DECARBONIZING U.S. INDUSTRY

C2ES CLIMATE INNOVATION 2050

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This brief provides an overview of emissions trends and projections, and of decarbonization challenges and opportunities, in the industrial sector. Key points include:

- While greenhouse gas emissions from the industrial sector have declined over the last 20 years, they are projected to increase through mid-century, fueled by low prices for energy, particularly natural gas and natural gas liquids.
- Direct emissions from a wide range of sources account for more than 73 percent of the sector's total emissions. Indirect emissions from the use of electricity generated off-site account for the rest. On-site fossil fuel combustion is the largest source of industrial emissions.
- Energy-related carbon dioxide (CO_2) emissions (from both on-site fossil fuel combustion and off-site electricity) account for around three-quarters of the sector's total greenhouse gas emissions. In 2016, bulk chemicals, refining, and iron and steel production were responsible for nearly half of the sector's total energy-related CO_2 emissions.
- Options for reducing emissions in the industrial sector include: improved energy efficiency, developing and deploying new manufacturing techniques, switching to lower-emitting fuels, combined heat and power, carbon capture and storage, and more efficient use of resources.

OVERVIEW

The industrial sector encompasses a wide range of sub-sectors including manufacturing (e.g., steel, cement, chemicals), mining, and construction.[1] Manufacturing, construction and non-oil and gas mining contributed more than $3 trillion in GDP in 2016[2] and employed nearly 20 million people.[3]

The United States' five largest energy-consuming industries—bulk chemicals,[4] oil and gas, steel, paper, and food products—account for 56.5 percent of industrial energy use, but only 20.8 percent of product value. Other energy-intensive industries include glass, cement, and aluminum.

Industrial sector emissions have been declining since the mid-1990s, driven by the adoption of new, less carbon-intensive processes, fuel switching (e.g., coal to natural gas and renewables), increased efficiency, a shift in metal production to other countries, and the United States' continued transition from a manufacturing to a

more service-oriented economy and from more energy-intensive to less energy-intensive industries.

In general, energy-intensive industries are growing more slowly in the United States than industries with lower energy intensities.[5] However, sustained investments in the U.S. chemicals industry are expected to continue the strong growth in domestic bulk chemical production.[6]

EMISSION TRENDS AND PROJECTIONS

In 2015, *direct* emissions from the industrial sector represented 21.4 percent of total U.S. greenhouse gas emissions. Direct emissions come from diverse sources and accounted for roughly three-quarters of the sector's total emissions. On-site combustion of fossil fuels for heat and power made up 53.7 percent of the sector's direct emissions for 2015, while various industrial processes were responsible for 16.6 percent. Direct emissions from industry make the sector the third-largest source of greenhouse gases (after transportation and electric power) in the United States.

Indirect emission from the use of electricity generated off-site account for the rest of the sector's emissions. Including its direct and indirect emissions, industry is the largest greenhouse gas-emitting sector in the United States, accounting for nearly 30 percent of total U.S. emissions.

Sub-sector emissions profiles vary widely. According to the Energy Information Administration's (EIA) 2018 *Annual Energy Outlook* (AEO), bulk chemicals, refining and iron and steel production were the three largest sources of energy-related carbon dioxide emissions, which account for around three-quarters of the sector's total (direct and indirect) emissions (**Figure 1**).[7]

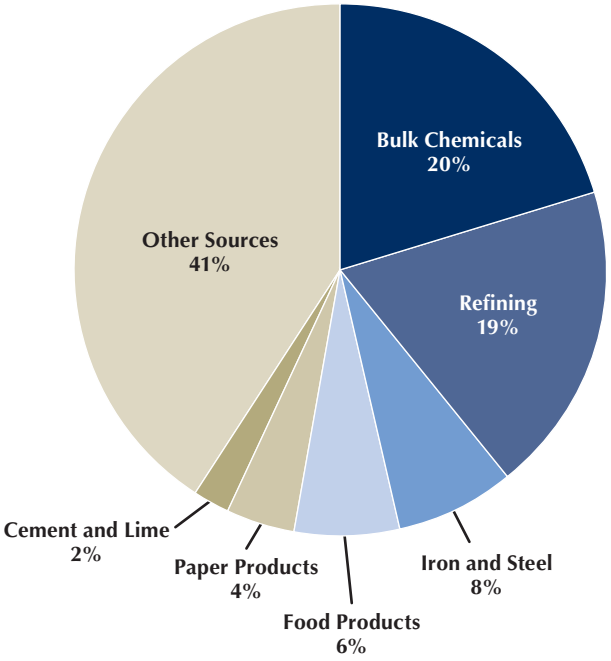
In addition to CO_2, industry accounts for 25 percent of total U.S. non-CO_2 greenhouse gas emissions, including 41 percent of methane, 7 percent of nitrous oxide, and 20 percent of other greenhouse gas (e.g., hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride) emissions.[8]

From 1996 to 2015, industry emissions declined about 18.7 percent, including a 15.1 percent decline in direct emissions and a 27 percent decline in indirect emissions from off-site electricity) as shown in **Figure 2**. While total emissions have been fairly flat since 2010, the share of direct emissions has been increasing.

From 1990 to 2015, direct emissions from industrial processes and product use increased by about 10.5 percent, driven primarily by a 270 percent increase in emissions of HFCs, which are substitutes for ozone-depleting substances.[9] Emissions from cement production increased 19.1 percent during this period due to increased production, primarily driven by increased construction activity. Emissions have also increased in semiconductor manufacturing, titanium dioxide production, and petrochemical production.

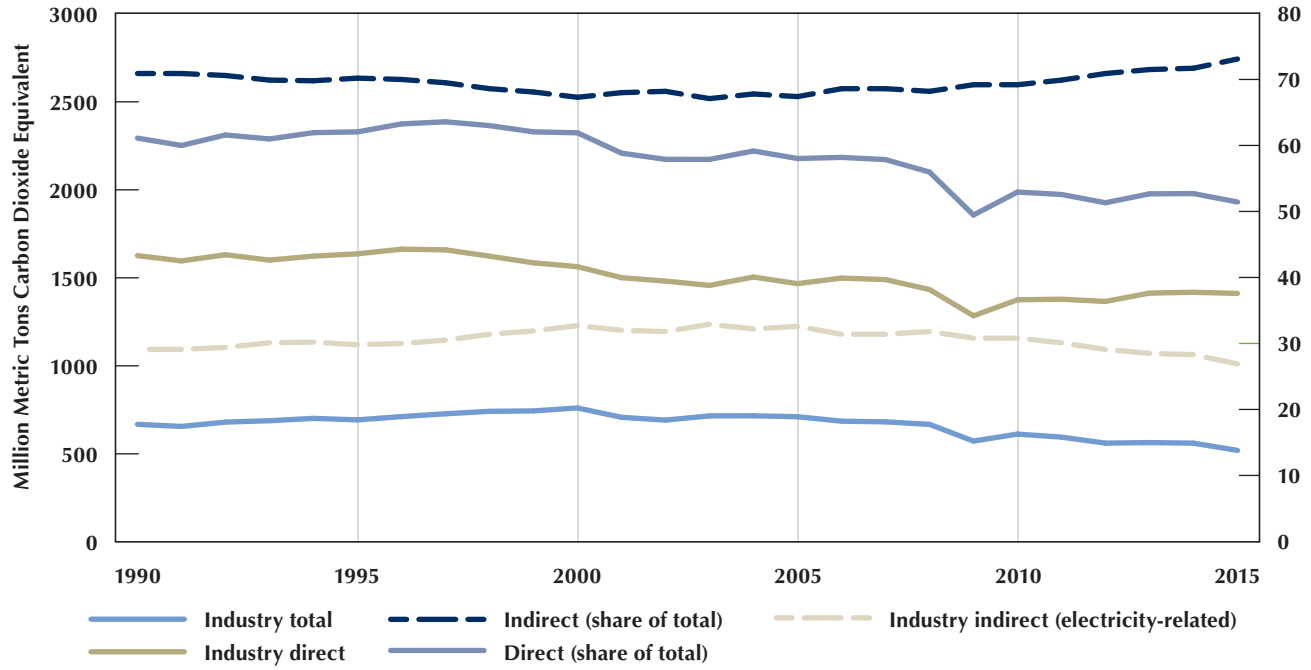
Projections of future emissions focus primarily on energy-related CO_2, which currently represents roughly three-quarters of total industry emissions. The EIA projects total delivered energy consumption in the

FIGURE 1: Energy-Related CO_2 Emissions from Industry (2016)



Source: U.S. Energy Information Administration, Annual Energy Outlook 2018 (Washington, DC: U.S. Department of Energy, 2018), Table 19 Energy-Related Carbon Dioxide Emissions by End Use, https://www.eia.gov/outlooks/aeo.

FIGURE 2: Direct and Indirect Industrial Sector Emissions



Source: U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015 (Washington, DC: U.S. Environmental Protection Agency, 2017), U.S. Greenhouse Gas Emissions Allocated to Economic Sectors, Table 2-12, https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.

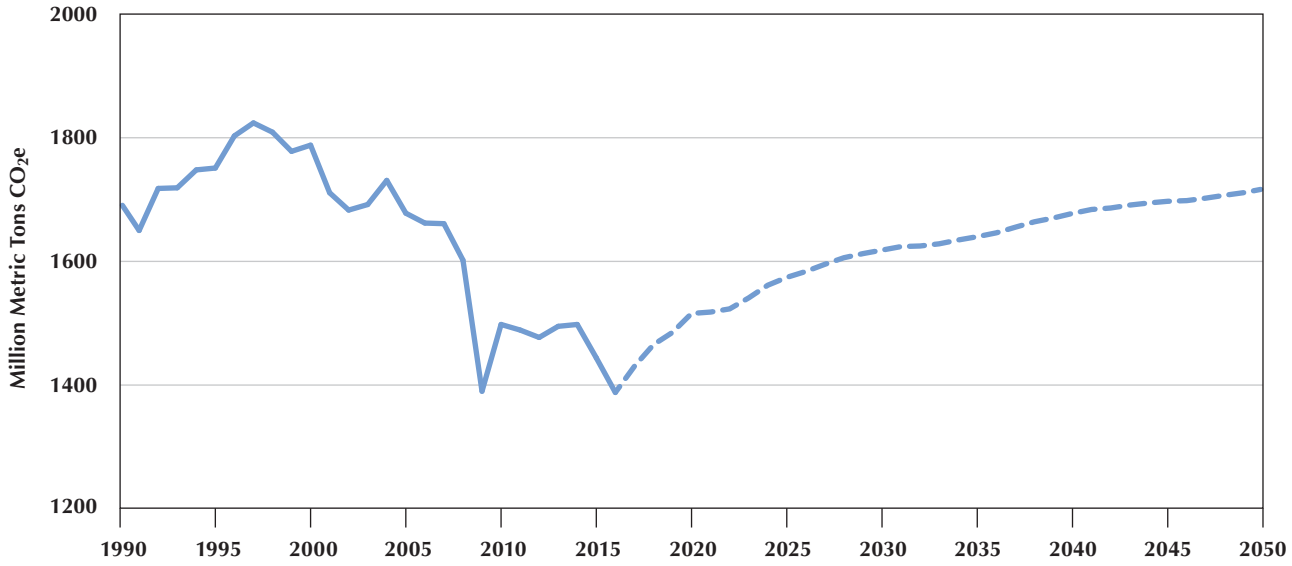
industrial sector will grow about 33.7 percent from 2017 to 2050, driven primarily by economic growth and relatively low energy prices.

Having fallen through 2010, and remained flat through 2015, the sector's energy-related CO_2 emissions are now projected to increase 17.6 percent through mid-century, fueled by low prices for energy, particularly natural gas and natural gas liquids (**Figure 3**).[10] The six largest sources of manufacturing emissions are expected to continue to be bulk chemicals, refining, iron and steel, food products, paper products, and cement and lime production. In absolute terms, emissions from bulk chemical manufacturing are forecast to increase the most, 126.7 $MMtCO_2$ or 45 percent.[11] Other manufacturing areas expected to see increases are food products (41.4 percent), fabricated metal products (37.1 percent), plastics (27.8 percent), aluminum (23.9 percent), and transportation equipment (20.3 percent). These six categories account for 60 percent of projected increases in energy-related CO_2 emissions from industry.

DECARBONIZATION OPPORTUNITIES AND CHALLENGES

Decarbonizing the industrial sector is generally considered more technically challenging than in the building and transportation sectors, as it concerns emissions not only from heat and power but also from products and processes. Potential pathways toward substantially reducing the sector's GHG emissions include: improved energy efficiency; fuel switching; carbon capture, utilization, and storage (CCUS); and process changes.

FIGURE 3: Industry energy-related carbon dioxide emissions, 1990–2050



Source: U.S. Energy Information Administration, Monthly Energy Review February 2018, DOE/EIA-0035(2018/02) (Washington, DC: U.S. Department of Energy, 2018), https://www.eia.gov/totalenergy/data/monthly, and U.S. Energy Information Administration, Annual Energy Outlook 2018 (Washington, DC: U.S. Department of Energy, 2018), https://www.eia.gov/outlooks/aeo.

ENERGY EFFICIENCY

Improving the efficiency of heating and motors will be particularly important because they account for about 30 percent of total industry energy use and could yield benefits across diverse sub-sectors.

The emergence of the "internet of things" (e.g., embedding digital technologies within industrial machinery) has created new opportunities for intelligent efficiency and automation, which can further reduce industrial-scale resource and fuel consumption and emissions. One recent study found that intelligent efficiency could reduce global CO_2 emissions 20 percent by 2030, with about 22 percent of that reduction potential in the manufacturing sector.[12]

Combined heat and power (CHP) systems have helped reduce energy use across industrial sectors (e.g., bulk chemicals, pulp paper, petroleum and coal). Separate centralized electricity generation and on-site heat generation have a combined efficiency of around 45 percent, whereas CHP systems can reach efficiency levels of 80 percent. However, adoption of CHP systems has stalled in recent years due to high capital costs, technical complexity, and policy changes.[13]

FUEL SWITCHING

Increased electrification of the industrial sector will reduce emissions. Since on-site fossil fuel combustion is the largest direct source of emissions, steps to reduce these emissions, including electrification and the use of (decarbonized) pipeline gas, offer perhaps the biggest reduction potential. While industrial electric technologies (e.g., electric boilers and electric technologies for process heat) already exist, they are only used in a subset of industrial sectors. Challenges in decarbonizing via electrification include large capital investments for equipment, the high relative cost of electricity vs. fossil fuels, and technical hurdles associated with electrifying energy-intensive and high-temperature processes.

CARBON CAPTURE, UTILIZATION, AND STORAGE

Industrial carbon capture, utilization, and storage (CCUS) can play an important role in reducing emissions in subsectors. CCUS technologies can be applied to steel, cement, chemicals, fertilizer production plants, hydrogen and refining.[14] Experience with early CCUS projects like the Archer Daniels Midland Illinois

Industrial Carbon Capture and Storage project—the world's first commercial-scale ethanol plant retrofitted with carbon capture—could help lower the cost of future CCUS projects. Recently adopted federal tax credits for CCUS will help deploy some projects. However, more targeted, industry-specific support is likely needed for research, development, demonstration, and deployment, as well as support for private sector commercialization.

PROCESS IMPROVEMENTS

For specific industries, process improvements can reduce energy needs and, therefore, greenhouse gas emissions. For example, shifting from basic oxygen blast furnaces to electric arc furnaces in the production of iron-ore steel contributed to a 37 percent reduction in the energy intensity of U.S. crude steel production from 1991–2010.[15] In some cases, switching inputs or raw materials can reduce emissions—for instance, using fly ash from coal-fired power plants instead of carbon-intensive clinker in cement production. Other process changes and substitutions can reduce emissions of non-CO_2 gases with high global warming potential.

ENDNOTES

1 Industry sources include: carbon dioxide from fossil fuel combustion, natural gas systems, non-energy use of fuels, coal mining, iron and steel production, petroleum systems, cement production, petrochemical production, substitution of ozone depleting substances, lime production, nitric acid production, ammonia production, abandoned underground coal mines, other process uses of carbonates, HCFC-22 production, semiconductor manufacture, aluminum production, carbon dioxide consumption, adipic acid production, N_2O from product uses, stationary combustion, soda ash production and consumption, ferroalloy production, titanium dioxide production, mobile combustion, glass production, urea consumption for non-agricultural purposes, magnesium production and processing, phosphoric acid production, zinc production, lead production, and silicon carbide production and consumption.

2 U.S. Department of Commerce, Bureau of Economic Analysis (BEA). *GDP by Industry Data* (Washington, DC; BEA, 2018) https://bea.gov/iTable/iTable.cfm?reqid=51&step=51&isuri=1&5114=a&5102=1#reqid=51&step=51&isuri=1&5114=a&5102=1

3 U.S. Department of Labor, Bureau of Labor Statistics (BLS). *Employment by major industry sector,* (Washington, DC: BLS 2018) https://www.bls.gov/emp/ep_table_201.htm

4 Bulk chemicals are intermediate chemicals used to produce final products like plastics and fertilizers. Bulk chemicals fall into four categories: resins, organic chemicals, agricultural chemicals, and inorganic chemicals. Natural gas, hydrocarbon gas liquids and petrochemical feedstocks are inputs to the production of bulk chemicals.

5 Figures based on Table 24 Industrial Sector Macroeconomic Indicators and Table 19 Energy-Related Carbon Dioxide Emissions by End-Use in U.S. Energy Information Administration, *Annual Energy Outlook 2018* (Washington, DC: U.S. Department of Energy, 2018), https://www.eia.gov/outlooks/aeo.

6 Ed Crooks, "Investment in US chemicals industry rises," Financial Times, June 14, 2015, https://www.ft.com/content/5c969680-12b1-11e5-8cd7-00144feabdc0. See also "ExxonMobil to Build 13 New Chemicals Facilities," Powder & Bulk Solids, March 7, 2018, http://www.powderbulksolids.com/news/ExxonMobil-to-Build-13-New-Chemicals-Facilities-by-2025-03-07-2018.

7 Emissions are exclusive of non-carbon dioxide emissions (e.g., methane, fluorinated gases, etc.) and non-energy-related carbon dioxide.

8 U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015* (Washington, DC: U.S. Environmental Protection Agency, 2017), U.S. Greenhouse Gas Emissions by Economic Sector and Gas with Electricity-Related Emissions Distributed and Percent of Total in 2015, Table 2–12, https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.

9 U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015* (Washington, DC: U.S. Environmental Protection Agency, 2017), Emissions from Industrial Processes and Product Use, Table 4-1, https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2015.

10 U.S. Energy Information Administration, Annual Energy Outlook 2018 (Washington, DC: U.S. Department of Energy, 2018), https://www.eia.gov/outlooks/aeo.

11 Electrical equipment (50.3 percent) is expected to increase the most in percentage terms albeit from a very low base.

12 Global e-Sustainability Initiative, *SMARTer2030* (Brussels, Belgium: Global e-Sustainability Initiative, 2015), http://smarter2030.gesi.org/downloads/Full_report.pdf.

13 Mark Schipper and Joel Douglas, "Industrial onsite electricity concentrated in chemicals, oil, and paper manufacturing," Today in Energy, May 20, 2014, https://www.eia.gov/todayinenergy/detail.php?id=16351.

14 International Energy Agency, *Carbon Capture and Storage: The solution for deep emissions reductions* (Paris, France: International Energy Agency, 2015), https://www.iea.org/publications/freepublications/publication/carbon-capture-and-storagethe-solution-for-deep-emissions-reductions.html.

15 Kelly Perl, "Changes in steel production reduce energy intensity," Today in Energy, July 29, 2016, https://www.eia.gov/todayinenergy/detail.php?id=27292.

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