2.2 CHEMICALS SECTOR (NAICS 325)

2.2.1. Overview of the Chemicals Manufacturing Sector

The chemicals manufacturing sector is an integral component of the U.S. economy, converting raw materials such as petroleum, natural gas, minerals, coal, air, and water into more than 70,000 diverse products. Chemical products are critical components of consumer goods and are found in everything from automobiles to plastics to electronics.

This sector creates its diverse output from raw materials of two general types: organic (oil, natural gas, coal) and inorganic (minerals, metals, air, water). Table 2.2-1 shows the subsector categories in the chemicals sector with data reported in the 2006 EIA Manufacturing Energy Consumption Survey (MECS).

Table 2.2-1. Chemicals subsectors with data reported in MECS

NAICS code	Chemicals subsector
325	Chemicals
325110	Petrochemicals
325120	Industrial gases
325181	Alkalines and chlorine
325182	Carbon black
325188	Other basic inorganic chemicals
325192	Cyclic crudes and intermediates
325193	Ethyl alcohol
325199	Other basic organic chemicals
325211	Plastics materials and resins
325212	Synthetic rubber
325222	Noncellulosic organic fibers
325311	Nitrogenous fertilizers
325312	Phosphatic fertilizers
3254	Pharmaceuticals and medicines
325412	Pharmaceutical preparation
325992	Photographic film, paper, plate, and chemicals

The chemicals sector is the largest consumer of primary energy in U.S. manufacturing. The manufacture of chemicals is complex and energy-intensive, often requiring large quantities of thermal energy to convert raw materials into useful products. The efficiency of the processes and equipment used to produce chemicals are constrained by thermodynamic, kinetic, and transport limitations, and operating conditions may be severe, comprising high temperatures, high pressures, and corrosive environments. These operational factors contribute to relatively high energy use per pound of product compared to other sectors.

2.2.2. Energy Use Profile for the Chemicals Sector

A snapshot of how the chemicals sector ranks in terms of energy use and losses within manufacturing is shown in Table 2.2-2, along with total and onsite GHG combustion emissions. Energy losses are shown in red font. All values represent annual energy use and loss for calendar year 2006, and are based on the most currently available manufacturing energy use statistics. The chemicals sector ranks among the top two sectors in nearly all energy use or loss categories. The sector is the largest user of primary energy and the second largest user of onsite energy. The chemicals sector also releases more carbon emissions than any other sector, while ranking second in terms of onsite emissions.

Table 2.2-2. Snapshot and ranking of energy use, loss, and GHG combustion emissions in the chemicals sector

Category	Rank	Energy (TBtu)
Total primary energy use	1	4,513
Offsite losses	1	1,318
Onsite energy use	2	3,195
Onsite losses	2	1,645
Steam generation and distribution	2	634
Electricity generation	1	109
Process energy	2	813
Nonprocess energy	2	89
Feedstock energy	2	2,812
Total primary and feedstock energy[a]	2	6,467
GHG combustion emissions		**MMT CO_2e**
Total	1	275
Onsite	2	129

[a] When total primary energy and feedstock energy are summed, the energy value of byproduct fuels derived from feedstock energy sources is excluded to avoid double counting of feedstock energy

Although outside the scope of the footprint analysis, it is worth noting that a significant amount of non-fuel feedstock is consumed as raw materials, primarily for the production of petrochemicals, plastic materials and resin, and other basic organic chemicals. As shown in Fig. 2.2-1, the total feedstock energy consumed by the chemicals sector is 2.8 quads. When feedstock and fuel energy are summed, total primary fuel and feedstock energy used is about 6.5 quads. The focus of the energy use and loss analysis that follows excludes all feedstock energy use.

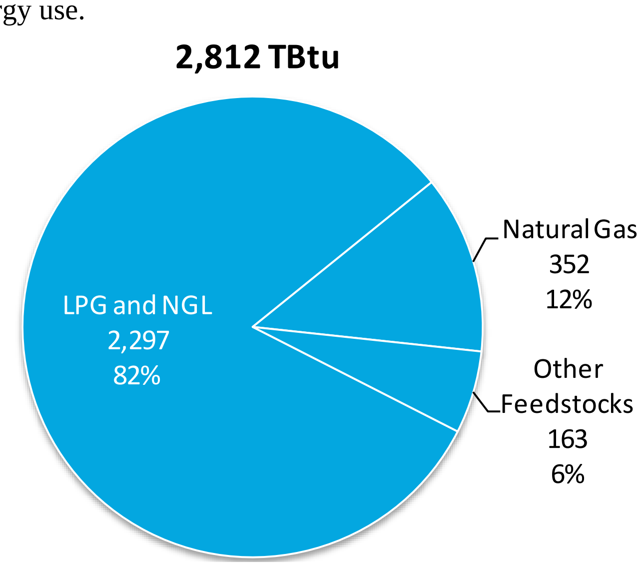

Fig. 2.2-1. Feedstock energy use in the chemicals sector

2.2.2.1. Energy and carbon footprint

The chemicals sector *Manufacturing Energy and Carbon Footprint* is shown in Fig. 2.2-2 and Fig. 2.2-3. The footprints serve as the basis for characterizing the offsite and onsite flow of energy, as well as carbon emissions, from generation through end use in the sector.

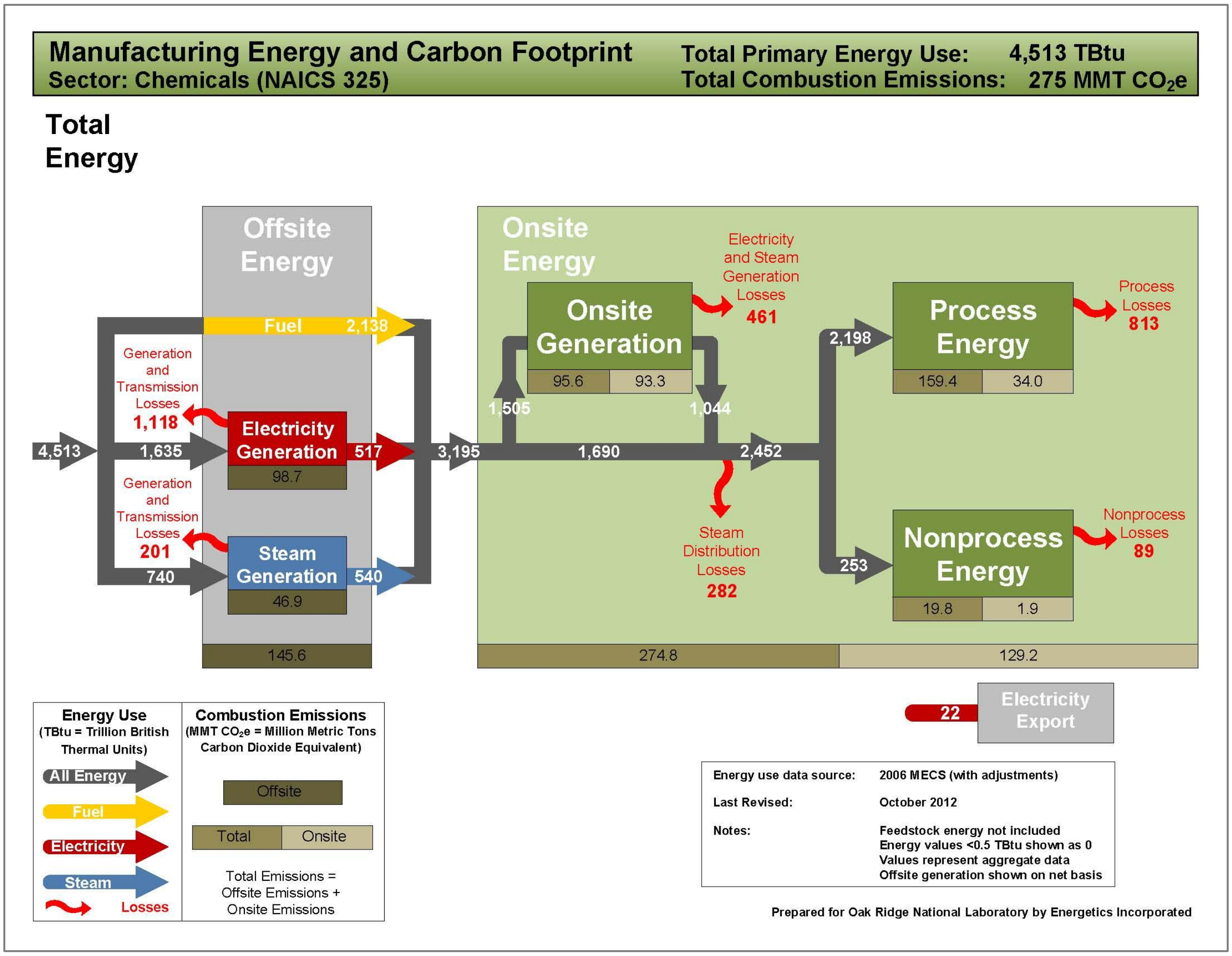

Fig. 2.2-2. Total energy and carbon footprint for the chemicals sector

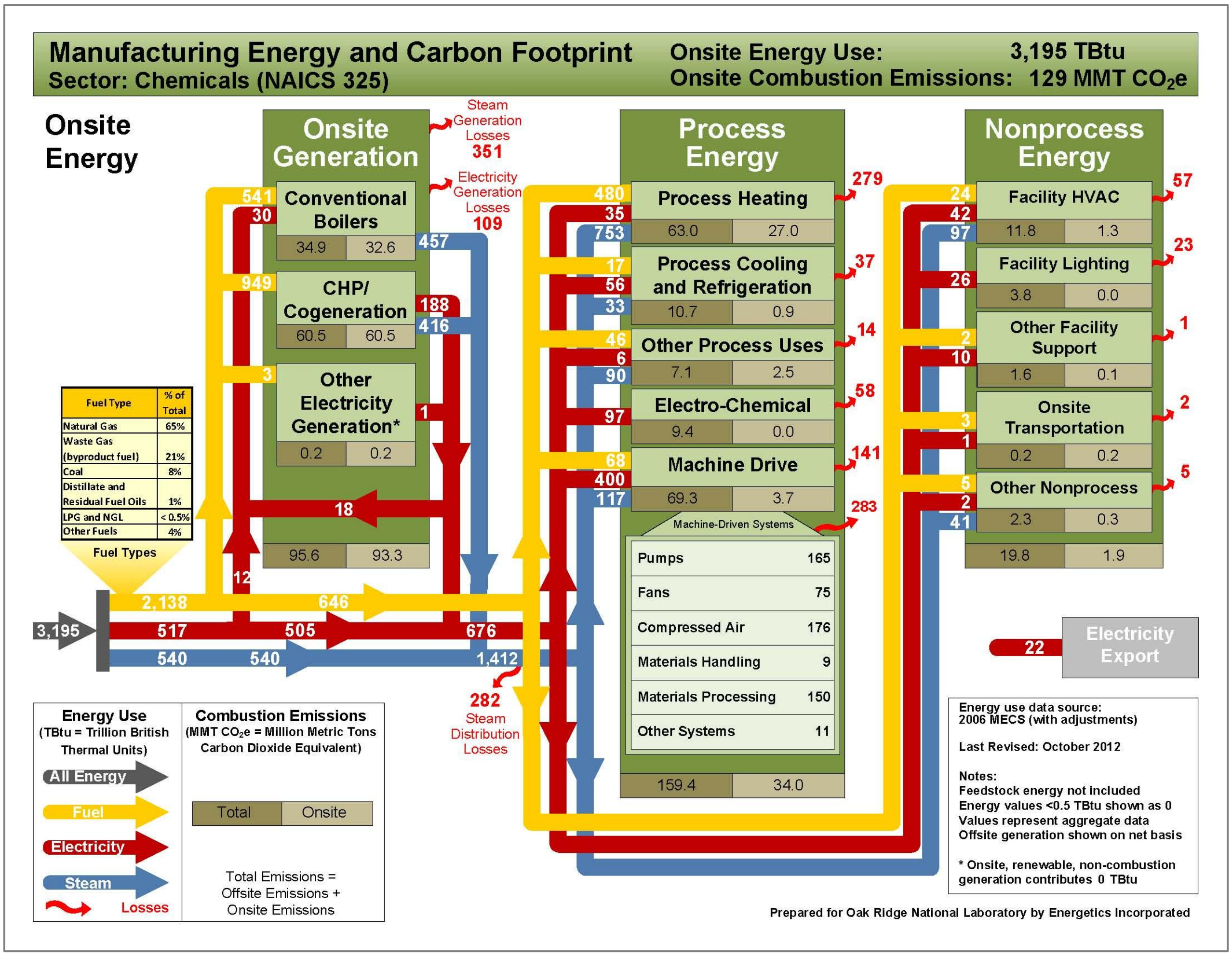

Fig. 2.2-3. Onsite energy and carbon footprint for the chemicals sector

2.2.2.2. Primary energy

Primary energy use includes fuels, electricity, and steam consumed in manufacturing, including the generation and distribution/transmission losses associated with offsite and onsite electricity and steam generation. In 2006, the chemicals sector used 4,513 TBtu of primary energy. The distribution of primary energy by energy type is shown in Fig. 2.2-4. Steam and electricity generation are roughly equal, consuming 44% and 42% of primary energy, respectively. Direct fuel use comprises the remaining 14% of primary energy consumption. Consistent with the footprints, blue represents steam energy, red represents electric energy, and yellow represents fuel energy. This same energy coloring scheme is used throughout this report.

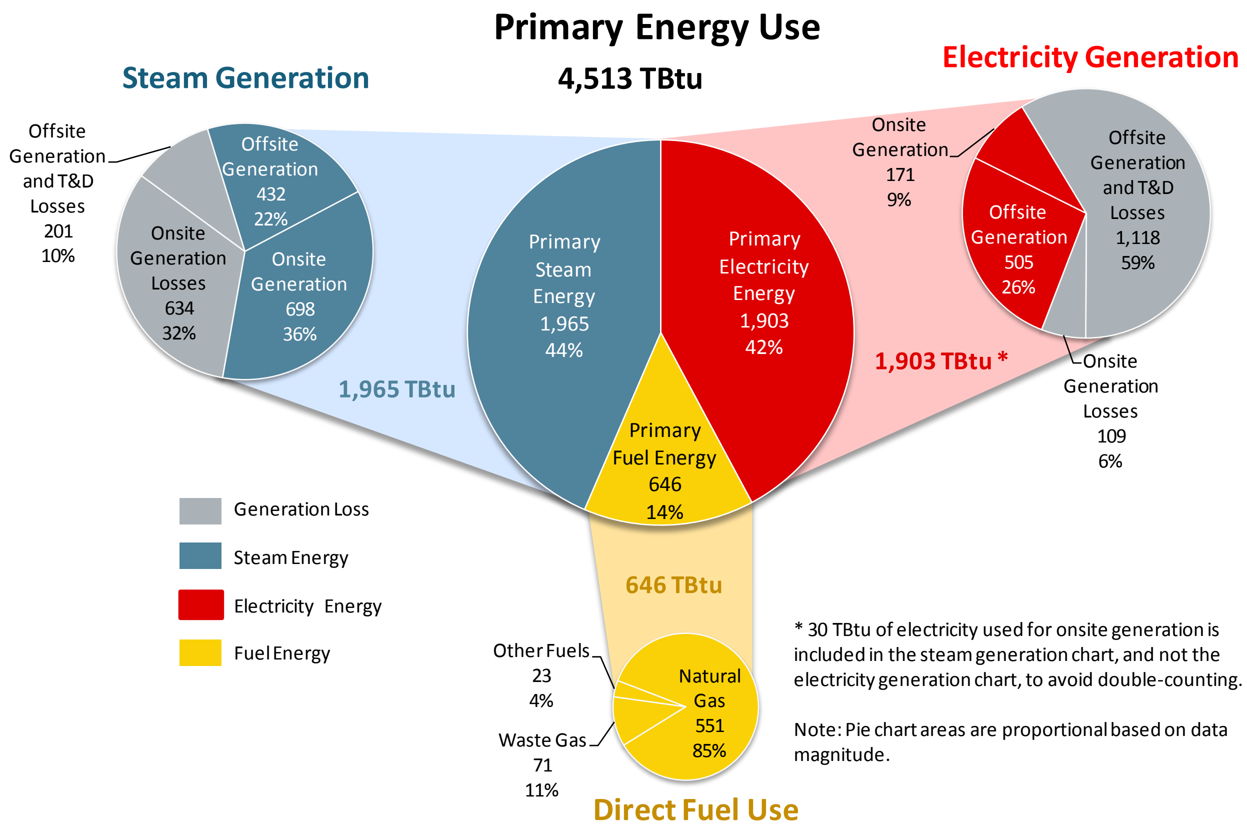

Fig. 2.2-4. Primary energy use by energy type in the chemicals sector

A considerable portion (46%) of the primary energy used in chemicals manufacturing is lost during offsite and onsite generation and distribution of energy. Electricity generation and distribution losses account for 60% of these losses, with the remaining 40% associated with steam generation and distribution. For electricity, the great majority (91%) of electricity losses occur during offsite generation and distribution. Conversely, the majority of steam losses (76%) occur through onsite generation and distribution of steam.

2.2.2.3. Onsite energy

Onsite energy is a measure of the energy entering the plant boundary in the form of three offsite energy types: fuel, electricity, and steam. This onsite energy is then used by processes and nonprocess end uses. Additionally, a large portion of the fuel is consumed onsite in order to generate additional electricity and steam for the manufacturing end uses. The amount of energy that entered chemical plants in 2006 was about 3.2 quads, or 71% of primary energy.

The offsite energy supply, shown in Fig. 2.2-5, is composed of 67% fuel (or feedstock that would later produce a byproduct fuel), 16% offsite electricity, and 17% offsite steam. The chemicals industry relies on hundreds of different chemical processes, and as a result, energy use patterns vary dramatically across subsectors. Processes used to produce petrochemicals, for example, are distillation and steam cracking, resulting in substantial fuel consumption, while chlorine production depends heavily on electricity used in electrolytic cells. Although the energy values presented here represent <u>total</u> energy use for the entire chemicals manufacturing sector, the breakdown by energy type is the <u>average</u> for the sector. As is clarified later in this chapter, a large portion of the offsite fuel use shown in this figure is used to generate a significant amount of steam and electricity onsite.

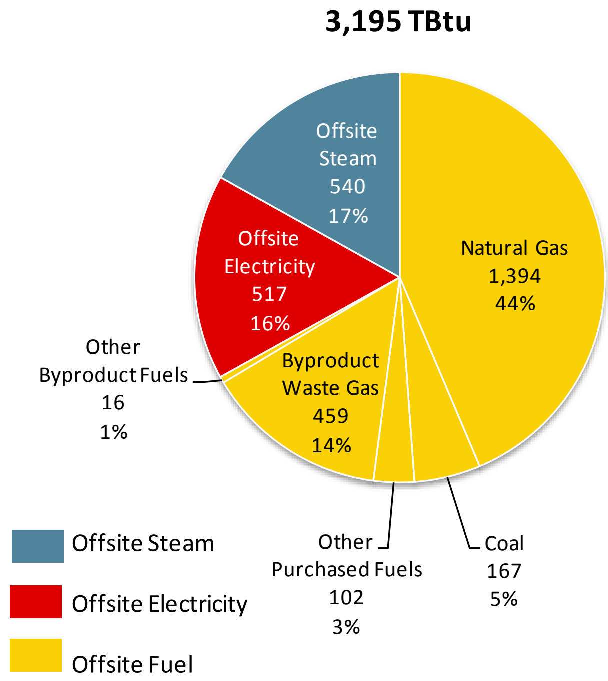

Fig. 2.2-5. Offsite energy supply in the chemicals sector

Fig. 2.2-6 shows the onsite energy use by the largest ten energy-consuming subsectors in chemicals manufacturing (the sum of onsite energy use across these subsectors is equal to 88% of sector-wide onsite energy use). The largest energy using subsectors are petrochemicals, other basic organic chemicals, and plastics materials and resins.

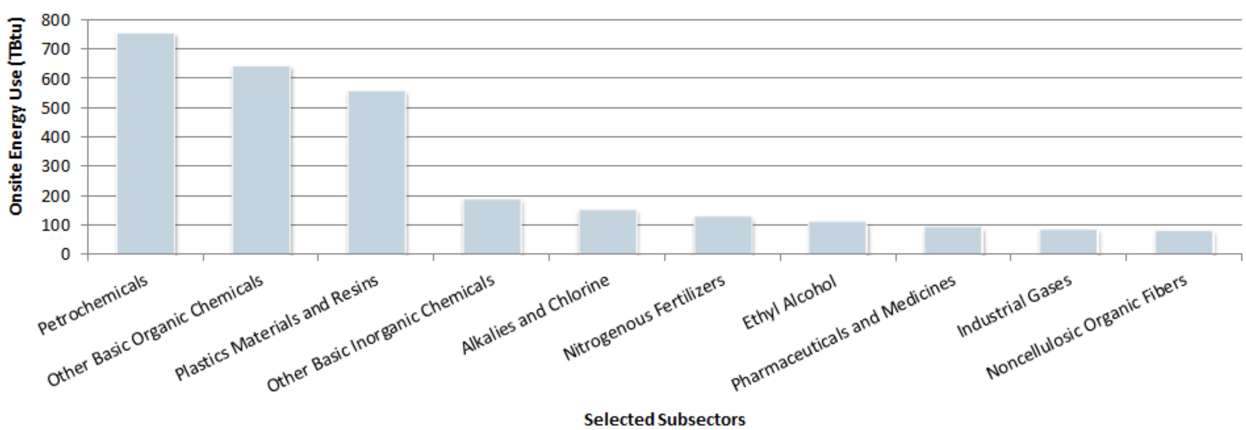

Fig. 2.2-6. Onsite energy use in selected chemicals subsectors

2.2.2.4. Fuel energy

Onsite fuel use in the chemicals sector was 2,138 TBtu in 2006, as can be seen by summing the energy consumption of the fuels shown in Fig. 2.2-5. Fuel use accounts for 47% of primary energy use, and 67% of onsite energy use. A significant proportion of fuel use, 70%, is used to generate onsite steam and electricity in this sector. Chemical sector manufacturing demands a great deal of electricity, ranking first in *direct* electricity demand (see Table 2.1-6); 28% of this onsite electricity demand is generated onsite using purchased and byproduct fuels, primarily in CHP units.

The dominant fuel used in the chemicals sector is natural gas, consuming 1,394 TBtu, thus making the sector particularly susceptible to fluctuations in natural gas prices. Byproduct gases and fuels are the next largest fuel use category, consuming 459 TBtu. Waste gas, or still gas, is the most commonly used byproduct fuel. Waste gas is produced and captured in the off-gases from distillation and reaction processes and is typically made up of methane, ethane, and other light end gases.

2.2.2.5. Electrical energy

In 2006, *direct* electricity use in the chemicals sector was 676 TBtu; this excludes 30 TBtu of *indirect* electricity input to onsite boilers, and includes 171 TBtu of electricity generated onsite.[9] Energy used to generate electricity accounts for 42% of primary energy use (as was shown in Fig. 2.2-4), but electricity accounts for only 15% of *direct* end use energy (Fig. 2.2-10). This discrepancy is due to the relative inefficiency of generation and distributing electricity compared to direct fuel use.

Figure 2.2-7 shows the large portion of primary energy consumed for electricity use is associated with generation, transmission, and distribution (T&D) losses, taking place mostly offsite. The smaller chart on the right shows the *direct* process and nonprocess end uses of electricity. Virtually all onsite electricity production is derived from CHP units. When considering electricity generation and T&D losses, CHP units are 64% efficient while the offsite electricity grid is assumed to be only 31.6% efficient. This near-doubling in efficiency is due to the greater efficiency of CHP and the elimination of transmission and distribution (T&D) losses. The overall efficiency of electricity production is 36%.

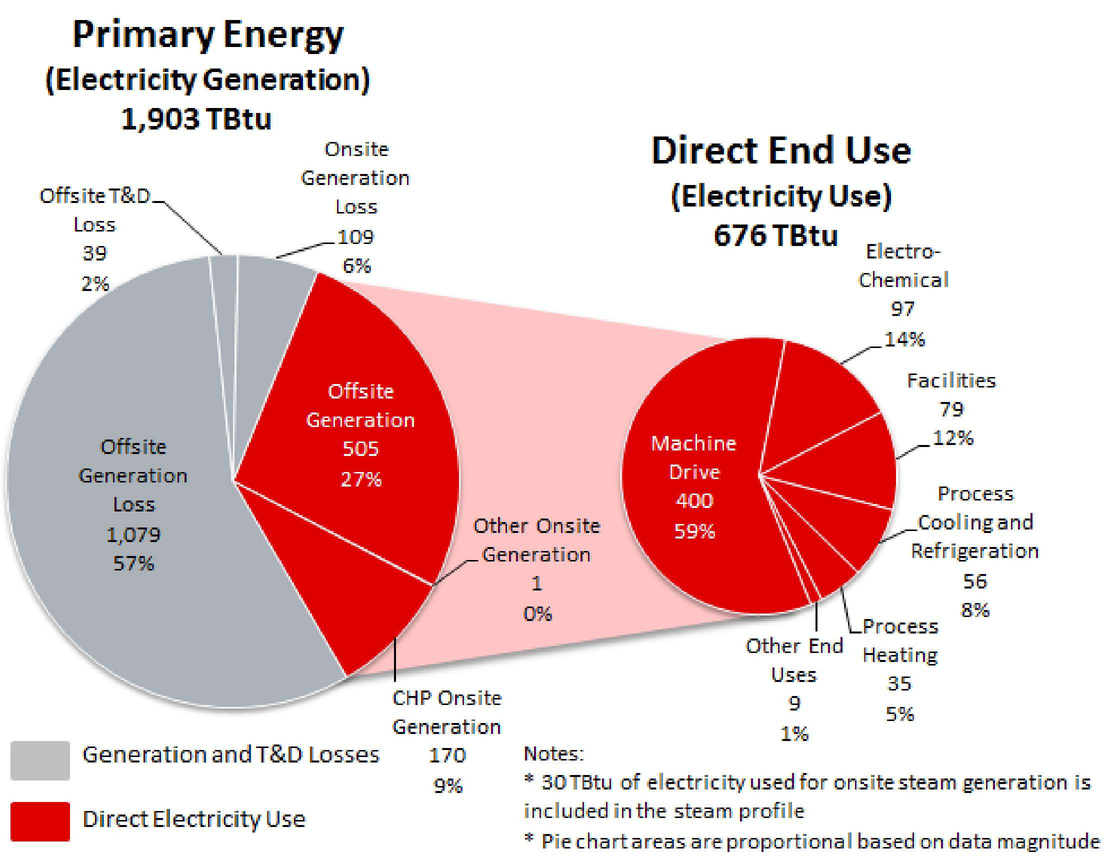

Fig. 2.2-7. Electricity generation and *direct* end use in the chemicals sector

[9] Onsite electricity generation consists of 188 TBtu of electricity from CHP units and 1 TBtu from other onsite sources; 18 TBtu of this onsite generated electricity does not end up as direct end use and is used as energy input to onsite boilers.

2.2.2.6. Steam energy

Figure 2.2-8 shows the primary energy use and losses that occur in steam generation and the *direct* end uses of steam. Steam generation is roughly evenly distributed among offsite sources, onsite CHP, and onsite conventional boilers. When taking into account steam generation, as well as transmission and distribution, efficiency ranges from a low of 51% for CHP systems to a high of 64% for conventional boilers, with offsite plants at 58%. (The low figure for CHP systems is misleading, however, because it does not capture the increased overall efficiency due to the cogeneration of steam and electricity.) The overall efficiency of steam production is 58%.

Most steam production losses occur in boilers, where thermal efficiencies range between 55%-–85%,[10] depending on the age of the boiler and type of fuel used. The chemicals sector has the largest amount of steam output from CHP units of any of the manufacturing sectors, 416 TBtu. Overall, the forest products sector has twice the CHP energy output as the chemicals sector (see Table 2.1-9); however, the proportion of steam generation is significantly lower than that of the chemicals sector.

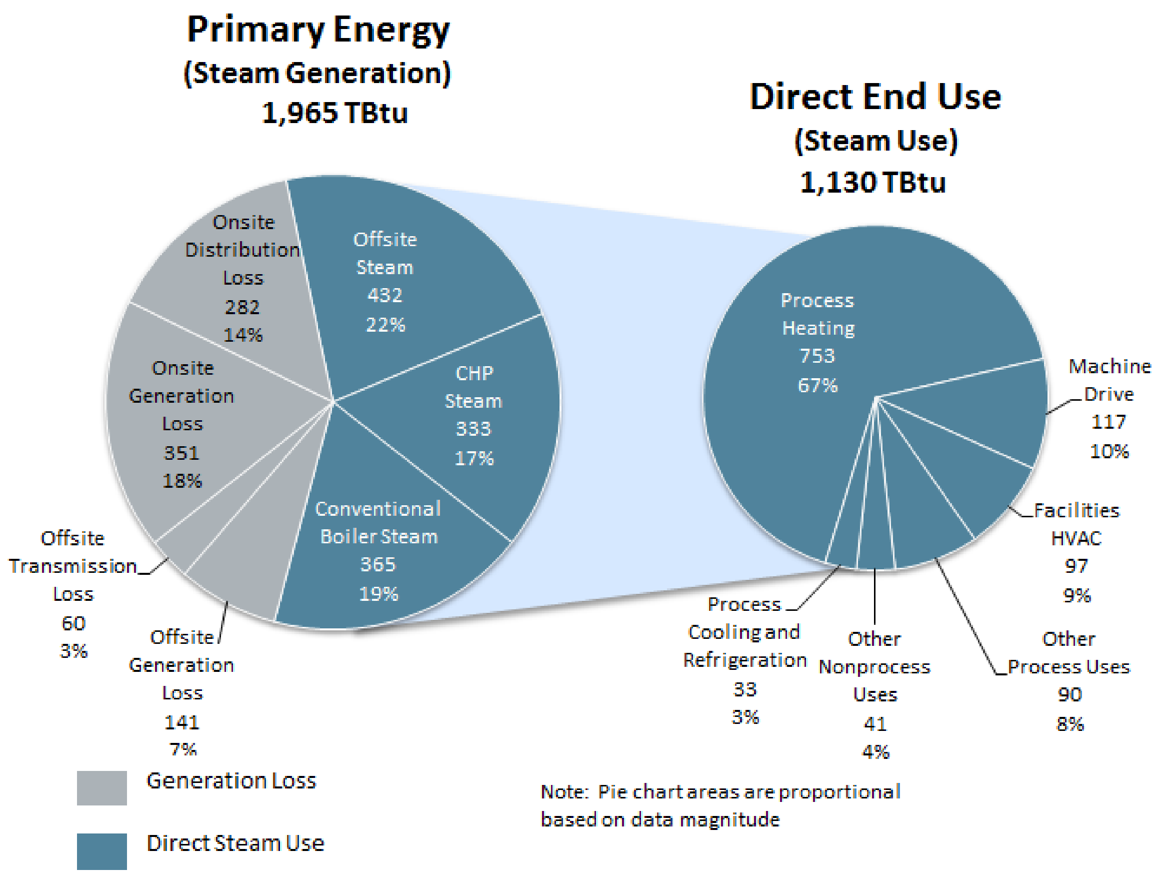

Fig. 2.2-8. Steam generation and *direct* end use in the chemicals sector

2.2.2.7. Combined heat and power energy

The chemicals sector meets a significant amount of energy demand through onsite generation, ranking first on onsite electricity generation, second in onsite steam generation, and second in CHP output across U.S. manufacturing. As shown in Fig. 2.2-9, 949 TBtu of fuel use for combined heat and power systems produces 604 TBtu of energy output, with about two-thirds in the form of steam (416 TBtu) and about one-third in the form of electricity (188 TBtu). CHP generation losses constitute 36% of CHP fuel use; CHP

[10] This report assumes 80% efficiency in boilers and 20% losses in onsite steam distribution.

efficiency estimates are referenced in Appendix D, Table D.2. Over 80% of CHP fuel use in the chemicals sector is in the form of natural gas or fuel.

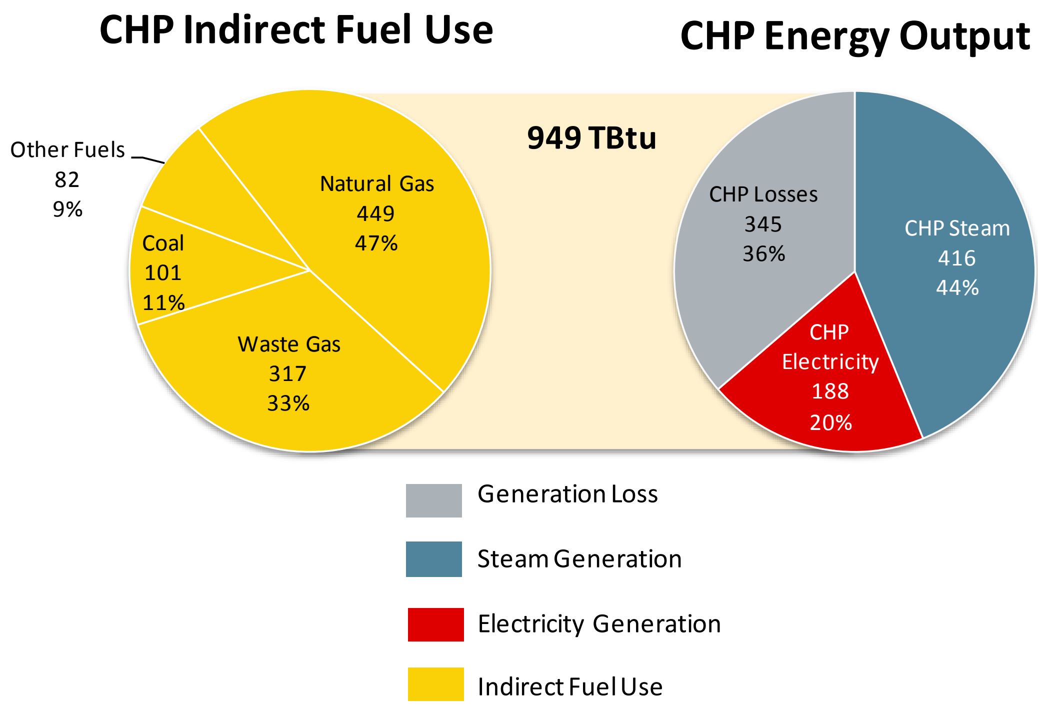

Fig. 2.2-9. CHP fuel consumption and energy output in the chemicals sector

2.2.2.8. Direct end use energy

Figure 2.2-10 shows the breakdown of primary energy by type (fuel, electricity, steam) at its *direct* end use. Steam is the most significant share of useful energy, with 25%, while electricity accounts for 15% and fuel accounts for 14% of primary energy use. The remaining 46% of primary energy is lost during steam and electricity generation and distribution.

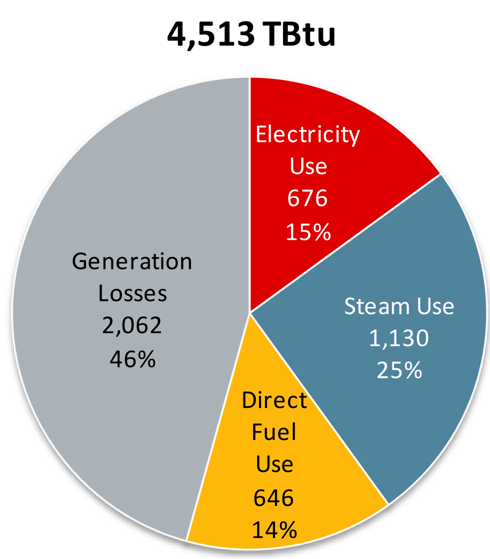

Fig. 2.2-10. Primary energy by type at *direct* end use in the chemicals sector

Direct end uses consume 54% of primary energy, primarily in process heating and machine-driven systems. Nonprocess end uses account for only 5% of *direct* end use energy. A breakdown of primary energy by all *direct* end uses is shown in Fig. 2.2-11.

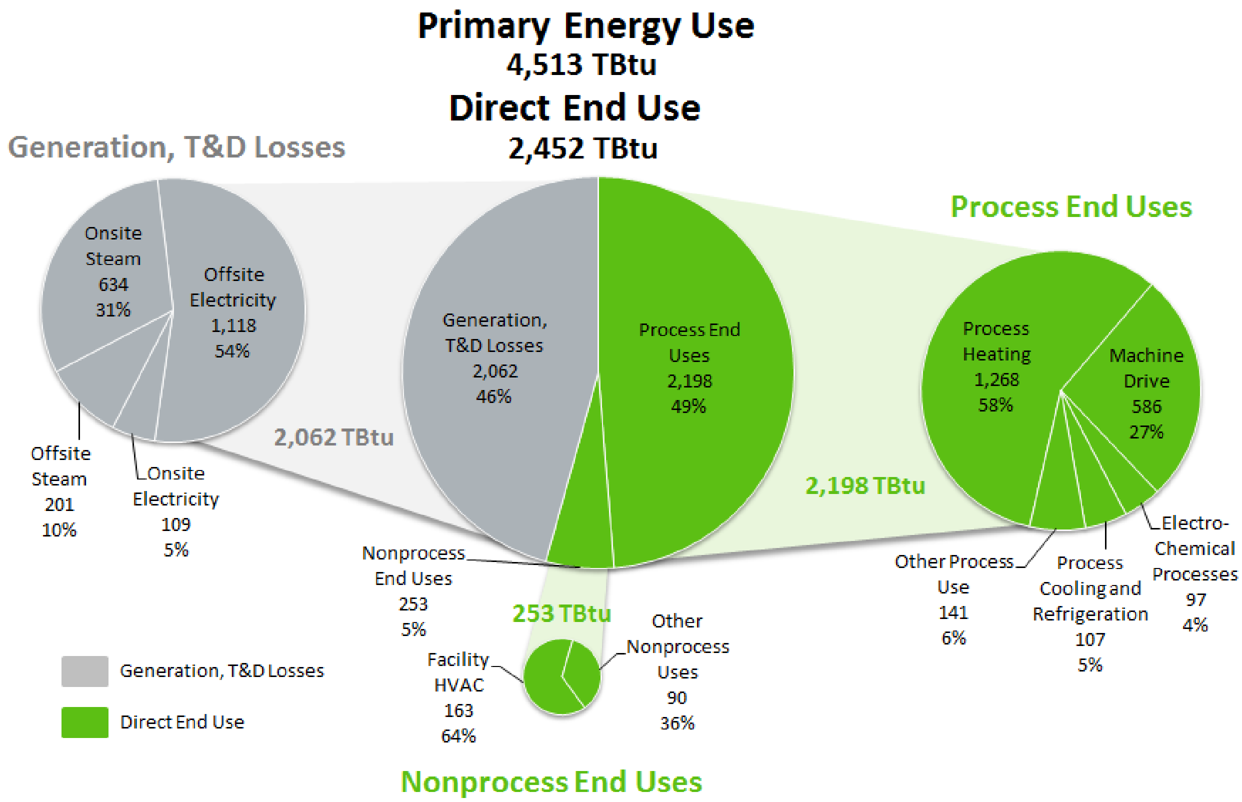

Fig. 2.2-11. Primary energy by *direct* end use in the chemicals sector

Process heating systems represent the bulk of energy use in chemicals manufacturing, consuming 58% of end use energy (28% of primary energy). These include steam-based systems and fired systems such as furnaces and reboilers. Machine-driven systems, including pumps, conveyors, compressors, fans, mixers, grinders, and other materials handling or processing equipment, rank second with 27% of end use energy (13% of primary energy). Facilities HVAC accounts for 7% of end use energy (4% of primary energy).

2.2.2.9. Applied end use energy

In addition to the energy generation losses identified above, direct end use losses have also been calculated in the energy footprint model. When both generation and end use losses are accounted for, the energy that remains is the *applied energy*. Applied energy can be illustrated by re-examining Fig. 2.2-4, which shows primary energy by energy type for chemicals manufacturing. Each of the energy types (i.e., fuel, electricity, or steam) shown in this figure have associated onsite and offsite generation losses (shown with onsite and offsite losses combined in light gray) that are incurred during energy generation (and transmission and distribution). While the majority of electricity generation losses take place offsite (shown in Fig. 2.2-7), the majority of steam generation losses are onsite (shown in Fig. 2.2-8), and direct fuel use is assumed to have no associated generation losses. After taking into account these generation losses, a further portion of the remaining energy is lost at direct end uses, due to process and nonprocess system and equipment inefficiencies, shown in dark gray. The remaining energy is applied to end uses, shown in light green as "Applied Energy" in Fig. 2.2-12.

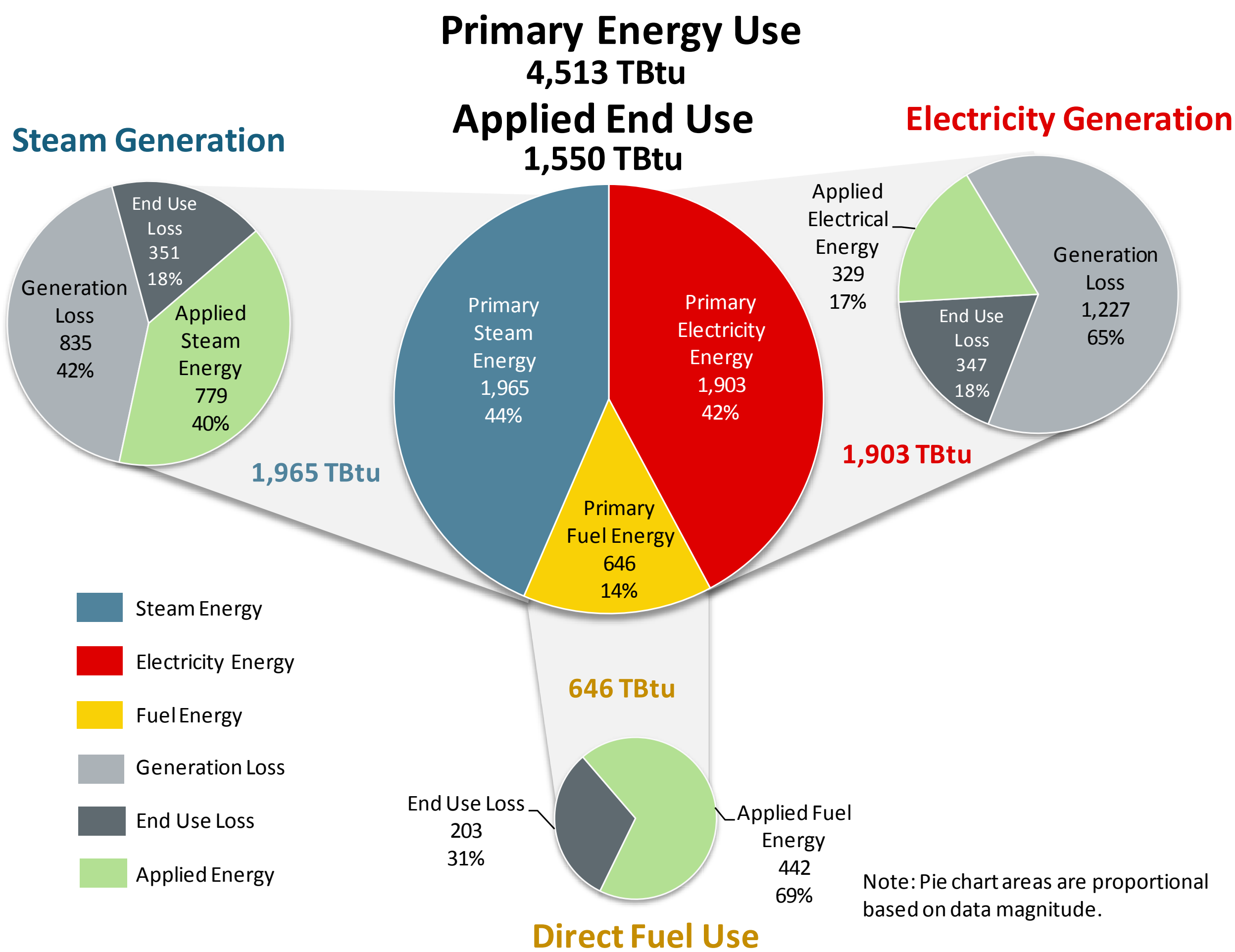

Fig. 2.2-12. Primary energy and applied energy by type in the chemicals sector

Figure 2.2-13 shows the breakdown of all primary energy by energy loss and applied energy. As for the manufacturing as a whole, 34% of primary energy input is applied to process and nonprocess end uses in the chemicals sector. Generation losses account for 46% of primary energy input and end use losses account for the remaining 20% of primary energy input.

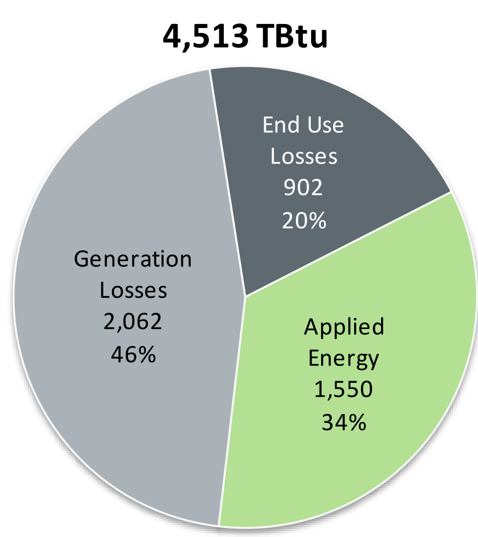

Fig. 2.2-13. Primary energy by loss and applied energy in the chemicals sector

Applied energy can also be calculated for specific end uses, as shown in Fig. 2.2-14. In this figure, generation losses are labeled as either steam or electricity losses. End use losses are labeled as process or nonprocess losses; in the case of machine drive end use, process losses are further defined as machine drive, or machine driven system losses. For process heating, 52% of primary energy is applied to the process. Process heating applied energy is relatively high compared to other end uses, because most process heating energy is consumed in the form of fuel or steam. In machine-driven systems, only 12% of primary energy is applied, primarily because of the inefficiency in electricity generation.

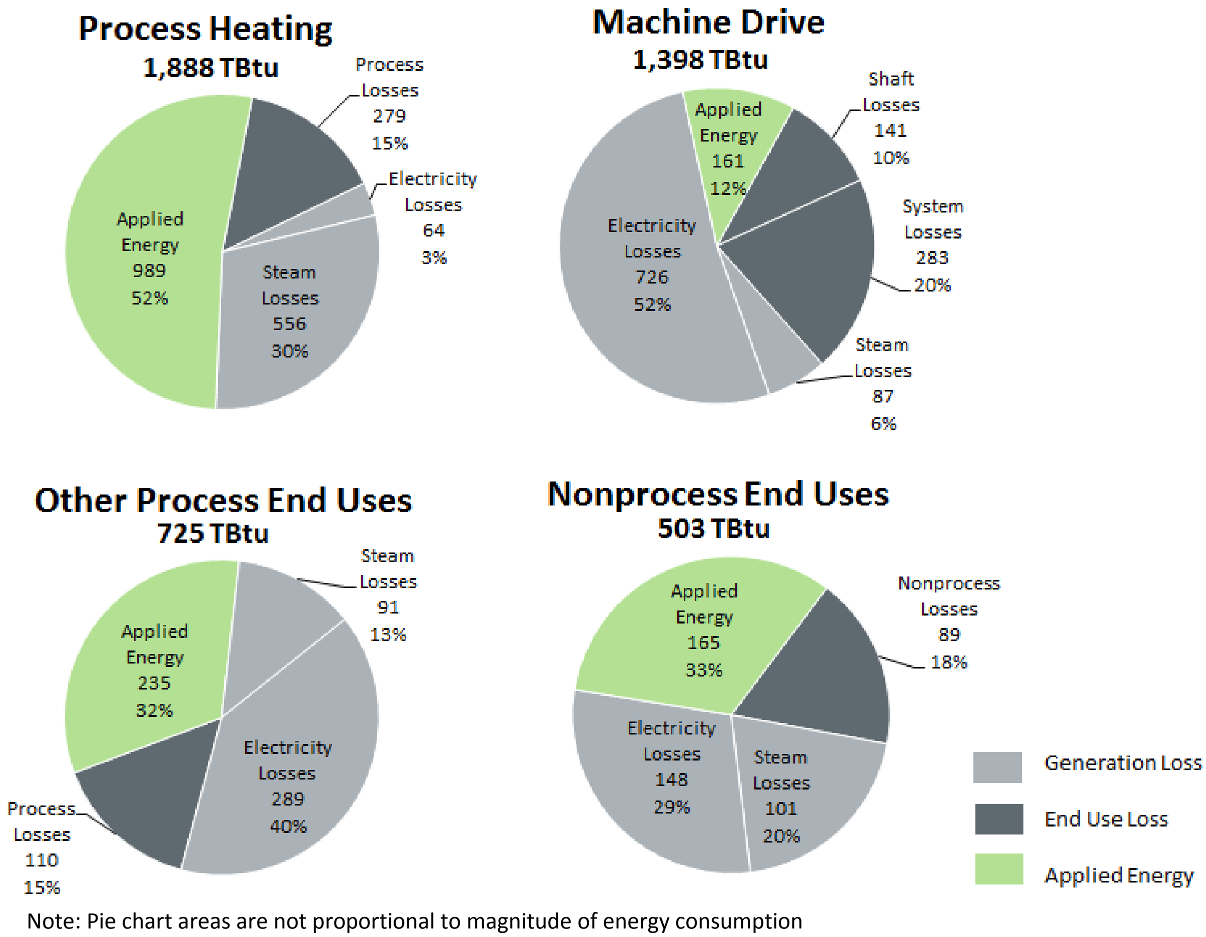

Fig. 2.2-14. Primary applied energy by *direct* end use in the chemicals sector

The machine drive, or shaft losses represent the inefficiency of converting fuel (in engines), steam (in turbines), or electricity (in motors) into rotating, kinetic energy. The machine driven system losses represent the inefficiency of applying this kinetic energy as effective work, such as compressing air in a rotary screw compressor. Machine-driven system losses total 283 TBtu and shaft losses comprise 141 TBtu, for a combined total of 424 TBtu, or 9% of primary energy.

2.2.3. Greenhouse Gas Combustion Emissions Profile for the Chemicals Sector

In 2006, GHG combustion emissions in the chemicals sector totaled 275 MMT CO_2e, contributing more emissions than any other manufacturing sector. Figure 2.2-15 shows total emissions by offsite energy supply type. Emissions released during offsite production of electricity contribute 36% of sector emissions, while 17% of emissions are attributed to the production of offsite steam. The onsite consumption of fuels (shown in yellow), including natural gas, byproduct fuels, coal, and other fuels accounts for nearly half of total emissions. These fuels are used for both direct (e.g., process or nonprocess) and indirect (e.g., fuel for CHP units or boilers) end uses. Table D.5 shows fuel GHG combustion emission factors associated with fuel combustion, as well as electricity and steam generation.

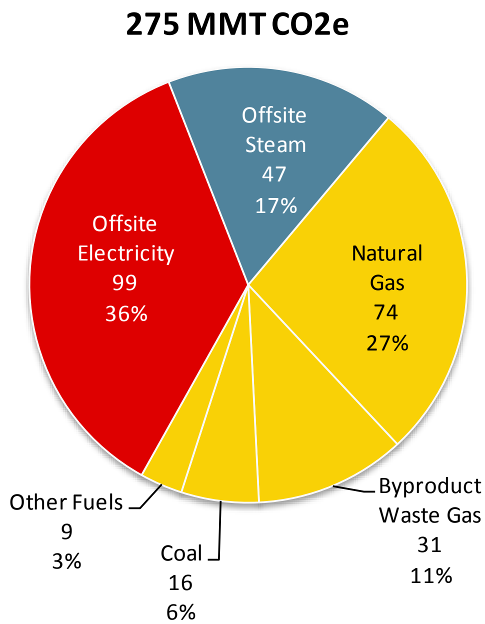

Fig. 2.2-15. Total GHG combustion emissions in the chemicals sector (shown by energy supply type)

An alternative view of emissions is shown in Fig. 2.2-16, which also shows total emissions by energy type, but this figure assigns emissions to onsite electricity and steam production (as opposed to assigning emissions strictly to offsite supplied fuels). All emissions associated with electricity production are shown in red, including emissions released during offsite electricity generation and emissions released during onsite generation of electricity. All emissions associated with steam production are shown in blue, including emissions released during offsite steam generation and emissions released to generate steam onsite in boilers and CHP systems. Lastly, all emissions associated with fuel combustion at process and nonprocess end uses are shown in yellow. Electricity generation (offsite and onsite) contributes about 43% of all emissions. Steam generation (offsite or onsite) contributes a further 44% of emissions, while the remaining 13% of emissions are released during fuel combustion for process and nonprocess end uses.

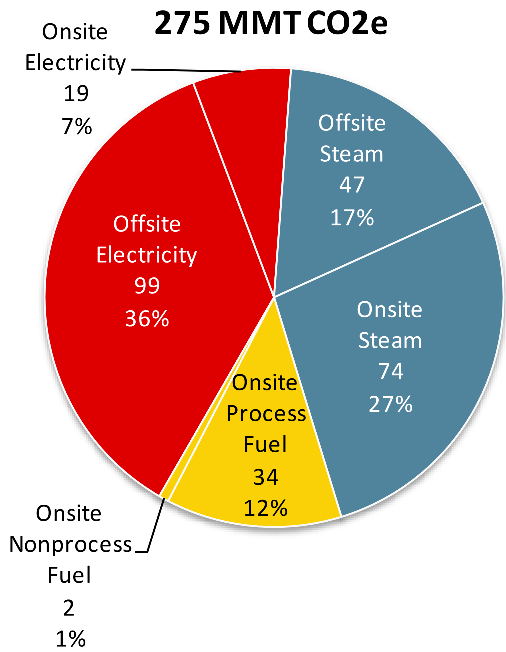

Fig. 2.2-16. Total GHG combustion emissions in the chemicals sector (shown by energy end use type)

Emissions can also be associated with the direct end uses of energy, as is shown in Fig. 2.2-17. In this figure, the emissions released from offsite both offsite and onsite electricity and steam generation are distributed to direct end uses, along with emissions resulting from fuel consumed at the direct end uses. This pie chart allows for a direct comparison of the emissions resulting from individual direct process and nonprocess end uses. Almost half of manufacturing sector end use emissions is the result of process heating applications. Machine-driven processes, which include a large proportion of offsite electricity emissions, are the next highest contributor of emissions. The emissions associated other process and nonprocess uses are also shown in the figure.

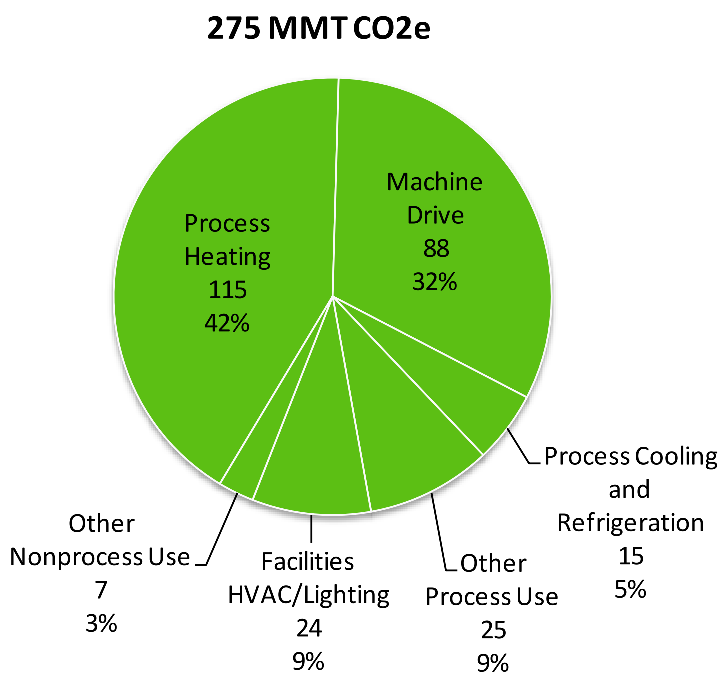

Fig. 2.2-17. Total GHG combustion emissions in the chemicals sector (shown by *direct* energy end use)

2.2.4. Energy and Emissions Profile Summary Table

The energy and emissions profiles for the chemicals sector discussed in this section are summarized in Table 2.2-3 below. Offsite and onsite contributions to energy supply, use and loss are shown separately in this table, along with GHG combustion emissions. "Applied energy" is calculated for each direct energy use area by subtracting associated offsite and onsite energy losses. For GHG combustion emissions, emissions from the point of use, whether offsite or onsite, are depicted in the first emissions column; offsite emissions are combined with onsite emissions in the total emissions columns. The values in this table correspond to the energy and carbon footprints, which show two carbon values associated with each onsite end use: at point of use and the total based on onsite use.

Table 2.2-3. Energy use, loss, and GHG combustion emissions in the chemicals sector

Chemicals			Energy (TBtu)			GHG combustion emissions (MMT CO_2e)		
			Energy use	**Energy loss**	**Applied energy**	**At point of use**	**Total based on onsite use***	**Total based on direct end use****
Offsite		Fuel supply (2,138 TBtu)	-	-	N/A	-	Distributed to onsite	Distributed to onsite direct
		Electricity generation/transmission	1,635	1,118		98.7		
		Steam generation/transmission	740	201		46.9		
		Total offsite (including fuel supply)	**4,513**	**1,318**		**145.6**		
Onsite	**Indirect**	Conventional boilers	571	114	N/A	32.6	34.9	Distributed to onsite direct
		CHP/cogeneration	949	345		60.5	60.5	
		Other electricity generation	3	2		0.2	0.2	
		Steam distribution	-	282		0.0	0.0	
		Total onsite generation	**1,523**	**743**		**93.3**	**95.6**	
	Direct	Process heating	1,268	279	989	27.0	63.0	115.0
		Process cooling and refrigeration	107	37	69	0.9	10.7	14.5
		Machine drive	586	424	161	3.7	69.3	88.5
		Electro-chemical	97	58	39	0.0	9.4	12.1
		Other process uses	141	14	127	2.5	7.1	13.4
		Nonprocess energy	253	89	165	1.9	19.8	31.4
		Total process and nonprocess	**2,452**	**902**	**1,550**	**35.9**	**179.3**	**274.8**

* These values are referenced as "Total" emissions in the footprints, Total emissions = onsite emissions + offsite emissions (i.e., emissions associated with offsite generation are distributed to indirect and direct onsite end uses)
** These values represent direct end use carbon emissions only (i.e., emissions associated with offsite and onsite generation are distributed to direct (and final) end use)