Innovation Gap: Hard-to-Decarbonize Industrial Sectors

BY COLIN CUNLIFF | NOVEMBER 2018

This briefing is an excerpt from "An Innovation Agenda for Deep Decarbonization." See itif.org/issues/energy-climate.

The gap between an aggressive energy research and development portfolio and a deep decarbonization pathway points to a set of "hard-to-decarbonize" sectors or technologies that are either not well represented in the federal energy research portfolio or are funded at levels that are insufficient to address the challenge of decarbonizing these sectors. These "difficult-to-eliminate" emissions will require fundamental breakthroughs and investment commensurate to the challenge.

"Hard-to-decarbonize" sectors are either not well represented in the federal energy research portfolio or are funded at levels that are insufficient to address the challenge of decarbonizing these sectors.

In the electric power sector, many studies have concluded that a 50 to 70 percent reduction in carbon emissions can be achieved with a mix of commercially available technologies—namely, by increasing the share of electricity from natural gas and wind and solar energy, and by maintaining the existing nuclear and hydropower capacity.[1] However, reaching near-zero emissions will require virtually all unabated coal and natural gas plants to be replaced with dispatchable zero-emissions sources that provide the same level of flexibility and essential reliability services as conventional fossil-fuel generation. This gap is sometimes referred to as "highly reliable electricity" or "firm electricity."[2]

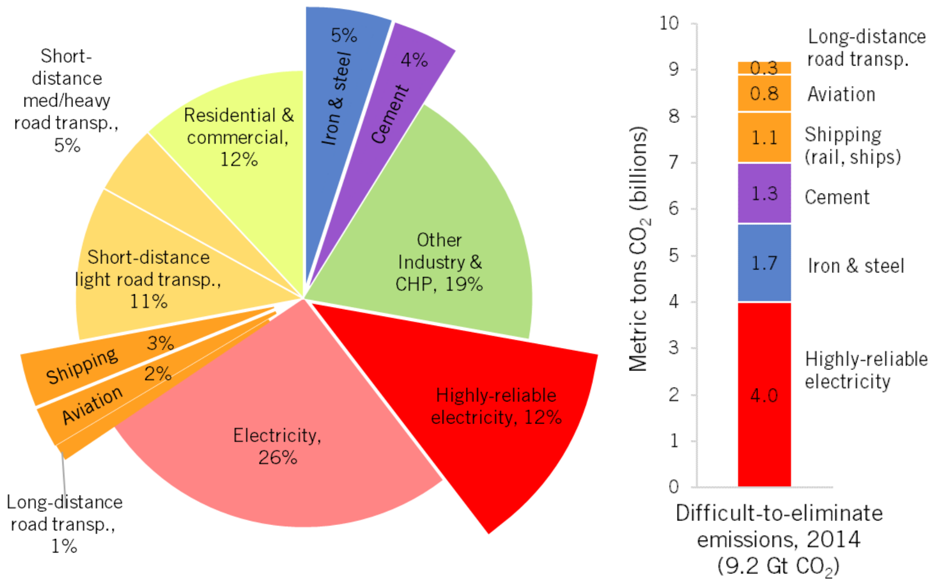
In the three end-use sectors—buildings, transportation, and industry—electrification of energy services, in tandem with decarbonization of electricity, has emerged as a viable pathway for reducing emissions. Of course, the electrification strategy is limited by the ability of the power sector to decarbonize. In addition, some sectors are not amenable to electrification. In the end-use sectors, "difficult-to-eliminate" equates to "hard-to-electrify."

In the transportation sector, batteries are getting cheaper and better, but have not yet achieved the reduced costs and increased performance necessary to enable unsubsidized widespread electrification of passenger vehicles and light-duty trucks. Moreover, the energy density requirements of aviation, shipping, and long-distance road transport make it unlikely batteries will ever be able to replace petroleum-based liquid fuels—and these sectors will need new zero-carbon fuels or other alternatives to reach deep decarbonization.

Similarly, the industrial sector includes two categories of emissions that cannot be eliminated through electrification. "Process" emissions result directly from industrial processes (such as steam methane reforming to make ammonia) and are independent from the source of energy used to drive the process. And the high-temperature heat (i.e., temperatures greater than 750°F) used in many industrial processes is currently provided by fossil fuel combustion and cannot be easily electrified.

A recent study published in *Science* quantifies these "difficult-to-eliminate" emissions. "Highly-reliable electricity" is estimated to account for 4 billion metric tons of carbon dioxide emissions (4 $GtCO_2$) annually. In the industrial sector, iron and steel production and cement production are the two largest sources of process emissions, accounting for 3 billion metric tons of annual carbon dioxide emissions (3 $GtCO_2$). And in the transportation sector, shipping, aviation, and long-distance road transport account for 2.2 billion metric tons annually. Altogether, these sources accounted for 27 percent of global carbon emissions in 2014 (Figure 1).

Figure 1. Global "difficult-to-eliminate" carbon emissions from the energy and industrial sectors[3]



DIFFICULT-TO-ELIMINATE EMISSIONS IN THE INDUSTRIAL SECTOR

The industrial sector is generally recognized as more challenging to decarbonize than the transportation and buildings sectors. There are two major obstacles to achieving a carbon-neutral industrial sector:

- **Process/feedstock emissions** result directly from industrial processes and are independent of the source of energy used to drive the process. For example, the calcination of limestone to make cement produces carbon dioxide as a byproduct. Similarly, ammonia production, which uses natural gas as a feedstock, results in direct emissions of CO_2. These emissions can only be reduced by changing feedstocks or processes, and cannot be eliminated by switching to low-carbon energy sources.

- **High-temperature heat** used in many industrial processes is primarily generated by combusting fossil fuels. Calcination of limestone to make cement (~2,500°F), melting iron ore to produce steel (~2,200°F), and steam cracking to produce ethylene (~1,500°F)—a key feedstock for plastics and other petrochemicals—all use fossil fuel combustion to generate high temperatures.[4] Most emphasis on electrification of heat has focused on lower-temperature applications, such as washing and sterilizing, which require temperatures of less than 750°F.[5] Electrification of high-temperature heat poses cost and technical barriers, and may require significant changes to industrial processes.

Scale of difficult-to-eliminate emissions in the industrial sector: There is no standard approach for identifying "difficult-to-eliminate" emissions, and the lack of data and large number of industrial processes makes a full accounting challenging. Cement (3 $GtCO_2$) and iron and steel production (2.9 $GtCO_2$) are the largest sources of industrial carbon dioxide, followed by ammonia (0.5 $GtCO_2$) and ethylene (0.2 $GtCO_2$).[6] Global emissions from these sectors alone have surpassed total annual U.S. carbon emissions, and demand for these products is projected to grow, especially in the developing world.

The *Science* study identified 1.7 $GtCO_2$ from iron and steel production and 1.3 $GtCO_2$

from cement production as "difficult-to-eliminate" because these emissions resulted from the processes or feedstocks used in production. However, this estimate likely undercounts difficult-to-eliminate emissions because the study does not include emissions from high-temperature process heat or emissions from other sectors.

"Difficult-to-eliminate" emissions in the industrial sector include process emissions from chemical transformations and emissions from high-temperature heat.

In the United States, the five largest sources of process CO_2 emissions—including the production of iron and steel, cement, petrochemicals, lime, and ammonia—accounted for 135 million metric tons of CO_2 emissions in 2016, or 82 percent of total domestic process emissions.[7] The five largest energy-consuming industries—refining, bulk chemicals, iron and steel, mining, and food products—accounted for 830 million metric tons of CO_2 in 2016, or about 60 percent of total industrial energy-related carbon emissions; however, it's not clear how much of this is related to high-temperature heat.[8]

Possible solutions: Capturing the carbon emitted from industrial processes may be the only option for process/feedstock emissions. High-temperature heat could be provided by the replacement of fossil fuels with biomass. Additionally, some advanced nuclear concepts operate at higher temperatures than the current light-water reactor designs, and could be used as a source of process heat. Electric arc furnaces can provide process heat for some kinds of steel. Hydrogen produced from electrolysis using zero-carbon electricity, or other carbon-neutral fuels, could also be combusted to generate high-temperature heat. With the exception of biomass combustion for heat, all options are far from commercial and require substantial RD&D to drive down costs.

ENDNOTES

1. Jesse D. Jenkins and Samuel Thernstrom, "Deep Decarbonization of the Electric Power Sector: Insights from Recent Literature," (Energy Innovation Reform Project, March 2017), 2,

https://www.innovationreform.org/wp-content/uploads/2018/02/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf.

2. Nestor A. Sepulveda et al.,, "The Role of Firm Low-Carbon Electricity Resources in Deep Decarbonization of Power Generation," *Joule* **2** 1-18 (October 17, 2018), DOI:10.1016/j.joule.2018.08.006; Davis et al.
3. Davis et al., "Net-zero emissions energy systems," *Science* **360**, eaas9793 (2018), http://dx.doi.org/10.1126/science.aas9793.
4. Arnout de Pee et al., "Decarbonization of Industrial Sectors: the Next Frontier," (McKinsey & Company, June 2018), 15, https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/how-industry-can-move-toward-a-low-carbon-future.
5. U.S. Environmental Protection Agency (EPA), "Renewable Industrial Process Heat," accessed November 18, 2018, https://www.epa.gov/rhc/renewable-industrial-process-heat.
6. Arnout de Pee et al., "Decarbonization of Industrial Sectors."
7. U.S. Environmental Protection Agency (EPA), "Inventory of U.S. Greenhouse Gas Emissions and Sinks," (EPA, April 2018), https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks, Table 4-1.
8. U.S. Energy Information Administration (EIA), Annual Energy Outlook 2018, (Washington, D.C.: EIA, 2018), https://www.eia.gov/aeo.

ACKNOWLEDGMENTS

The author wishes to thank Robert D. Atkinson, David M. Hart, and Lindsey Walter for providing input to this report. Any errors or omissions are the author's alone.

ABOUT THE AUTHOR

Colin Cunliff is a senior policy analyst for clean energy innovation with the Information Technology and Innovation Foundation. He previously worked at the U.S. Department of Energy (DOE) Office of Energy Policy and Systems Analysis (EPSA), with a portfolio focused on energy sector resilience and emissions mitigation. He holds a Ph.D. in physics from the University of California, Davis.

ABOUT ITIF

The Information Technology and Innovation Foundation (ITIF) is a nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized as one of the world's leading science and technology think tanks, ITIF's mission is to formulate and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress.

FOR MORE INFORMATION, VISIT US AT WWW.ITIF.ORG.