Understanding Manufacturing Energy and Carbon Footprints

The Manufacturing Energy and Carbon Footprints provide a mapping of energy use and carbon emissions from energy supply to end use. The latest footprints are an enhancement from the previous version of Manufacturing Energy Footprints published by the U.S. Department of Energy (DOE) Advanced Manufacturing Office (AMO).[1] Improvements include the addition of greenhouse gas (GHG) emissions from fuel consumption, energy use breakdown by energy type, and improved steam end use analysis. Footprints have been published for 15 individual sectors (representing 94% of all manufacturing energy use), and for the entire manufacturing sector. These sectors are defined in the document *Manufacturing Energy and Carbon Footprint Scope.*

Analysts and decision-makers utilize the manufacturing energy footprints to better understand the distribution of energy use in energy-intensive industries and the accompanying energy losses. The footprints provide a benchmark from which to calculate the benefits of improving energy efficiency and for prioritizing opportunity analysis. Greenhouse gas emissions have been added to the footprints in response to increased interest in the topic and recent U.S. Environmental Protection Agency (EPA) regulations requiring reporting of emissions by many manufacturing facilities.

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 several quadrillion Btus (British Thermal Units) and billions of dollars in energy costs each year.

It is clear that increasing the efficiency of energy use could result in substantial benefits to both industry 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, 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.

[1] The Advanced Manufacturing Office, previously Industrial Technologies Program (ITP), published earlier versions of the Manufacturing Energy Footprints based on 1998 and 2002 MECS data from EIA. The current Manufacturing Energy and Carbon Footprints are based on 2006 MECS, when the survey was last completed. Updated footprints will be published when 2010 MECS data is released by EIA.

Carbon Footprint Analysis

The greenhouse gas combustion emissions are based on manufacturing energy survey data. The carbon footprint presents the breakdown of combustion emissions within a manufacturing sector by end use source. From these footprints, a user is able to compare the relative carbon contribution by end use (e.g., HVAC vs. machine drive).

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 the 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 is made up of contributing CO_2, CH_4, and NO_2 emissions.

A Walkthrough of the Footprints

Energy-use statistics, relevant emissions guidelines, and industry expertise were all utilized to devise an analytical model for detailing sector-specific energy use and loss and associated carbon emissions.

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 previews the color legend used throughout this report. The chemicals sector energy and carbon footprint is provided as an example 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*.

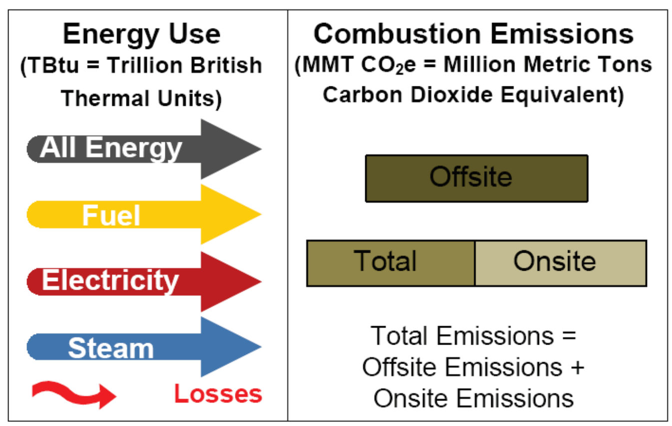

Figure 1. Footprint legend

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 byproduct fuel use), 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 are the use of black liquor and wood byproducts in pulp and paper mills and waste gas from petroleum refineries.

In the onsite energy footprint figure the energy demand is shown by energy type and end use. The onsite energy that reaches the plant boundary is used either 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, and other 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 byproduct fuels, 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. When this occurs, the excess energy is 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 the 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.

Energy losses occur along the entire energy supply and demand pathway and are estimated in the footprint analysis for the major loss areas described herein. Energy is lost in offsite and onsite power and steam generation systems and in process and nonprocess end uses due to equipment inefficiencies and mechanical and thermal limitations. In some cases, heat-generating processes are not optimally located near heat sinks, and it may be economically impractical to recover the excess energy. In other batch process cases energy is lost because it cannot be stored during off-peak times. Energy losses also occur in transmission systems distributing energy both to and within the plant. All of these estimated energy losses vary greatly by industry and by facility. For the sector-wide footprint analysis, conservative energy loss estimates are assumed with the understanding that these estimates are highly dependent on the specific manufacturing plant site.

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. An efficiency savings opportunity analysis (energy and carbon) will be published separately from the footprint analysis.

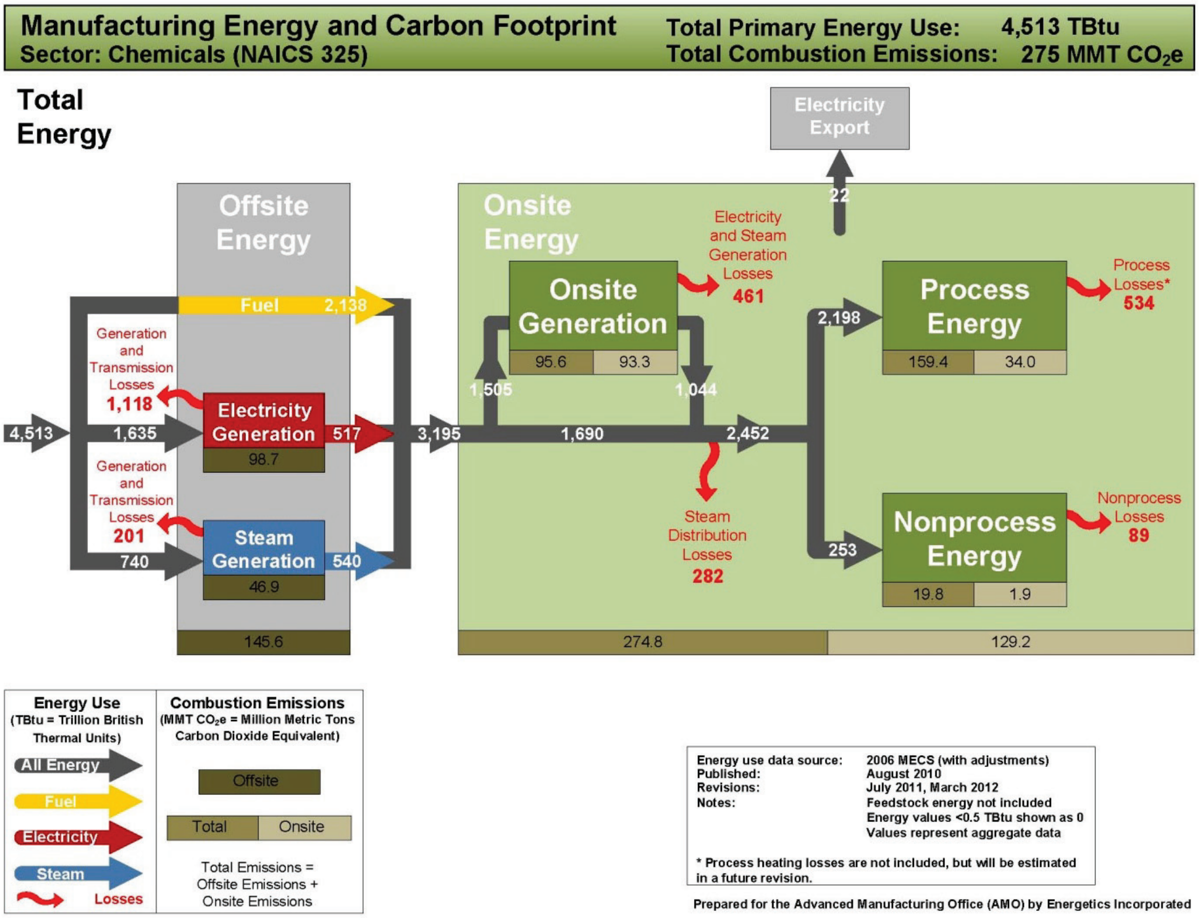

Figure 2: Total Primary Energy Use for the Chemical Sector

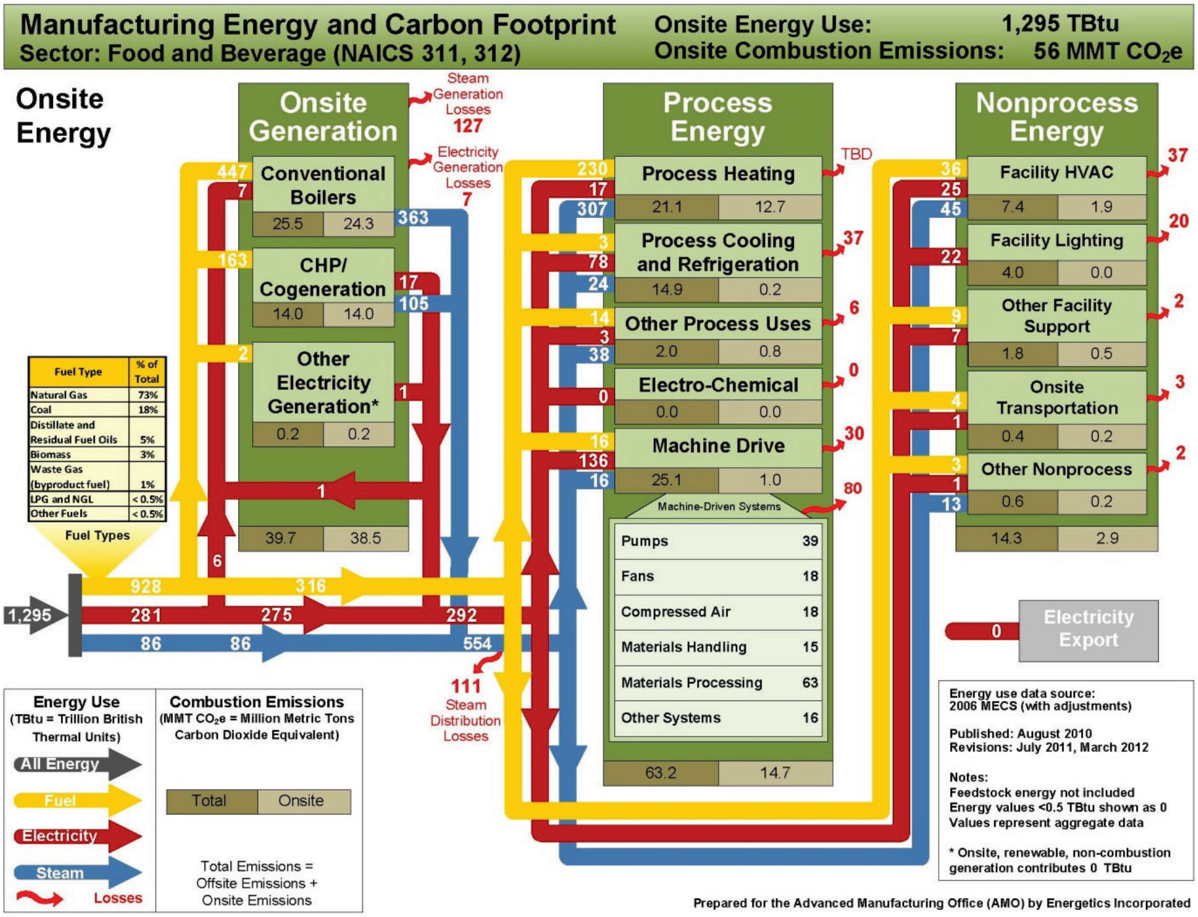

Figure 3: Onsite Energy Use for the Chemical Sector