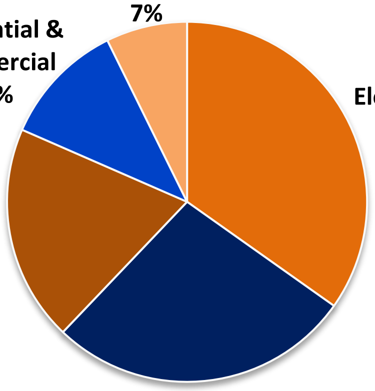
Industrial Emissions in the United States

Greenhouse gas (GHG) emissions data can be reported either by economic sector, which includes electric power generation as a separate sector, or by end-use sector, which distributes the emissions from electricity generation across the economic sectors where the electricity is used. The industrial sector encompasses a wide range of activities, including all facilities and equipment used for producing, processing, or assembling goods.[1] GHG emissions are produced from diverse processes, including the combustion of fossil fuels for heat and power, the non-energy use of fossil fuels, and numerous industrial processes. The industrial sector is a large consumer of electricity, so it is appropriate to address both emissions from direct sources and electricity end use for this sector.

Direct emissions

Direct emissions from the industrial sector account for 19 percent of total GHG emissions in the United States (see Figure 1).

Figure 1: U.S. Greenhouse Gas Emissions by Economic Sector (2008)

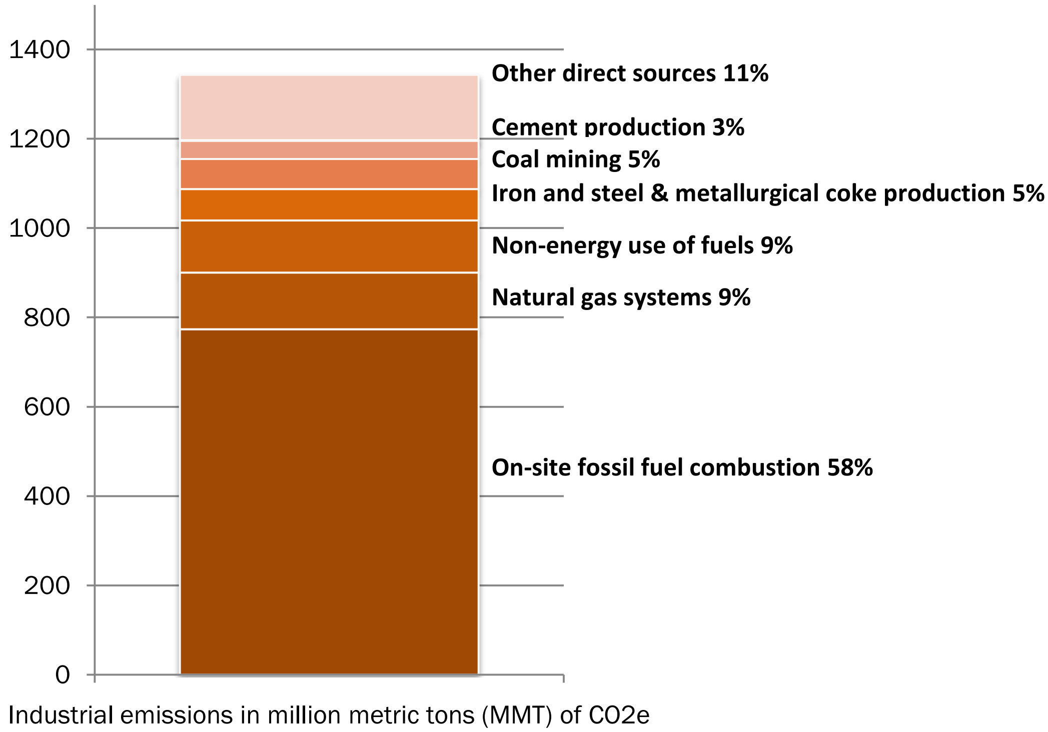


Source: Environmental Protection Agency (EPA), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008,* Table ES-7, 2010. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Direct emissions from the industrial sector come from both the on-site combustion of fossil fuels (54 percent of direct emissions) and from certain non-energy-related industrial production processes (46 percent of direct emissions)[2]. For example, heating iron ore to produce iron directly releases carbon dioxide (CO_2). Similarly, the cement manufacturing process requires heating limestone, which also results in the release of CO_2.

Figure 2 shows the main sources of direct industrial emissions in the United States, including the following sources of process emissions: natural gas production and refining (9 percent), the non-energy use of fuels (9 percent), iron and steel production and metallurgical coke production (5 percent), coal mining (5 percent), cement production (3 percent), and a variety of other sources (11 percent).[3] Industrial process emissions, which include all direct emissions except on-site fossil fuel combustion, account for 5 percent of total U.S. GHG emissions.

Figure 2: Direct Emissions of Greenhouse Gases from the U.S. Industrial Sector (2008)[4]



Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, Table 2-14, 20010. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Industrial process emissions include numerous GHGs, including several gases with high global warming potentials, like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Global warming potential (GWP) is a metric used to compare the warming effects of different gases. Over a 100-year time horizon, carbon dioxide (CO_2) is assumed to have a GWP of one. In comparison, SF_6 has a GWP of 23,900, which means that over 100 years one ton of SF_6 will have the same effect as 23,900 tons of CO_2 (see Table 1).[5]

The industrial sector emits more non-CO_2 gases than any other end-use sector and is responsible for 71 percent of U.S. methane (CH_4) emissions and 59 percent of non-CO_2 and non-CH_4 emissions.[6]

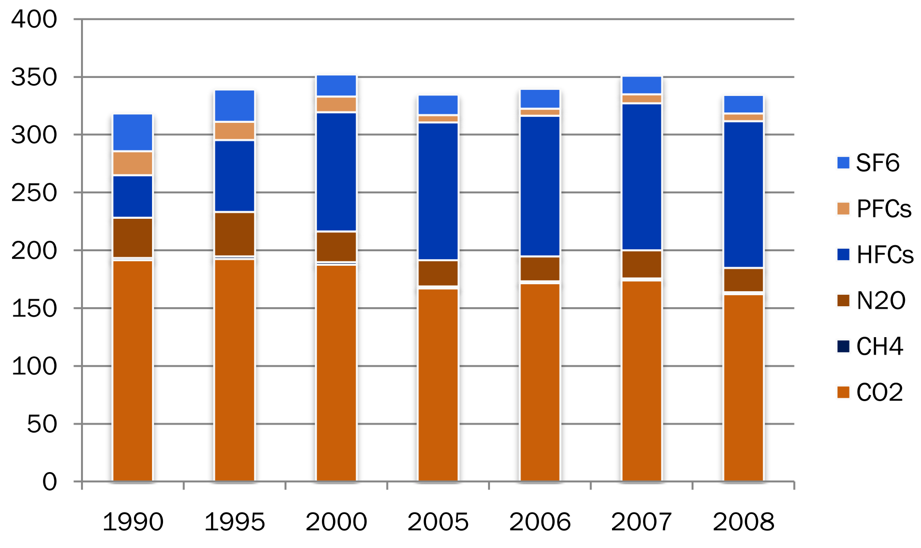
Table 1: Global Warming Potentials for 100-year Time Horizon

Gas		GWP
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbons (HFCs)	HFC-23 HFC- 32 HFC-125 HFC-134a HFC-143a HFC-152a HFC-227ea HFS-236fa HFC-4310mee	11,700 650 2,800 1,300 3,800 140 2,900 6,300 1,300
Perfluorocarbons (PFCs)	CF_4 C_2F_6 C_4F_{10} C_6F_{14}	6,500 9,200 7,000 7,400
Sulfur hexafluoride	SF_6	23,900

Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, Table ES-1, 2010.
http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Between 1990 and 2008, total industrial process emissions increased more than 9 percent even though several individual GHGs decreased during this time period (see Figure 3).[7]

Figure 3: Industrial Process Emissions by Greenhouse Gas Type in Million Metric Tons (MMT) of CO_2e[8]



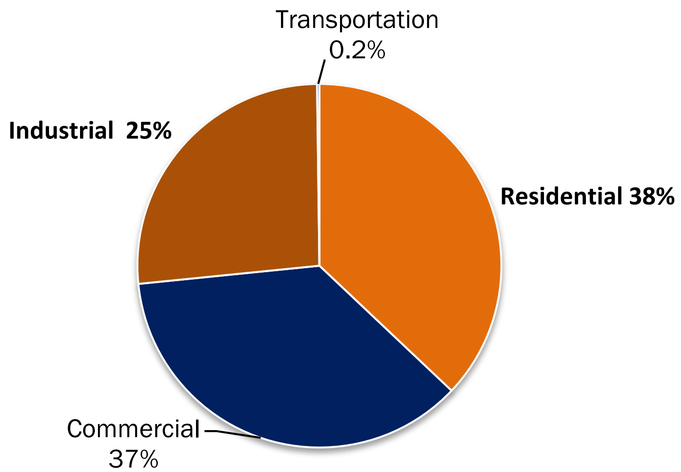
Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, Table 2-6, 2010.
http://www.epa.gov/climatechange/emissions/usinventoryreport.html

Two trends in the industrial sector account for most of the rise in industrial process emissions: increased emissions from the cement industry and the emission of HFCs as substitutes for substances that deplete the ozone layer, such as chlorofluorocarbons (CFCs).

End-use emissions

U.S. electricity sales are split among the residential, commercial, and industrial sectors, with the industrial sector accounting for 25 percent of sales (see Figure 4).

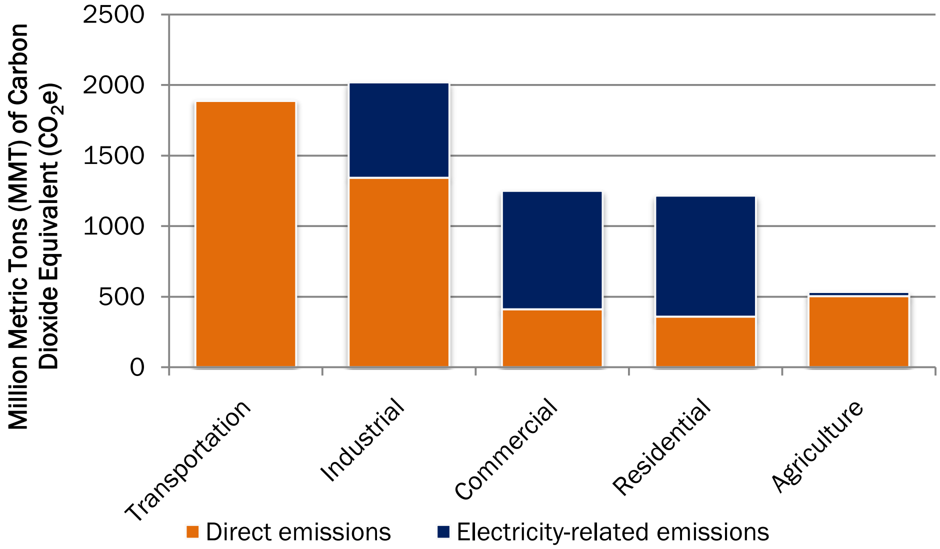
Figure 4: Retail Sales of Electricity to Ultimate Customers, Total by End-Use Sector (2009)[9]



Source: U.S. Energy Information Administration (EIA), *Electric Power Monthly*, Table 5.1, 11 March 2011. http://www.eia.doe.gov/cneaf/electricity/epm/table5_1.html

When GHG emissions from electricity generation are distributed across the end-use sectors, the industrial sector is the largest source of GHG emissions, responsible for 27 percent of total U.S. emissions (see Figure 5). Emissions from the use of electricity generated off-site ("electricity-related emissions" in the graph below) are also called *indirect emissions* to distinguish them from the direct emissions released on site.

Figure 5: Direct and Electricity-related Emissions by End-Use Sector (2008)



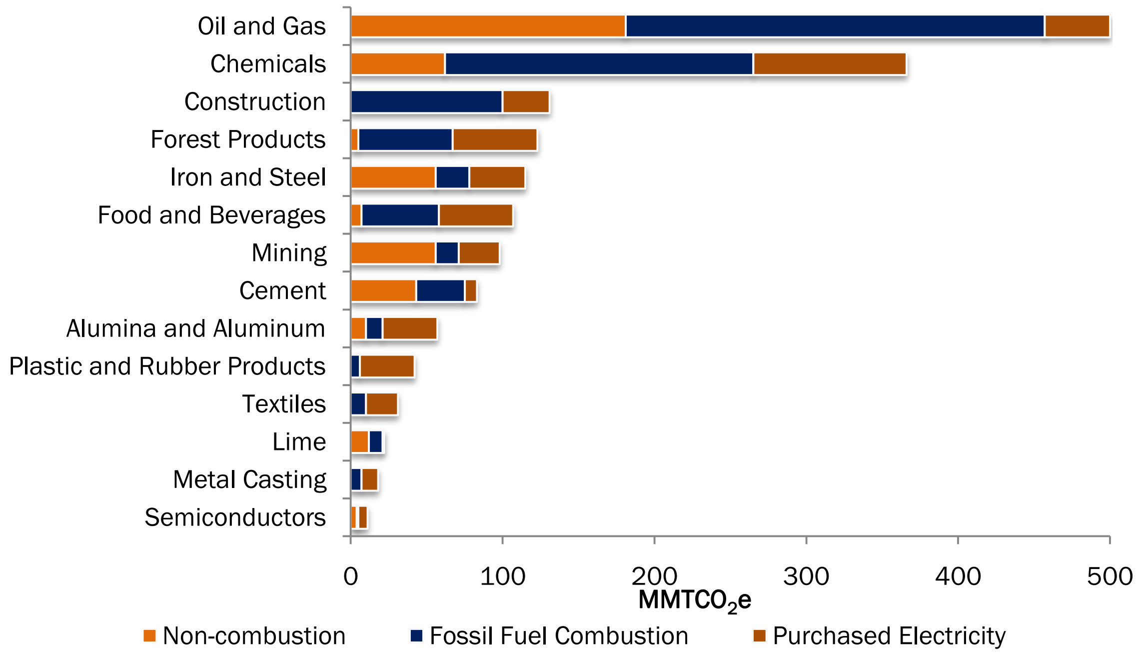
Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, Table 2-14, 2010. http://epa.gov/climatechange/emissions/usinventoryreport.html

Relative to the residential and commercial sectors, a smaller percentage of the industrial sector's GHG emissions come from electricity use. The industrial sector relies less on purchased electricity in part because of the on-site production of heat and power, also known as cogeneration or combined heat and power (CHP).

Industrial Emission Sources and Types

The industrial sector encompasses a diverse collection of industries that have very different energy and feedstock needs to produce products that range from paper to gasoline to pharmaceuticals. While GHG emissions from the electricity sector depend largely on the type of fuel used, and emissions from the residential and commercial sectors come largely from buildings, similar generalizations cannot be made about the industrial sector. Examining industrial emissions on an industry-by-industry basis shows that the magnitude of emissions associated with different industries varies significantly (see Figure 6).

Figure 6: GHG Emissions for Key Industrial Sub-sectors in Million Metric Tons (MMT) of CO_2e (2002)



Source: EPA, *Quantifying Greenhouse Gas Emissions from Key Industrial Sectors in the United States*, Working Draft, Table 1-3, 2008. http://www.epa.gov/ispd/

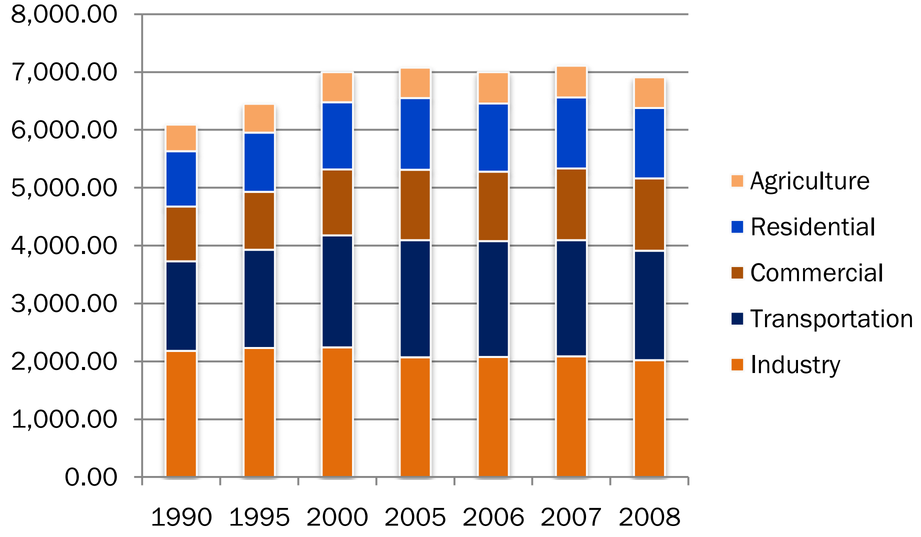
Figure 6 also shows the relative importance of different types of emissions to individual industries. For example, five industries (oil and gas, chemicals, iron and steel, mining, and cement) produce the majority of non-combustion-related direct emissions. Similarly, oil and gas, chemicals, construction, forest products, and food and beverages produce large amounts of GHG emissions from on-site fossil fuel combustion.

Certain industries are termed *energy-intensive* because they require large energy inputs per unit of output or activity. The largest energy-consuming industries in the United States are bulk chemicals, oil and gas, steel, paper, and food products; these five industries account for 60 percent of industrial energy use, but only 22 percent of the value of the products. Other energy-intensive industries include glass, cement, and aluminum. In general, energy-intensive industries are growing more slowly in the United States than industries with lower energy intensities.[10]

Historical Trends

Total industrial emissions in the United States have gradually declined over the past decade in both absolute and relative terms (see Figure 7). From 1990 to 2008 U.S. industrial output increased by 56 percent, while CO_2 emissions from industrial processes decreased by over 9 percent. Several factors have contributed to this reduction, including fuel switching, increased efficiency, and changes to the U.S. economy from a more manufacturing-based to a more service-based economy and from more energy-intensive industries to less energy-intensive industries. Over time, the proportion of industrial GHG emissions from electricity use has increased, while the proportion of GHGs from direct emissions has decreased.[11]

Figure 7: GHG Emissions by End-Use Sector in Million Metric Tons (MMT) of CO_2e



Source: EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008*, Table 2-14, 2010. http://www.epa.gov/climatechange/emissions/usinventoryreport.html

The industrial sector is the largest end-user of energy in the United States. Since 1970, total energy consumption has increased across all end-use sectors, but the growth rate has been slowest in the industrial sector.[12] This is due to three primary factors: a shift away from manufacturing and towards a more service-oriented economy; a move towards less energy-intensive manufacturing, and energy efficiency in the industrial sector.[13]

Global Context

At the global level, the industrial sector is a key energy consumer and GHG producer. Manufacturing industries account for nearly a third of total energy consumption and 37 percent of CO_2 emissions from energy use.[14] At the global level, data on non-CO_2 gases and non-combustion CO_2 emissions have higher levels of uncertainty.[15] A small number of industries account for a large percentage of global industrial emissions. In 2007, five industries (chemicals and petrochemicals, iron and steel, non-metallic minerals, pulp and paper, and non-ferrous metals) accounted for 50 percent of total industrial energy use.[16]

Trends in global industrial energy use and emissions include:

- Overall industrial energy use increased between 1971 and 2004, with demand growing especially rapidly in emerging economies.
- Energy efficiency in energy-intensive manufacturing industries has increased, with Japan and Korea generally achieving the highest levels of energy efficiency.
- Cost-effective GHG mitigation opportunities exist for the industrial sector but are currently under-utilized in both developed and developing countries. The adoption of best practice commercial

technologies by manufacturing industries could reduce industrial sector CO_2 emissions by 19-32 percent annually by, for example, improving the efficiency of motor systems.[17]

- Since 1970, several energy-intensive industries have seen significant growth. For example, production of steel increased 84 percent; paper, 180 percent; ammonia, 200 percent; aluminum 223 percent; and cement, 271 percent.[18]
- Developed economies usually have a more energy-efficient industrial sector, and a larger fraction of their output comes from non-energy-intensive sectors than is the case for developing economies. On average, industrial energy intensity, which is the industrial sector's energy consumption per dollar of economic output, is double in developing countries. Energy-intensive manufacturing industries are growing in many developing countries. Industrial energy use frequently accounts for a larger portion of total energy consumption in these countries; for example, an estimated 75 percent of delivered energy in China was used by the industrial sector in 2007.[19]
- In 2007 the industrial sector comprised 51 percent of global energy use, and is projected to grow at an annual rate of 1.3 percent.[20]

Industrial Sector Mitigation Opportunities

The diverse opportunities for reducing GHG emissions from the industrial sector can be broken down into three broad categories:[21]

- **Sector-wide options**

  Some mitigation options can be used across many different industries, for example energy efficiency improvements for cross-cutting technologies, such as electric motor systems, can yield benefits across diverse sub-sectors. Other sector-wide mitigation options include the use of fuel switching, combined heat and power, renewable energy sources, more efficient electricity use, more efficient use of materials and materials recycling, and carbon capture and storage.

- **Process-specific options**

  Certain mitigation opportunities come from improvements to specific processes and are not applicable across the entire sector. For energy-intensive industries, process improvements can reduce energy demand and, therefore, GHG emissions and energy costs. Other improvements can reduce emissions of non-CO2 gases with high global warming potentials.

  Case studies can help illuminate the effectiveness of these process-specific options. For example, Alcoa's aluminum smelters collectively reduced their emissions of perfluorocarbons (PFCs) from anode effects, which occur when a particular step in the smelting process is interrupted, by more than 1.1 million tons in 2008.22

- **Operating procedures**

  A variety of mitigation opportunities can be achieved through improvements to standard operating procedures. These options can include making optimal use of currently available technologies, such as improving insulation and reducing air leaks in furnaces.

A variety of public and private efforts have been developed to help reduce industrial GHG emissions, energy use, or energy intensity. Some of these programs include:

- Climate Leaders – U.S. Environmental Protection Agency (EPA)
- Partnership between industry and government to develop comprehensive climate change strategies. http://www.epa.gov/stateply/
- Climate VISION – Interagency program, including U.S. Department of Energy (DOE), U.S. EPA, U.S. Department of Transportation, and U.S. Department of Agriculture
- Voluntary program to reduce U.S. GHG emissions intensity. http://climatevision.gov/
- ENERGY STAR® for Industry – U.S. EPA
- Program to improve corporate energy management. http://www.energystar.gov/index.cfm?c=industry.bus_industry
- Save Energy Now – U.S. DOE, Industrial Technologies Program
- Program to achieve the goal of reducing industrial energy intensity 25 percent by 2017, per the *Energy Policy Act of 2005*. http://www1.eere.energy.gov/industry/saveenergynow/
- Voluntary Programs to Reduce High Global Warming Potential Gases – U.S. EPA
- A variety of programs to reduce gases with high global warming potentials, including perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6). http://www.epa.gov/highgwp/voluntary.html

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[1] U.S. Energy Information Administration (EIA). *Glossary*. http://www.eia.doe.gov/glossary/glossary_i.htm. Accessed 4 May 2007.

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

[3] U.S. EPA, 2010

[4] One million metric ton is equal to one teragram. For reference, one million metric ton of CO_2e is equal to 280,000 new cars each being driven 12,500 miles or 90 minutes of U.S. energy consumption or 1 day of U.S. energy emissions from lighting buildings, see U.S. Department of Energy (DOE), *2009 Buildings Energy Data Book*. Prepared for U.S. Department of Energy Office of Energy Efficiency and Renewable Energy by D&R International, Ltd. Silver Spring, MD. 2009. http://buildingsdatabook.eren.doe.gov

[5] Global warming potential is a system of multipliers devised to enable warming effects of different gases to be compared. The cumulative warming effect, over a specified time period, of an emission of a mass unit of CO_2 is assigned the value of 1. Effects of emissions of a mass unit of non-CO_2 greenhouse gases are estimated as multiples. For example, over the next 100 years, a gram of methane (CH_4) in the atmosphere is currently estimated as having 23 times the warming effect as a gram of carbon dioxide; methane's 100-year GWP is thus 23. Estimates of GWP vary depending on the time-scale considered (e.g., 20-, 50-, or 100-year GWP) because the effects of some GHGs are more persistent than others.

[6] EIA, *Distribution of Total U.S. Greenhouse Gas Emissions by End-Use Sector, 2008*. December 2009. http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/enduse_tbl.pdf

[7] EPA, 2010

[8] Carbon dioxide equivalent (CO_2e) is a unit used to measure the emissions of a gas, by weight, multiplied by its global warming potential.

[9] This figure excludes commercial and industrial facility use of onsite net electricity generation, which was roughly 4 percent of net electricity generation in 2007.

[10] EIA, *Annual Energy Outlook 20010*. May 2010. http://www.eia.doe.gov/oiaf/aeo/demand.html

[11] U.S. EPA, 2010

[12] U.S Environmental Protection Agency, *Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes.* 2007. http://www.epa.gov/sectors/pdf/energy/ch2.pdf

[13] Department of Energy. *Industrial Total Energy Consumption.* April 14, 2008. http://www1.eere.energy.gov/ba/pba/intensityindicators/total_industrial.html

[14] Intergovernmental Panel on Climate Change (IPCC), "Industry." In *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report. Cambridge: Cambridge University Press, 2007. http://www.ipcc.ch/ipccreports/ar4-wg3.htm

[15] IPCC, 2007.

[16] EIA, *International Energy Outlook 2010*. July 2010. http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2010).pdf

[17] IPCC, 2007.

[18] Ibid.

[19] EIA, July 2010.

[20] Ibid.

[21] IPCC, 2007.

[22] Alcoa, "Alcoa Smelters Meet Challenge to Reduce Greenhouse Gas Emissions by One Million Tons Annually," http://www.alcoa.com/global/en/about_alcoa/sustainability/case_studies/2009/case_ghg_million_ton.asp. Accessed 6 May 2009.