimating energy loss from (or heat loss) from this end use. Process heating energy loss can appear in different forms, including: input losses such as incomplete combustion, system losses such as radiation and convection losses, and exhaust or vent losses.

Process heating energy loss results were needed for the following fifteen individual footprint sectors (listed in alphabetical order) and a weighted average of process heating energy loss for all of U.S. manufacturing: alumina and aluminum; cement; chemicals; computers, electronics, and electrical equipment; fabricated metals; food and beverage; forest products; foundries; glass; iron and steel; machinery; petroleum refining; plastics; textiles; and transportation equipment.

TIMELINE AND APPROACH

The Manufacturing Process Heating Energy Loss Working Group was a seven month peer review effort. The working group met on three separate occasions between January 2012 and August 2012 and conducted additional analysis between meetings.

During the first meeting in January 2012, the working group reviewed the topic and discussed methods already considered for estimating process heating energy loss. These prior analysis approaches are briefly summarized in Table F.2.

**Table F.2. Alternative analysis approaches considered by Energetics**

| Source | Brief description |
|---|---|
| Early version of the energy footprint | System losses estimated to be 15% for all sectors; exhaust loss not estimated. |
| *Waste Heat Recovery: Technology and Opportunities in U.S. Industry*, BCS, 2009 | System losses estimated to be 15% for all sectors; process heating key equipment and exhaust loss estimates derived from BCS report. |
| *Energy and Environmental Profile… Petroleum Refining Industry, Pulp and Paper Industry, Aluminum Industry*, Energetics, 2007, 2005, 1997 | System losses estimated to be 15% for all sectors; process heating key equipment from profile reports; exhaust loss from other sources including draft exhaust model. |
| *1992 Industrial Process Heat Energy Analysis*, Gerhardt, et al., EEA, 1992 | System losses estimated to be 15%; process heat key equipment from 1992 report; exhaust loss not estimated. |
| *Energy Analysis of 108 Industrial Processes*, Brown et al., 1985 | System losses, process heat key equipment, and exhaust loss from 108 processes compiled in to a spreadsheet model. |

After a quick review of Energetics' prior research on this subject, it was agreed by the working group that the reference book *Energy Analysis of 108 Industrial Processes* was the most comprehensive data source for the scope of analysis. After the first working group meeting the following Rules of Engagement were agreed upon by the group:

**Group title:** Manufacturing Process Heating Energy Loss Working Group

**Group focus:** Review and contribute to the process heating energy loss estimates by sector that will appear in the AMO Manufacturing Energy and Carbon Footprints.

**Original data source for process heating energy balance model:**
Energy Analysis of 108 Industrial Processes (*108 Processes*), 1985, based on 1976 Census, (year of data = approximately 1980)

**Group Agreement:** The group recognized that *108 Processes* was approximately 30 years out of date. The group recognized that *108 Processes* is being used as a baseline for process heating energy balance analysis, and that resulting process heating energy loss figures will be reviewed by industry experts and adjusted as necessary to account for industry advancements (in terms of energy efficient technologies and waste heat recovery equipment) and other inaccuracies.

The working group agreed that results would be finalized through consensus of the group.

At the time of the second working group meeting in February 2012, the results from a spreadsheet model based on *108 Industrial Processes* data were presented to the group. Some adjustments were made to the results to account for process efficiency gain in the 30-plus years since publication of the report. Process heating loss from the 108 Processes model was found to range from 27% to 88%, with weighted average for All Manufacturing of 58%.

At the conclusion of the second working group meeting the group agreed that the spreadsheet model was the best that could be done with the data available. However, a common perception held that the results of the spreadsheet model could be improved upon. Concerns with the results included:

The process energy data from *108 Processes* is for a typical individual plant. When multiple subsectors are averaged in the model there is no accounting for production differences, they are weighted equally. Inclusion of production data was thought to be too time consuming.
The process energy data in the reference is for all process energy end uses, not just process heating. Assumptions were made as to which process steps constituted process heating end use.
It was unclear whether energy recovery was accurately accounted for in the spreadsheet model.
Feedstock considerations – in some cases it was not clear whether fuel use included feedstock energy
Properly accounting for energy released in exothermic reactions was not always possible

In a small group discussion it was agreed that the best approach to determining realistic sector-wide process heating energy loss results would be to speak with manufacturers directly and build an estimate from the ground up, rather than trying to modify a model with questionable results. It was agreed that a range of subsector estimates would add greater substantiation to the sector-wide estimate.

In the period from March through August 2012 representatives from Energetics Incorporated and ORNL met with a number of plant operation managers and energy managers both by phone and in person to explain the analysis and solicit plant-based estimates of process heating energy loss. Estimates in various forms of completeness were obtained from the manufacturing organizations in Table F.3.

**Table F.3. Contributing manufacturing organizations**

| | | | | |
|---|---|---|---|---|
| ArcelorMittal | Carus Corporation | Darigold | Davisco Foods | Del Mar Food Products |
| Didion Dry Corn Milling | Foster Farms | Hilmar Cheese Company | Phillips 66 | Saint Gobain |
| Shell | Spreckels Sugar | Tenova Core | former employee- Kimberly Clark and Georgia Pacific | |

To guide conversation during these meetings a simple energy balance spreadsheet tool was developed detailing key processing heating equipment by manufacturing subsector (e.g., furnace, dryer, melter, oven, evaporator, etc.). Since process heating equipment varies greatly by sector and by plant, a simplified energy balance was suggested to make it easier to gather energy loss estimates uniformly. Arvind Thekdi, a process heating expert assisting Energetics with the footprint analysis, provided oversight in developing the process heating energy balance approach. Figure F.4 and Table F.4 were produced with Arvind's guidance and were used in explaining the energy balance approach to others. Similar process heating energy balance methodology is referenced in other DOE publications and tools (*Process Heating System Performance: A Sourcebook for Industry*, February 2008, and Process Heating Assessment and Survey Tool, PHAST version 3.0, November 2010).

Stated simply, for a given amount of fuel, steam or electricity energy input, energy losses can occur either in energy input, in system or box losses, or as exhaust or vent losses. Remaining energy input is retained in the form of process heat. Table F.4 gives more detail on the broad energy balance areas shown in Fig. F.4.

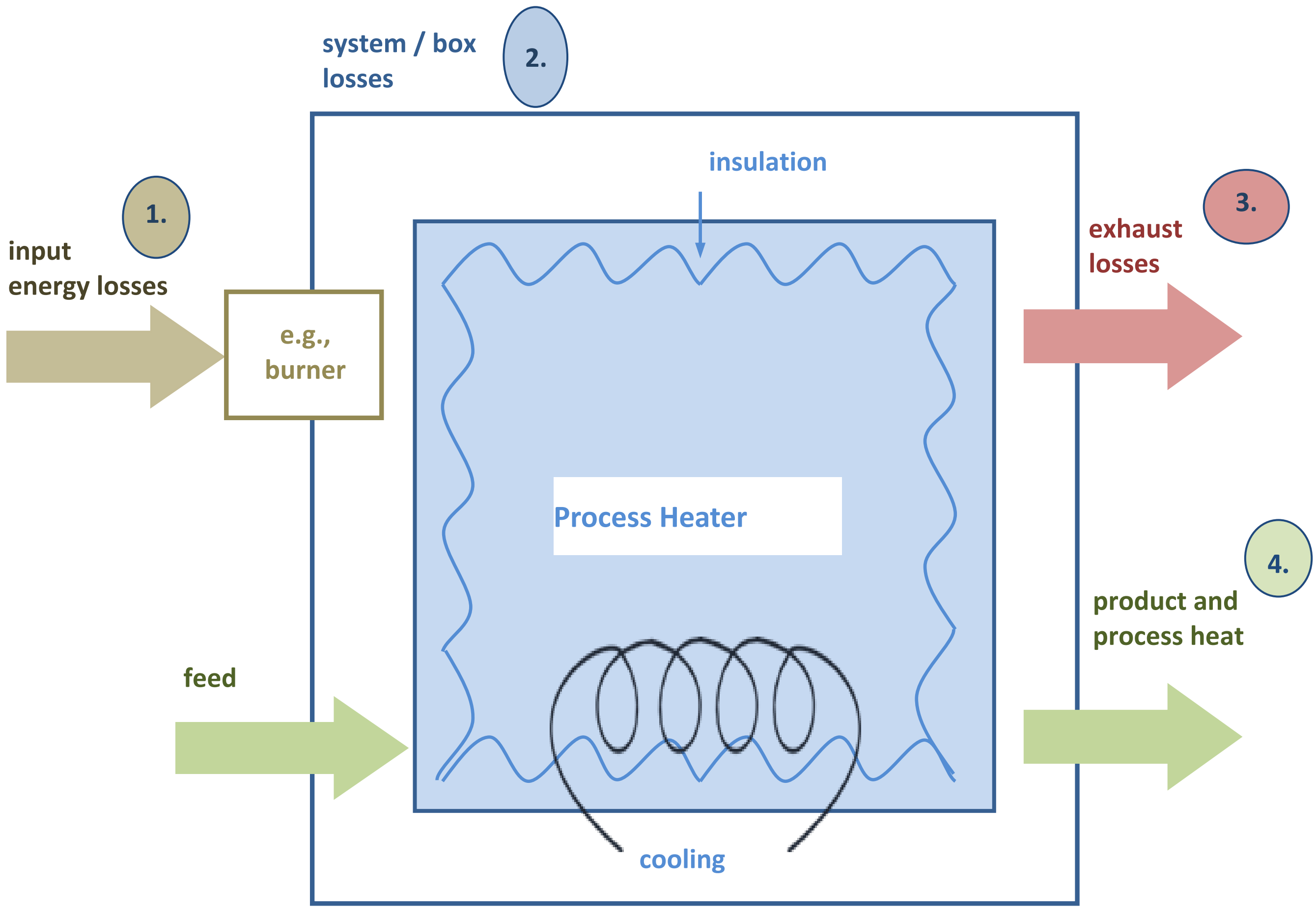


**Fig. F.4. Simplified process heating equipment energy balance (as derived from *Improving Process Heating System Performance: A Sourcebook for Industry*, Figure 2, Page 13)**

**Table F.4. Simplified process heating energy balance loss areas explained**

| Energy use and loss area | | Energy use and loss area description | Explanation |
|---|---|---|---|
| 1. | Input energy losses | Input fuel and feed losses, e.g., incomplete combustion losses | Compared to other Energy Use and Loss Areas, input/combustion losses are considered insignificant for commonly used fuels (natural gas and fuel oils) |
| 2. | System/box losses | Radiation and convection losses, wall, door and insulation losses, opening losses, cooling losses, conveyor losses, furnace heat storage and load conveyor losses (all losses except heat going to the product and heat content of the exhaust gases) | System losses vary widely depending on size, age, and application. System losses are estimated to range between 5 and 25% of energy input in process heating applications. |
| 3. | Exhaust losses | Flue (exhaust heat) losses | Exhaust losses vary widely depending on the process conditions – temperature, loading conditions and equipment design (such as use of recuperators). Exhaust losses are estimated to range between 25 and 55% in process heating applications. |
| 4. | Product and process heat | Product and process heat requirement includes sensible and phase change heat, and heat of reaction | Product and process heat requirement represents the balance of total input energy after losses are accounted for |

The energy system boundary was a challenge to define in some cases. Generally speaking, if energy is retained in the product stream and there is further processing of the product (i.e., the energy value is utilized or lost in downstream end use) the process heating equipment energy loss will be less than 100%. How much energy is lost, and where, is estimated in the spreadsheet model. In cases where there is no retained energy value in the product stream, energy loss is assumed to be 100%. For example, in container glass conditioning and annealing, process heating losses are assumed to be 100%. Product enters the forehearth at approximately 2400 degrees Fahrenheit and exits at 2000 degrees Fahrenheit. In conversations with glass plant engineers it was agreed that the energy input, normally in the form of natural gas fired burners in this case, is “lost” via system losses (e.g., refractory losses) or exhaust losses.

In addition to process heating loss estimates from meetings with plant engineers, various data sources were consulted to add detail to the spreadsheet model. U.S. DOE Save Energy Now Assessment data was referenced, and a number of technical studies were cited in support of some sector estimates.

A third and final working group meeting was held in August 2012. During this meeting the results of the simplified energy balance approach were shared with the working group and sources were discussed. Working group representatives in attendance at this third meeting reached consensus on the approach and results presented. The results from the simplified energy balance approach were thought to be more realistic than the results obtained initially from the 108 processes model.

Based on comments and questions from working group participants during the third working group meeting, four follow up topics were identified for further study: exhaust losses in petroleum refining, dryer losses in forest products and food and beverage, efficiency gains in electric arc furnaces, and glass annealing losses. These follow-up topics were addressed shortly after the meeting and updated results were distributed to the working group.

RESULTS

Process heating loss estimates were derived for seven manufacturing sectors, representing 84% of manufacturing process heating energy use: petroleum refining, chemicals, forest products, iron and steel, food and beverage, cement, and glass. Based on the weighted average of the seven sectors, average process heating loss for all of U.S. manufacturing was calculated to be 38%.

With the remaining sectors accounting for just 16% of process heating energy use and timing and budget constraints, the remaining sectors were not studied with the same level of detail. However, to provide estimates for process heating losses in all footprint sectors, the results from the seven sectors that were studied were applied to the remaining eight sectors as follows:

All Manufacturing average – applied to fabricated metals,
transportation equipment, computers and electronics, and machinery

Iron and Steel – applied to foundries and aluminum

Chemicals – applied to plastics and rubber

Food and Beverage – applied to textiles

The process heating energy loss results for all sectors are summarized in Table F.5. The sectors are defined by North American Industrial Classification System (NAICS) code. Process heating energy use is also shown in Table F.5, along with the contributing percent of total process heating energy use. Process heating energy is shown in terms of trillion British Thermal Units (TBtu) and is the sum of fuel, electricity and steam energy for the sector as a whole in the United States. The first seven sectors in Table F.5 consume 84% of manufacturing process heating energy use.

**Table F.5. Results for process heating energy loss from the manufacturing process heating energy loss working group**

| Manufacturing sector | NAICS code | Process heating energy loss estimate | Process heating energy use (TBtu) | Percent of total U.S. manufacturing process heating energy use |
|---|---|---|---|---|
| Petroleum refining | 324110 | 18% | 2,346 | 30% |
| Chemicals | 325 | 22% | 1,268 | 16% |
| Forest products | 321-322 | 68% | 1,102 | 14% |
| Iron and steel | 3311-3312 | 51% | 723 | 9% |
| Food and beverage | 311-312 | 68% | 555 | 7% |
| Cement | 327310 | 40% | 311 | 4% |
| Glass | 3272, 327993 | 56% | 255 | 3% |
| Fabricated metals | 332 | 38% | 201 | 3% |
| Transportation equipment | 336 | 38% | 117 | 1% |
| Foundries | 3315 | 51% | 106 | 1% |
| Plastics and rubber | 326 | 22% | 101 | 1% |
| Textiles | 313-316 | 68% | 100 | 1% |
| Alumina and aluminum | 3313 | 51% | 100 | 1% |
| Computers, electronics, and electrical equipment | 334-335 | 38% | 51 | 1% |
| Machinery | 333 | 38% | 37 | <0.5% |
| All manufacturing | 31-33 | 38% | 7,814 | 100% |

A list of the sources consulted for the seven sectors is provided in Table F.6. The Save Energy Now Assessments do not correspond to the manufacturers listed in Table F.6. The assessments were selected at random based on applicable NAICS code; company information was kept confidential

**Table F.6. Sources consulted in estimating process heating energy loss**

| Manufacturing sector | Manufacturing meetings | DOE's Save Energy Now Assessments | Technical studies |
|---|---|---|---|
| Petroleum refining | Phillips 66, Shell, CHT Analytics | 4 assessments | N/A |
| Chemicals | Carus Corporation | 0 | Ref 1 |
| Forest products | Former employee of Kimberly Clark and Georgia Pacific, Dick Reese and Associates, E3M | 0 | Ref 2, Ref 3, Ref 4 |
| Iron and steel | ArcelorMittal, Tenova Core, E3M | 1 assessment | Ref 5, Ref 6 |
| Food and beverage | Davisco Foods, Darigold, Spreckels Sugar, Foster Farms, Didion, Del Mar Food Products, Hilmar Cheese Company | 1 assessment | Ref 7, Ref 8 |
| Cement | | 0 | Ref 9, Ref 10 |
| Glass | Saint Gobain | 4 assessments | Ref 11, Ref 12, Ref 13, Ref 14 |

## APPLICATION OF RESULTS

The results from the Manufacturing Process Heating Energy Loss Working Group have been significant in improving and updating the Manufacturing Energy and Carbon Footprints. The inclusion of process heating energy loss estimates in the footprints allows for estimation of overall generation and end uses losses in the report. This data will also help AMO staff evaluate opportunities to reduce, recycle, and recover waste heat from process heating equipment.

The Manufacturing Energy and Carbon Footprints have undergone multiple rounds of review in the finalization process including review and input from AMO, ORNL, EIA, and representatives from various industry organizations and associations. The results from the Manufacturing Process Heating Energy Loss Working Group and the Steam End use Working Group have been incorporated in to the Energetics energy footprint model and updated energy footprints have been posted on the AMO website.

## CONCLUSION

The Manufacturing Energy and Carbon Footprints (published on the AMO website) serve as a useful reference for industrial energy use characteristics and allow for comparisons of energy consumption across and within sectors. The Manufacturing Process Heating Energy Loss Working Group was created at the request of DOE and ORNL to obtain industry expert input that could be applied to the Manufacturing Energy and Carbon Footprints.

This small, focused working group was successful in meeting the peer review objectives in the timeframe allotted. The working group results improved the accuracy of the Manufacturing Energy and Carbon Footprints. The authors of this paper would like to express their gratitude to the working group members and to the manufacturers that were consulted in this effort. Their efforts were voluntary and greatly appreciated.

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