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BATTEN BRIEFING

IMPROVING THE WORLD THROUGH ENTREPRENEURSHIP AND INNOVATION

PATH TO 2060:

Decarbonizing the Industrial Sector

A Long Road Ahead for Low-Carbon Manufacturing

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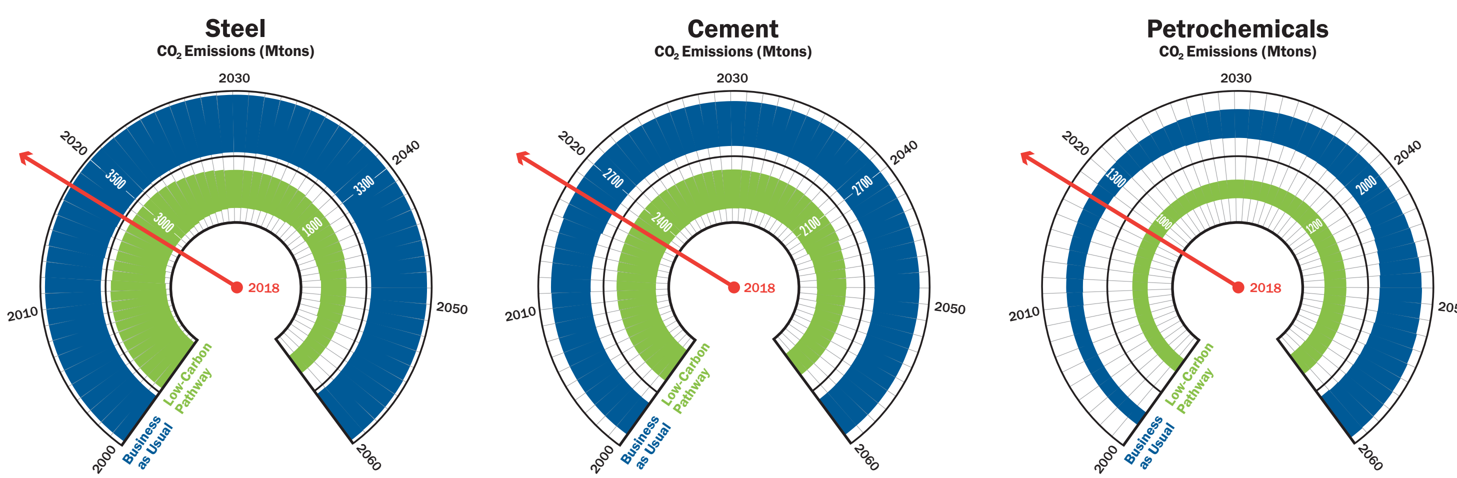
Industrial manufacturing accounts for 21% of global greenhouse gas emissions.[1] Decarbonizing this sector will require industry-specific solutions that span electricity generation, thermal processing, and the sourcing of raw materials. Companies are interested in low-carbon technologies, but without a financial incentive many are reluctant to deploy these solutions. What can motivate change and encourage investment in a decarbonized industrial future?

This *Batten Briefing* summarizes the key findings of our report titled **Path to 2060: Decarbonizing the Industrial Sector**. Here, we examine three industries—steel, cement, and petrochemicals—and explore current technological approaches to reducing global emissions. We also discuss both accelerators and probable roadblocks to decarbonizing the industrial sector by 2060.



The **Business as Usual** scenario represents the IEA 6 degree baseline, where no new policies are introduced and technologies progress as they would normally. The **Low-Carbon Pathway** scenario represents the IEA 2 degree target, which considers available and known technologies, including CCS adoption that ramps up in 2030. For petrochemicals, low-carbon pathway captures emerging technologies that are in the later R&D stages, in demonstration or could realistically be commercialized (e.g. steam cracking substitute). To completely decarbonize these industries, we will need significant innovation supported by low-carbon policies.

Sources: Bas J. van Ruijven et al, "Long-term model-based projections of energy use and CO_2 emissions from the global steel and cement industries", Science Direct, Resources, Conservation, and Recycling, vol. 112 (2016), p. 15–36, IEA Technology Roadmap: Low-Carbon Transition in the Cement Industry, IEA Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes.

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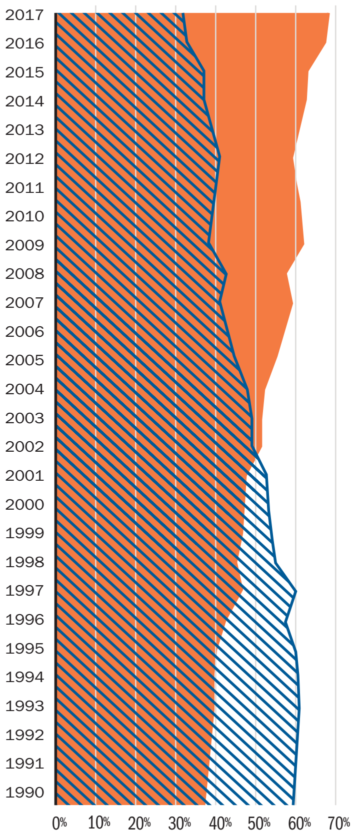
THE CARBON-INTENSE NATURE OF INDUSTRIALS

US Steel Production by BOF versus EAF processes

Source: US Geological Survey Minerals Information: Iron and Steel 1990–2017.



INDUSTRIALIZATION HAS BEEN CRITICAL TO ECONOMIC GROWTH, but it has come at a cost. Production of goods and raw materials accounts for 21% of global greenhouse gas emissions. Identifying a set of sector-wide solutions for industrials is complicated by the breadth and diversity of manufacturing operations. We focus our research efforts on the three most carbon-intensive industries.

STEEL

Steel manufacturing represents 6.7% of global carbon emissions.[2] Most steel products today are made from iron ore in basic oxygen furnaces (BOFs). The ironmaking process alone represents 70%–80% of steelmaking carbon emissions. Electric arc furnaces (EAFs) use electricity to melt scrap steel, avoiding the ironmaking step and its associated emissions. Powering EAFs with renewables would fully decarbonize the process. US steelmaking has shifted almost entirely to EAFs (see Figure 1), but BOFs continue to dominate globally with a 75% share of production. Economic growth projections, particularly in developing countries, will drive demand for new steel, which cannot be fulfilled by EAFs alone. Scrap availability and price will also challenge broader EAF adoption, as will low-cost fossil fuel pricing.

CEMENT

The cement industry accounts for about 7% of global carbon emissions.[3] Chemical reactions involved in the production process of Portland cement, the most common type of cement in general use, account for the largest share of emissions. Blending cement with alternative materials has helped to reduce these emissions. Yet there are limits on the amount of substitution allowed in concrete, imposed by the industry's standard-making bodies to ensure long-term durability and safety. Novel approaches and materials are being introduced that could more significantly drive down carbon emissions. For instance, several companies are exploring the capture and use of emitted carbon in the concrete-curing process, while others are studying replacements for Portland cement. Price sensitivities and the lack of long-term performance data challenge broader adoption of these alternatives.

PETROCHEMICALS

Petrochemical production, largely driven by the demand for plastics, accounts for roughly 7% of global carbon emissions.[4] Petrochemicals are derived from oil and natural gas and require large amounts of thermal energy to manufacture. Today, most of that thermal energy is supplied by coal and natural gas. Alternatives to fossil fuel-dependent chemical reactions exist, but they face several barriers to commercialization. For example, the natural gas-sourced hydrogen required to make ammonia could instead be sourced using electrolysis. The process, which uses electricity to split water into hydrogen and oxygen, is widely known and demonstrated, but is currently cost-prohibitive.

[1] US Environmental Protection Agency, Global Greenhouse Gas Emissions Data, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (accessed August 2018). The share provided here represents direct emissions, or those generated on-site to support industrial operations. Electricity generated off-site is covered by the previous report, *Path to 2060: Decarbonizing the Electric Utility Industry*.

[2] World Steel Association, Publications: Position Papers, "Steel's Contribution to a Low Carbon Future," https://www.worldsteel.org/publications/position-papers/steel-s-contribution-to-a-low-carbon-future.html (accessed July 2018).

STRATEGIES FOR ACHIEVING LOW-CARBON MANUFACTURING

THE INDUSTRIAL SECTOR OFTEN PRODUCES COMMODITY PRODUCTS destined for use by downstream market actors. As a result, these industries tend to be highly competitive, with low profit margins. The additional cost of deploying new technologies and systems must be negligible or offset by some competitive advantage. What strategies might be effective for influencing change?

INCREASE R&D INVESTMENT

Many low-carbon technology solutions are in the early stages of development. Public and private funding for research, testing, and field demonstration can play a critical role in reducing costs related to commercializing these technologies. Clean technologies, such as electric vehicles and solar, have benefited from early-stage government funding. Today, these technologies are becoming cost competitive with fossil fuel options and are on track to dominate their respective markets in the next 30 years. Private companies and investors responding to external pressures (or perhaps acting on their own concerns about climate change) can also accelerate the rate of commercialization. For example, the Breakthrough Energy Coalition, led by Microsoft founder Bill Gates, has built a network of private companies and investors committed to funding innovative, clean technologies, including several poised to reduce industrial emissions.

ADOPT INDUSTRIAL-FRIENDLY RENEWABLE ENERGY

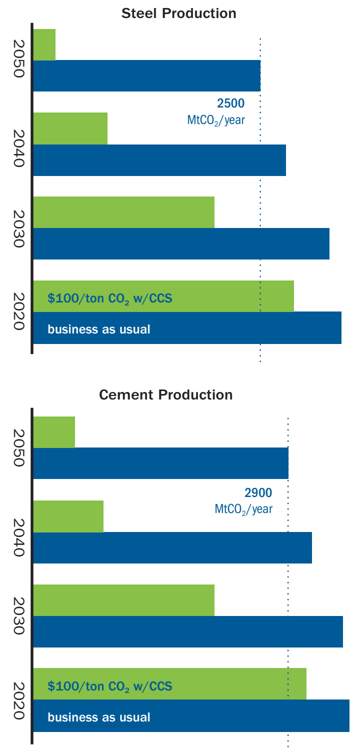
Renewables offer a zero-carbon pathway to power industries and an opportunity for operators to own and operate energy-producing assets. Yet the high thermal demands of many industrials, such as cement and petrochemicals, limit use of these technologies. Research is underway to develop a concentrated solar technology that could reach temperatures closer to the needs of high-heat demand industries. Another option is bioenergy, which reaches temperatures comparable to natural gas and coal. Even if these alternatives are technically feasible, currently they can't compete with fossil fuels on cost and availability. Industrials with low- and medium-heat demands (i.e., less than 400 degrees Celsius) may offer a more immediate entry point for renewables.

PUT A PRICE ON CARBON

Carbon capture and storage (CCS) could drastically change the trajectory of carbon emissions in the industrial sector, especially if the technology is rewarded with financial incentives (see Figure 2). Without these incentives, manufacturers will be slow to adopt CCS strategies. State and national governments around the world are exploring two policy options: federal tax incentives to offset the capital costs of CCS, and national carbon-trading schemes to create a carbon market in which companies buy and sell emissions permits and credits, motivating investment in clean technologies. However, to date these pricing signals have fallen short of what is needed to spur innovation. Another idea is to use CO_2 as an input to other industrial processes, placing a value on carbon itself and providing a long-term storage solution.

Impact of CO_2 Tax

Source: Bas J. van Ruijven et al., "Long-Term Model-Based Projections of Energy Use and CO_2 Emissions from the Global Steel and Cement Industries"



[3] Araceli Fernandez and Yvonne Leung, "Technology Roadmap: Low-Carbon Transition in the Cement Industry," International Energy Agency and the Cement Sustainability Initiative of the World Business Council for Sustainable Development, April 6, 2018, https://webstore.iea.org/technology-roadmap-low-carbon-transition-in-the-cement-industry, 12.

[4] "Technology Roadmap: Energy and GHG Reductions in the Chemical Industry via Catalytic Processes," International Energy Agency, International Council of Chemical Associations, and DECHEMA, June 2013, https://webstore.iea.org/technology-roadmap-energy-and-ghg-reductions-in-the-chemical-industry-via-catalytic-processes, 1.

This briefing is the third in a series of sector-focused reports published by the Batten Institute for Entrepreneurship and Innovation at the University of Virginia Darden School of Business. Previous reports explore the automobile and electric utility industries. Upcoming research will take a look at the agriculture industry. Visit **www.darden.virginia.edu/innovation-climate** to listen to a podcast discussing the findings of this report and to learn more about Darden's Business Innovation & Climate Change Initiative.

ENCOURAGE DOWNSTREAM DEMAND FOR GREEN PRODUCTS

Green building trends, new fuel efficiency standards, and consumer demand for recycled content and sustainable sourcing; these are examples of the market influences that could drive changes in the industrial sector. Global corporations looking to green their supply chains are using their buying power to shift entire industries. Certification and labeling programs could help to guide end users to green products and reward the innovative companies that supply the materials to make them.

ACCELERATE DIGITAL TRANSFORMATION

Many experts believe we are in the midst of a fourth Industrial Revolution, led by technological advances such as artificial intelligence and the Internet of Things. These so-called "smart" technologies are disrupting the industrial sector and hold promise to reduce greenhouse gas emissions, optimizing resources and energy efficiencies while increasing productivity. The potential for energy savings and further reductions in carbon emissions is encouraging; some studies suggest possible reductions of 25% through process digitization, real-time monitoring of systems, and advanced data analytics.[5] Yet the proliferation of data, and the associated growing need for storage, could end up increasing energy consumption. Equally smart policies need to be put in place to guard against the broader impact that these smart solutions could have on the electric grid.

THE LONG ROAD TO DECARBONIZATION

INDUSTRIAL PRODUCTS, SUCH AS STEEL AND CEMENT, will be difficult to substitute as they are the backbone of economic growth and development. Moreover, the rise of new product markets is increasing the demand for plastics and petrochemicals. Although demand for steel, cement, and petrochemicals is slowing in more developed countries, analysts expect continued growth in worldwide production across these three industries, driven largely by rapid urban expansion in China and India. Fueled by natural gas and coal, growth in these and other developing countries will challenge decarbonization efforts.

Decarbonization of the industrial sector by 2060 seems highly unlikely. A concerted effort is needed to create the economic conditions for the rise of breakthrough technologies within each industry—especially steel, cement, and petrochemicals. Actions to subsidize research and development, put a price on carbon, encourage the transition to renewable energy to power industrial processes, increase downstream demand for green products, and accelerate the digital transformation of the industrial sector need to be taken worldwide. To meet the 2060 deadline, we will need to pull all the levers at our disposal.

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[5] World Economic Forum, "Impact of the Fourth Industrial Revolution on Supply Chains," October 2017, http://www3.weforum.org/docs/WEF_Impact_of_the_Fourth_Industrial_Revolution_on_Supply_Chains_.pdf.