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) Industrial Technologies Program (ITP).[1] Improvements include the addition of greenhouse gas (GHG) emissions from fuel consumption, an energy use breakdown by energy type, and an analytical model that allows for customized footprints by manufacturing sector or subsector. 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 and power 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 measures the effectiveness by which energy resources are converted into usable work. Efficiency is a commonly-used performance measure for energy conversion equipment such as process heaters, boilers, and power generators, and is defined as the ratio of useful heat and/or electricity output to the heat content of the fuel consumed.

Energy efficiency varies dramatically across industries, across manufacturing processes, and even between different plants manufacturing the same products. 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 industry sectors, such as steam generators, onsite power systems, fired heaters, heat exchangers, compressors, motors, pumps,

[1] Previous versions of the Manufacturing Energy Footprints were based on data from the Energy Information Administration's (EIA) 1998 and 2002 Manufacturing Energy Consumption Survey (MECS). Energy data in the current Manufacturing Energy and Carbon Footprints are based off of the 2006 MECS, when the survey was last completed.

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 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 this 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. The model and footprints can be adapted to other sectors and subsectors as needed.

The Chemical sector energy and carbon footprint is shown in Figure 2 and Figure 3 below as an example. Figure 2 offers an overview of the sector's total primary energy flow including offsite energy and losses, while Figure 3 presents a more detailed breakdown of the onsite energy distribution. **Onsite energy** includes *direct* process and nonprocess energy end uses and *indirect* energy from onsite steam and electricity generation within the industrial plant boundary. The term "Total" in the footprints refers to the total sum of offsite plus onsite values. In energy terms, this is often referred to as *Total Primary Energy*.

Energy use is shown as input and output flow lines to the various pathway stages, with numerical energy values appearing 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 presented as numerical values in 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).

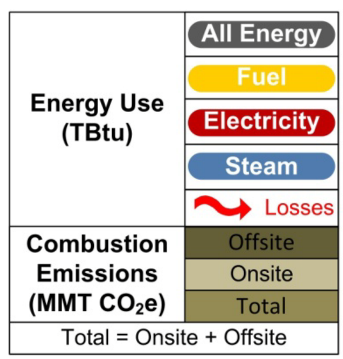

Figure 1. Footprint legend

The footprint pathway captures both energy supply and demand. On the supply side, the footprints provide details on energy purchases and transfers in, electricity export, overall fuel use (including byproduct fuel use), and indirect energy from onsite steam and electricity generation. On the demand side, the footprints illustrate where and how energy is used within a typical plant, from process energy end uses such as process heaters and motors, to nonprocess energy uses such as HVAC and lighting. Additionally, the footprints 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 lower energy consumption through best energy management practices and improved energy systems.

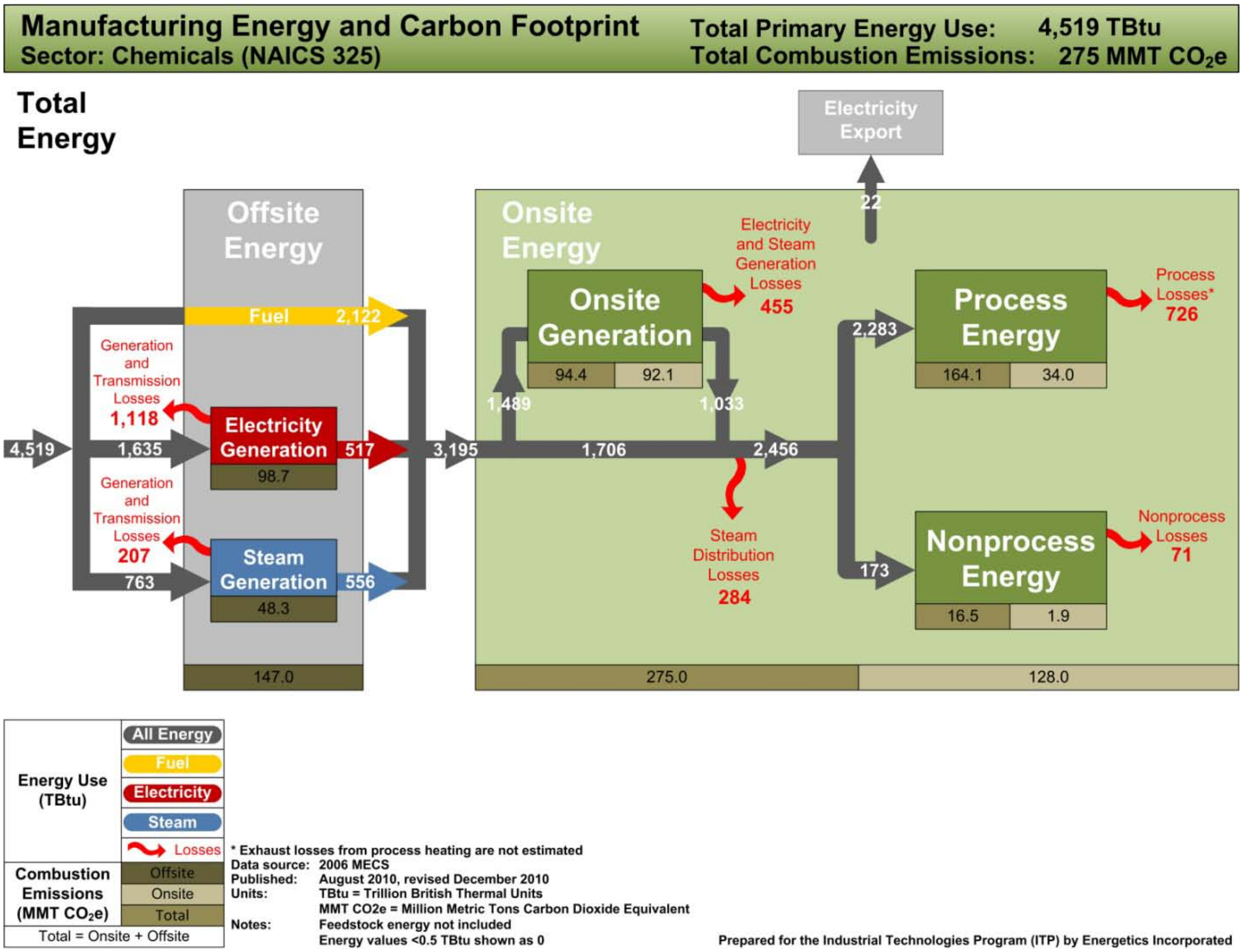

Figure 2: Total Primary Energy Use and Combustion Emissions for the Chemical Sector

As Figure 2 shows, the energy supply chain begins with the fuel, electricity, and steam supplied to the plant boundary from offsite power plants, fuel and gas distributors, and other transfers in. Many industries generate byproducts, 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 still gas from petroleum refining processes.

Once the energy reaches the plant boundary (shown as the light green box in Figure 2), it is used either indirectly for onsite energy generation or distributed directly to process and nonprocess end uses. Onsite energy generation contributes to the electricity and steam required for process and nonprocess end use, sometimes creating more energy than is needed at the plant site. When this occurs, the excess energy is exported offsite to the local grid or another plant within close proximity. 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 not explicitly shown in the footprint.

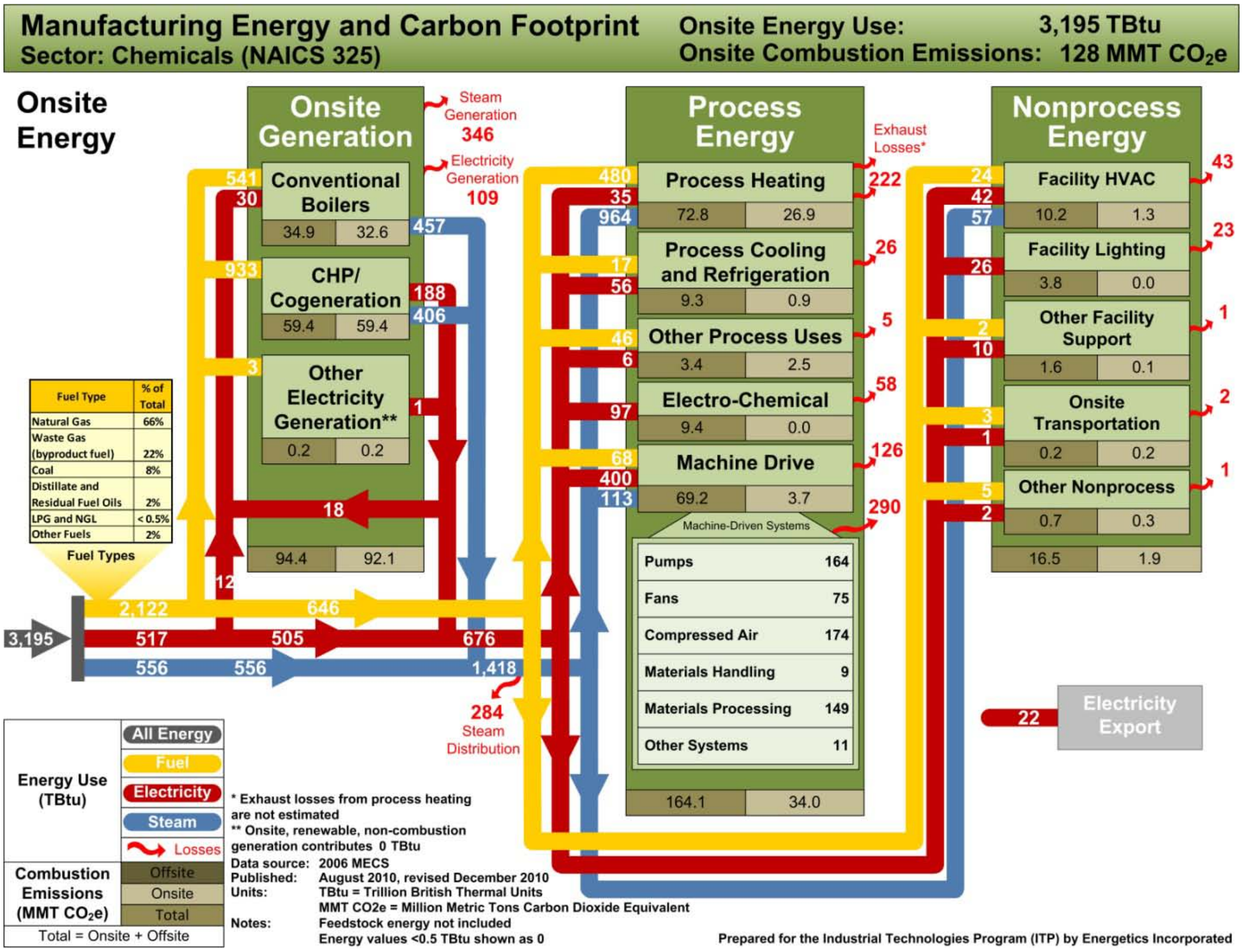

Figure 3: Onsite Energy and Carbon Emissions for the Chemical Sector

The light green Onsite Energy box in Figure 2 is outlined in detail in Figure 3. Onsite energy input is used either indirectly for **Onsite Generation**, or directly for **Process Energy** or **Nonprocess Energy** end use. Onsite generation comprises conventional boilers, CHP/cogeneration, and other electricity generation, which includes renewable energy sources such as solar, geothermal, and wind power. Byproduct fuels that are generated from nonfuel feedstocks are also a contributing source of onsite generation. 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 fuel pathway.

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. As a final step in the energy pathway, energy is distributed to nonprocess energy for purposes that are not industry-specific. This involves the use of energy for facility HVAC, facility lighting, other facility support (e.g., cooking, water heating, and office equipment), onsite transportation, and other nonprocess use.

Energy losses occur all along the energy supply and demand pathway. Energy is lost in offsite and onsite power and steam generation systems and in process and nonprocess end uses due to equipment inefficiency 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.

With some batch processes, energy is lost during off-peak times simply because it cannot be stored. Energy is further lost in transmission systems carrying energy to the plant and distribution within the plant boundaries. 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 (see the document *Manufacturing Energy and Carbon Footprint Assumptions and Definitions* for details) 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.