Understanding Manufacturing Energy and Carbon Footprints

The Manufacturing Energy and Carbon Footprints map energy use and carbon emissions from energy supply to end use. Footprints are published for 15 manufacturing sectors (representing 94% of all manufacturing energy use) and for U.S. manufacturing as a whole. These sectors are described in more detail in the document *Manufacturing Energy and Carbon Footprint Scope*.

Manufacturing Energy and Carbon Footprint Sectors:

- All 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
- Transportation Equipment

Each footprint visualizes the flow of energy (in the form of fuel, electricity, or steam) to major end uses in manufacturing, including boilers, power generators, process heaters, process coolers, machine-driven equipment, facility heating, ventilation, and air conditioning (HVAC), and lighting. The footprints present data at two levels of detail. The first page provides a high-level view of primary energy (offsite and onsite), while the second page shows details of how energy is distributed to onsite end uses.

Aggregate data provided in each of the sectors includes:

- Electricity and steam generated offsite and transferred to the facility, as well as electricity and steam generated onsite
- Fuel, electricity, and steam consumed by major end uses in a manufacturing facility
- Offsite and onsite energy losses due to generation, transmission and distribution, heat loss, friction, incomplete combustion, emissions, thermodynamic limits, and other loss sources (some losses are not recoverable)
- Greenhouse gas emissions released during the combustion of fuel

Analysts and decision-makers utilize the Manufacturing Energy and Carbon Footprints to better understand the distribution of energy use in energy-intensive industries and to compare the use, loss, and carbon emission characteristics within and across sectors. Areas of high energy consumption or significant energy losses can indicate opportunities to improve efficiency by implementing energy management best practices, upgrading energy systems, or developing new technologies. The footprints provide a macro-scale benchmark from which to calculate the benefits of improving energy efficiency and for prioritizing opportunity analysis in manufacturing.

The Role of Energy Efficiency

The U.S. manufacturing sector depends heavily on energy resources to provide fuel, power and steam for the conversion of raw materials into usable products. The efficiency of energy use, as well as the cost and availability of energy, consequently have a substantial impact on the competitiveness and economic health of U.S. manufacturers. More efficient use of energy lowers production costs, conserves limited energy resources, and increases productivity. The more efficient use of energy also has positive impacts on the environment, including reduced emissions of greenhouse gases and air pollutants.

Energy efficiency varies dramatically across manufacturing sectors, and across the various process and non-process end uses within each sector. The physical and chemical parameters of a process, as well as equipment design, age, and operating and maintenance practices, can lead to real-world performance below the ideal efficiency. Less-than-optimal energy efficiency means that some of the input energy is lost either mechanically or as waste heat. In the manufacturing sector, energy losses amount to billions of dollars of energy costs each year, and millions of metric tons of greenhouse gas emissions.

It is clear that increasing the efficiency of energy use could result in substantial benefits to both U.S. manufacturers and the nation. Unfortunately, the sheer complexity of the thousands of processes used in the manufacturing sector makes this a daunting task. There are, however, significant opportunities to address energy efficiency in the common energy systems that are used across manufacturing, such as onsite power systems, fired heaters, boilers, pumps, facility HVAC equipment, and others. A first step in realizing these opportunities is to identify how industry is using energy. Where does it come from? What form is it in? Where is it used? How much is lost? Answering these questions for U.S. manufacturing sectors is the focus of the footprint analysis.

Carbon Footprint Analysis

The carbon footprint calculations conform to the EPA GHG mandatory reporting requirements, referencing the same emissions calculations and fuel-specific emission factors. Unique emission factors were used for each sector based on fuel type breakdown. Process emissions are excluded from the analysis as these are not directly related to the use of energy as fuel. Emissions are reported as CO_2-equivalent (CO_2e), as per the GHG reporting requirements. CO_2e consists of contributing CO_2, CH_4, and NO_2 emissions.

A Walkthrough of the Footprints

To produce the footprints, an analytical model for detailing sector-specific energy use and loss and associated carbon emissions was devised to utilize energy-use statistics, relevant emissions guidelines, and consultation with appropriate industry experts.

The output from the footprint model is presented in the form of graphical "footprints" that map the flow of energy supply, demand, and loss for selected U.S. manufacturing industries. Figure 1 shows the color legend used in the footprints, as shown in the example footprint for the chemicals sector in Figure 2 and Figure 3. Each footprint consists of two figures; the first figure offers an overview of the sector's total **primary energy** flow including offsite energy and losses, while the second figure presents a more detailed breakdown of the **onsite energy** flow. The term "Total" in the footprints refers to the total sum of offsite and onsite values. In energy terms, this is referred to as *total primary energy*.

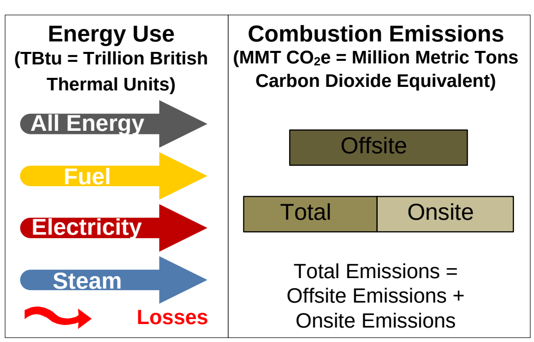

Figure 1. Footprint legend

Energy use is shown as input and output flow lines to the various pathway stages; energy values appear in white font within the flow arrows. Energy use is broken down by energy type and distinguished by color (as shown in Figure 1): dark gray = all energy, yellow = fuel, dark red = electricity, and blue = steam. Energy losses are represented as wavy red arrows. Carbon emissions are shown in the boxes along the bottom of each pathway stage. Offsite, onsite, and total carbon emissions are distinguished by color as shown in the legend: dark brown = offsite carbon, light brown = onsite carbon, and medium brown = total carbon (offsite + onsite).

The footprint pathway captures both energy supply and demand. On the supply side, the footprints provide details on energy purchases and transfers in to a plant site (including fuels derived from byproducts), and onsite generation of steam and electricity. On the demand side, the footprints illustrate the end use of energy within a given sector, from process energy uses such as heaters and motors to nonprocess uses such as HVAC and lighting. The footprints also identify where energy is lost due to generation and distribution losses and system inefficiencies, both inside and outside the plant boundary. Losses are critical, as they represent immediate opportunities to improve efficiency and reduce energy consumption through best energy management practices and technologies.

In the primary energy footprint figure, the energy supply chain begins with the fuel, electricity, and steam supplied to the plant boundary from offsite sources (power plants, fuel and gas distributors, etc.). Many industries generate byproduct fuels, and these are also part of the energy supply. Notable examples of byproduct fuels include the use of black liquor and wood byproducts in pulp and paper mills and waste gas from petroleum refineries.

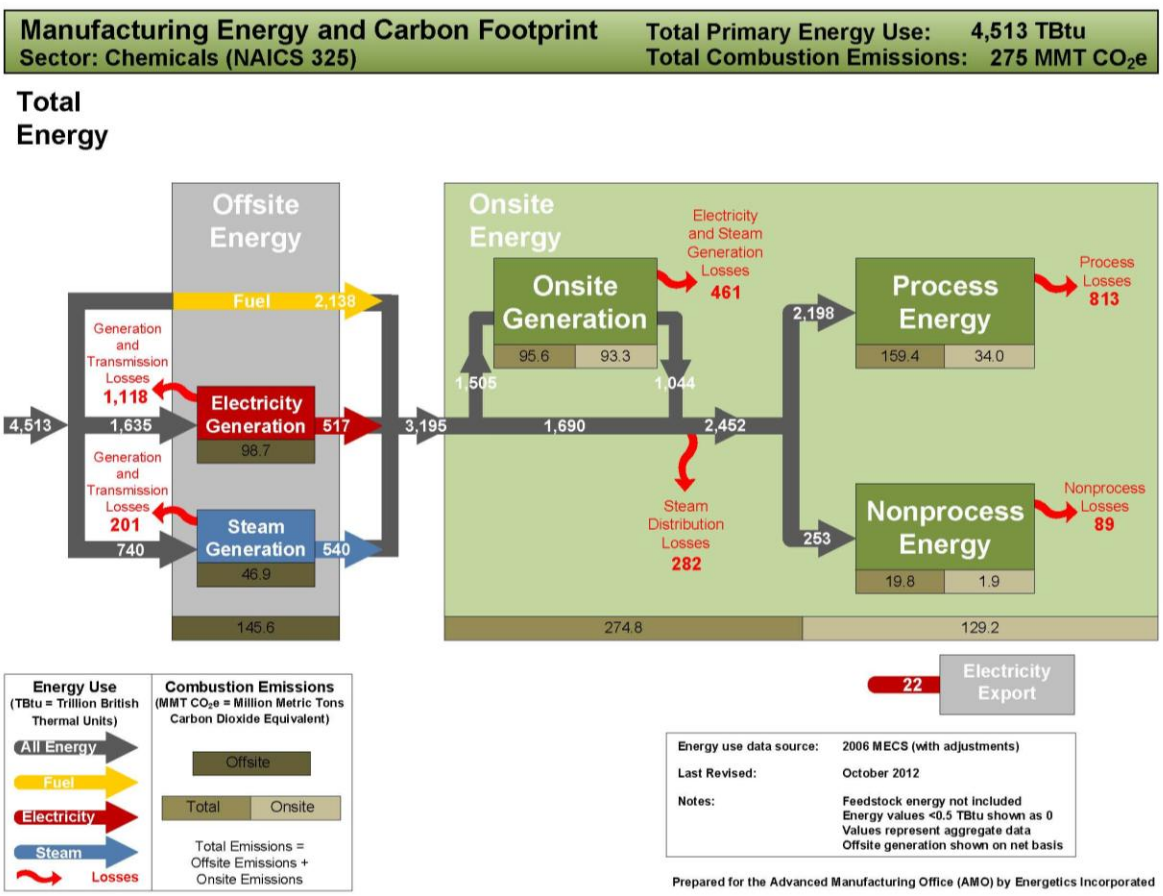

Figure 2: Total primary energy use and GHG combustion emissions for the chemicals sector

In the onsite energy footprint figure, energy demand is shown by energy type and end use. The onsite energy that reaches the plant boundary is used indirectly for onsite generation or directly for process and nonprocess end uses. Onsite energy generation, which consists of conventional boilers, combined heat and power (CHP)/cogeneration systems controlled by a manufacturing establishment, and other onsite electricity generation such as renewable energy sources, contributes to the electricity and steam demands of process and nonprocess end uses. A percentage breakdown of energy use by fuel type, including fuels derived from byproducts, is presented as a yellow call out box at the beginning of the onsite fuel pathway. Often, onsite generation of energy creates more energy than is needed at the plant site, allowing any excess energy to be exported offsite to the local grid or other nearby plants. Total primary and onsite energy use values are based on net electricity and do not include exported electricity. Exported steam is accounted for in MECS net steam data, and thus is not explicitly shown in the footprint.

Process energy systems consist of the equipment necessary for process heating (e.g., kilns, ovens, furnaces, strip heaters), process cooling and refrigeration, electro-chemical processes (e.g., reduction processes), machine drive (e.g., motors and pumps associated with process equipment), and other direct process uses. Another step in the energy pathway is the energy that is distributed to nonprocess end uses. This involves the use of energy for facility HVAC, facility lighting, other facility support (e.g., water heating and office equipment), onsite transportation, and other nonprocess use.

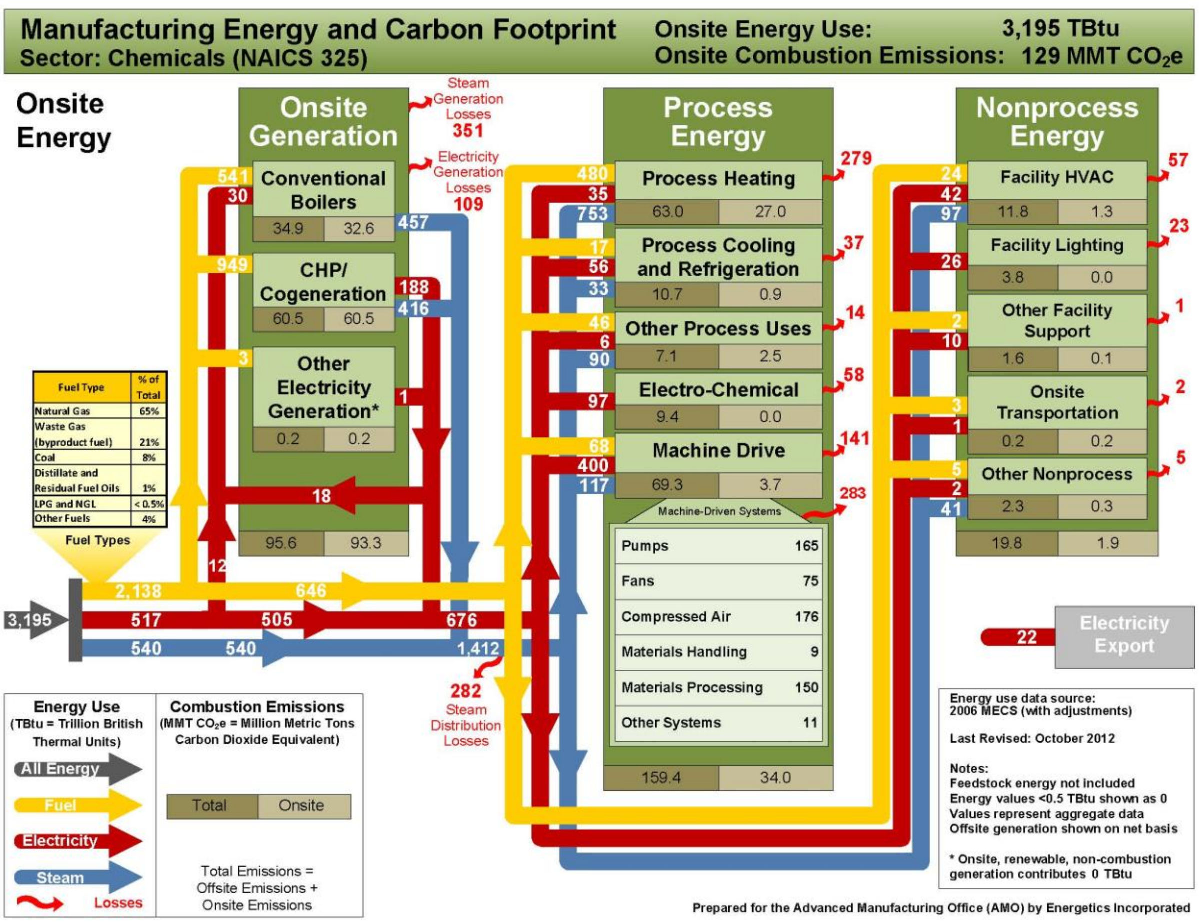

Figure 3: Onsite energy and carbon emissions for the chemicals sector

Energy losses occur along the entire energy pathway from generation and delivery to end use. Energy is lost in generating power and steam, in transmitting power and steam, and in process and nonprocess end use of power, steam, and fuel. In the footprint analysis these energy loss values are estimated. Energy losses vary greatly by industry and by facility, so conservative sector-wide energy loss estimates are assumed with the understanding that these estimates are highly dependent on the specific manufacturing plant site. A summary of footprint loss assumptions is outlined in the document *Manufacturing Energy and Carbon Footprint Definitions and Assumptions* and presented in Appendix D of the *Manufacturing Energy Use and Loss and Emissions Analysis* report. Energy losses do not equate to recoverable energy. While a portion of energy losses are recoverable, the footprints do not attempt to identify and distinguish between recoverable and non-recoverable losses.

The energy and carbon footprints are based on actual plant survey data and therefore represent a genuine distribution of energy use and losses across the sector as a whole. Through them, we can begin to assess the magnitude of energy consumption and losses, both by end use and fuel type. They also provide a baseline from which to calculate the benefits of improving energy efficiency. The carbon values in the footprint can be used to support carbon management planning and analysis.