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Chemicals Practice

Decarbonizing the chemical industry

Meeting decarbonization targets requires reducing CO_2 emissions from the difficult-to-abate chemical industry. The German chemical industry exemplifies what can be done if four levers are pulled.

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Chemicals is one of the largest industries worldwide, with annual revenue of approximately $4.7 trillion.[1] In addition, the products it creates are deeply embedded in the world's largest value chains, such as manufacturing and construction.

In 2021, the chemical industry's global emissions totaled approximately 925 million metric tons (MT) of CO_2,[2] accounting for around 2 percent of total emissions. Meanwhile, the industry has been subject to fundamental shifts, including increased consumer demand for lower-carbon products and increased consumer awareness of recycling and the use of recycled materials; greater demand for resource-efficient production; and heightened regulatory pressure for tighter material requirements.

As one of the most energy-intensive industries in Europe, chemicals can play a special role in restructuring the energy system and reducing CO_2 emissions. With this in mind, we studied more than 20 decarbonization projects in the chemicals industry across multiple countries, including Belgium, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, and Sweden. Our findings show that players can reduce emissions by pursuing steam generation, utilizing residual heat, changing electricity procurement, and improving energy efficiency.

We chose to focus our analysis and illustrative examples on the chemicals industry in Germany, given the magnitude and availability of data. This does not, however, negate the general applicability of the decarbonization levers for other countries.

Decarbonizing chemical emissions in Germany: An overview

In 2021, industry in Germany accounted for 181 MT of CO_2 out of a total 762 MT; within industry, chemicals accounted for 40 MT of CO_2 (Exhibit 1).

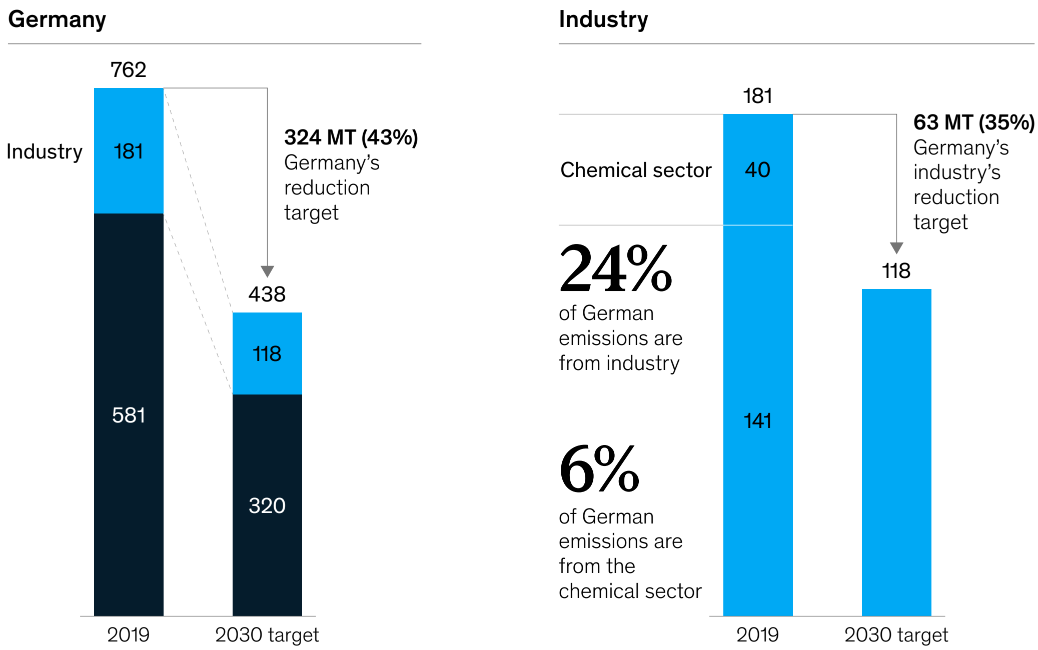
As one of the most energy-intensive industries in Europe, chemicals can play a special role in restructuring the energy system and reducing CO_2 emissions.

[1] "Chemical industry worldwide—statistics and facts," Statista, February 9, 2023.
[2] "Chemicals," International Energy Agency, accessed March 15, 2023.

Exhibit 1

In 2019, industry accounted for 181 million metric tons (MT) of Germany's CO_2 emissions.

CO_2 emissions, million metric tons (MT)



Source: "Chemical industry," German Energy Agency, accessed March 12, 2023; "Greenhouse gas emissions in Germany," German Environment Agency, March 15, 2022

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Current decarbonization targets aim to reduce the country's overall CO_2 emissions by approximately 45 percent by 2030, with reduction targets for industry of 35 percent or 63 MT of CO_2.[3]

Assuming emissions continue at today's levels, our projections show that the chemical industry will emit the most CO_2 in Germany by 2030. However, unlike in other emissions-intensive industries, such as energy or transport (in which almost all emissions are driven by the combustion of fossil fuels), emissions in the chemical industry are considered more challenging to abate. Fossil fuels used as feedstock and process gas for chemical processes require technological innovation, such as the use of recycled materials, captured carbon, and alternative reduction agents. The combustion of fossil fuels for steam, electricity, and heat generation can be electrified, but some reactions require temperatures that cannot yet be efficiently achieved with electric devices. Thus, decarbonization for chemicals will need to rely on solutions specific to these challenges.

[3] "Greenhouse gas emissions in Germany," German Environment Agency (Umweltbundesamt), March 15, 2022.

The decarbonization journey

To better understand the decarbonization journey for chemical players, we analyzed across multiple countries the plans of industrial clusters, also known as “chemical parks,” to substantially reduce emissions. (The ranges of emissions reduction targets by lever for different chemical parks are illustrated in Exhibit 2.) A chemical park is a conglomerate of chemical production plants—either owned by a single company or multiple companies—that shares infrastructure, such as utility supply and site services.

Based on this analysis, four levers of decarbonization typically have the largest effect: steam generation, heat integration, electricity procurement, and energy efficiency.

Steam generation

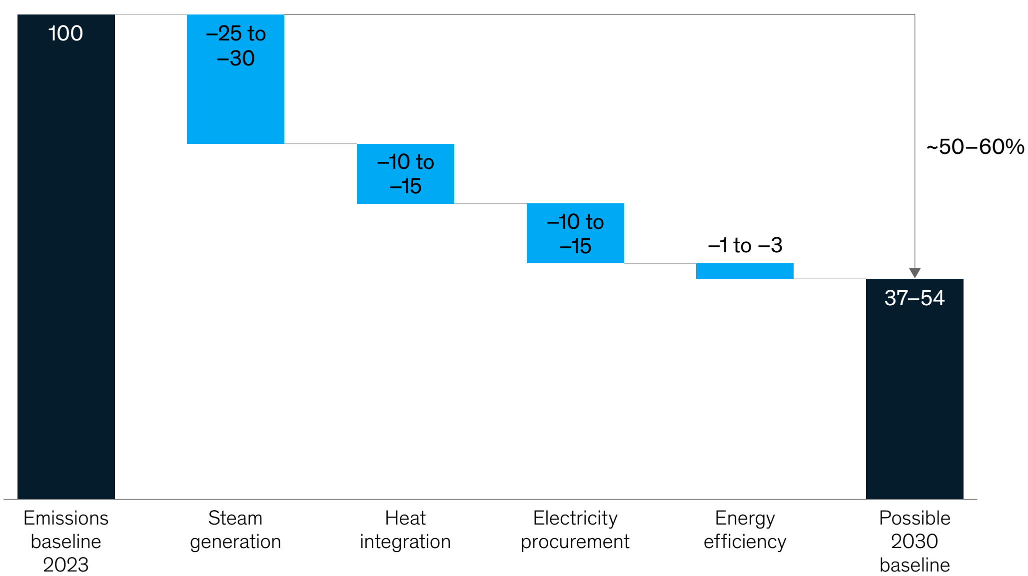
Although steam generation is the biggest lever for decarbonization, it entails phasing out coal where it is still used and ramping up carbon-free steam-generation capacities. On this point, there are seven carbon-free heat-source technologies—biomass, solar thermal, hydrogen, biogas, thermal storage, heat pumps, and e-boilers—each with varying levels of commercial availability (Exhibit 3).

Each heat source technology can be assessed for feasibility based on feedstock availability, regulatory applicability, and load-profile applicability (renewable-energy sources are subject to load variations, and chemical production requires a consistent base load). For instance, solar thermal energy relies on climates and regions with high

Exhibit 2

An analysis of the plans of ‘chemical parks’ shows four levers that have the highest potential for emissions reduction.

CO_2 emissions, %



Note: Countries included are Belgium, Finland, France, Germany, Italy, Netherlands, Norway, Spain, and Sweden.

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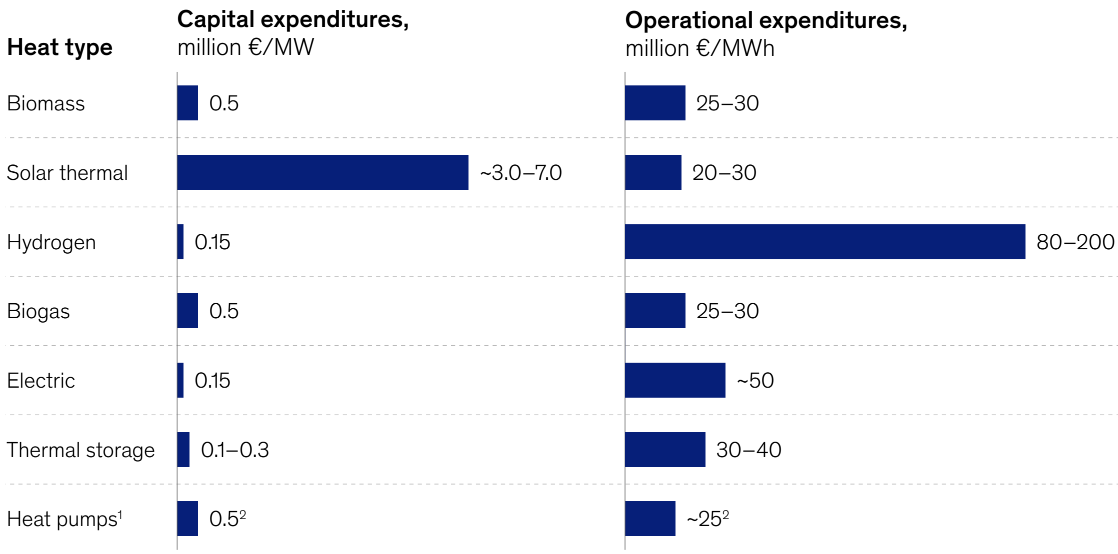
Exhibit 3

There are seven carbon-free heat source technologies with varying levels of commercial availability.



[1]Mechanical vapor recompression recovering waste heat.
[2]Sensitive on waste heat, start temperature, and lift, based on a heat price of €50/MWh.

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percentages of sunlight, while biomass relies on dedicated energy crops, such as corn. In some cases, we determined that the best solution for low-emitting, cost-effective steam generation by 2030 was to replace the conventional generation capacity with a flexible combination of hydrogen-ready gas-fired generators and electric steam generators.

Employing a combination of technologies—and thus enabling fuel-switching flexibility, depending on relative pricing—often proves beneficial, though this in turn requires installing and maintaining additional spare capacity. In some cases, the value of switching fuel for the most economic technology outweighs the additional operational and capital expenditures for spare capacity. However, this is a determination that should be made on a case-by-case basis.

Heat integration

Historically, the chemical industry has wasted large amounts of residual energy in the form of “off heat”—heat that is actively cooled down for disposal. This was primarily driven by the low cost of steam generation and the lack of technologies, such as heat pumps, to recycle low-energy residual heat. However, the chemical parks we studied determined that they could connect heat sinks and sources, leveraging digital twins and heat pumps to efficiently use residual heat.

Amplified by the gas shortage demand, several heat integration solutions have only recently become available. Among these technological solutions are high-temperature heat pumps, steam mechanical vapor recompression, and heat separation (Exhibit 4).

Connecting heat sinks and sources either directly or by using heat pumps to upcycle the residual energy to the required temperature level can dramatically increase the utilization of primarily generated heat. In turn, off heat can be upcycled and fed into steam or hot-water grids or connected directly to the appropriate offtakes. In addition, our research suggests that minimizing the energy consumed on-site by optimizing and redesigning consumers with net present value–positive cases can allow companies to reduce energy demand by as much as 20 to 40 percent.

Finally, heat integration enabled significant cooling water savings (and thus reduced electricity for pump operations). And digital twins of heat sinks and sources allowed for dynamic optimization of heat utilization as well as the optimal positioning of heat pumps. To maximize potential, a redesign of how heat sources are connected beyond company borders and assets is required. Leveraging digital capabilities creates models to economically simulate different options and assess feasibility.

Electricity procurement

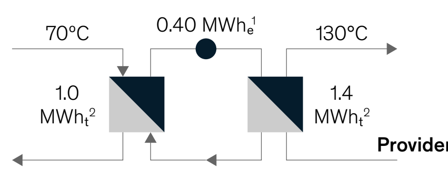
Electricity procurement can be as significant as steam generation for decarbonization in chemical parks, although it requires selecting the right strategy for procuring sources of renewable energy. For instance, power purchase agreements (PPAs) with renewable-electricity producers can help virtually or physically deliver power to the site. And

Exhibit 4

There are three technological solutions for connecting heat sinks and sources.

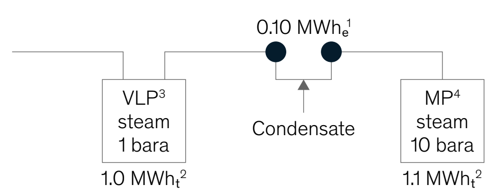
High-temperature heat pump

Waste heat is extracted from the heat source and lifted **to a higher temperature** level with **electricity**. **This amplified** waste heat can be used in processes that need high thermal energy.



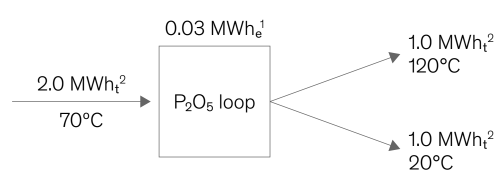
Steam mechanical vapor recompression

Waste steam with pressure too low to be used is **amplified to a higher pressure** with electricity. **High-pressure steam** can be used for other processes.



Heat separation

Waste heat is lifted to a higher temperature with a chemical reaction and low electricity input. **Less heat can be recovered this way** than with a high-temperature heat pump.



[1]Megawatt-hours electric.
[2]Megawatt-hours thermal.
[3]Vertical low pressure.
[4]Medium pressure.

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although replacing gray electricity (which is produced from fossil fuels) with electricity produced from renewables can be a quick win, it requires choosing the right long-term energy-procurement strategy.

With this in mind, renewable energy can be procured by purchasing certificates, such as Renewable Energy Guarantees of Origin in Europe[4]; PPAs; or investments in off-site assets (Exhibit 5). In addition, electric-grid capacity can be expanded to allow for electrification and to purchase additional green electricity as needed.

Chemical parks are in a special position because they have the potential to aggregate and bundle the capacities from many different plants or consumers. In this way, they can meet increasingly competitive prices because of economies of scale. Also, they can decrease the volatility in demand by counterbalancing between different peaks of consumer demand. Thus, if a combined-cycle plant is operated by the chemical park, a green baseload can be self-produced, and only demand peaks will need to be procured externally using PPAs.

Energy efficiency

The goal of increasing energy efficiency is to minimize energy losses in operations. Additional savings potential can be easy to realize because of the high number of small energy-efficiency measures. In fact, the chemical parks we studied prioritized different decarbonization ideas, accounting for a considerable potential reduction in CO_2 emissions per year. Because of their relative simplicity, the initiatives were primarily executed by the existing site team without significant capital expenditures or the need for external support.

Exhibit 5

There are several procurement options for sourcing renewable electricity.

Own projects	On-site, for self-consumption	Own development of renewable-energy source project on-site
	Off-site, for self-consumption	Own development of renewable-energy source project off the corporate production site
(Co)investments	For self-consumption	Direct (co)investment in renewable-electricity production for self-consumption
	Delivered to market	Direct (co)investment in renewable-electricity production, in which energy produced is sold to market and the same amount is purchased from electricity supplier
PPAs[1]	Physical	PPAs[1] with renewable-electricity producers to physically deliver power to the corporation's site(s)
	Virtual	PPAs[1] with renewable-electricity producers to virtually deliver power to the corporation's site(s)
Certificates	Bundled	Purchase of both physical electricity and certificates in one transaction or product (bundled offering)
	Unbundled	Purchase of certificates separate from purchase of physical electricity (asset owner can sell electricity to one buyer and certificates to another)

High acceptability

Low acceptability

The most pressure is likely to come from nongovernmental organizations (NGOs) and the Science Based Targets initiative (SBTi), then investors and rating firms. Customers themselves may often not be 100% able to differentiate but may follow vocal NGOs via press, etc.

[1]Power purchase agreements.

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[4] For more, see "Renewable Energy Guarantees of Origin (REGO)," Office of Gas and Electricity Markets (Ofgem), accessed March 15, 2023.

Changing market environments, production demands, and decarbonization initiatives could significantly affect the service portfolios of chemical parks.

How the chemical industry can decarbonize

Apart from the four decarbonization levers, there are three critical success factors to ensuring a successful journey: understanding market demands, adapting the commercial model, and governing decarbonization as a transformation.

Understanding market demands

Before shaping the decarbonization journey of any company, it is vital to gain an understanding of market and industry trends and shifts in demand. It is also important to get up to speed on the priorities of production, potential third parties, suppliers, regulators, and other stakeholders. Chemical players worldwide have set ambitious targets to reduce their CO_2 emissions by 2030, ranging anywhere from 25 to 60 percent. To reach these targets, companies can comprehensively address their emissions, considering utility provision and chemical-park operations.

In turn, gaining full transparency on market developments can require a multidimensional market model that is built to show trends and demands by product category and type of service. The overall demand for utilities such as steam generation in chemicals is decreasing because of energy-efficiency measures in chemical plants (such as oxygen depolarized cathodes [ODCs] in brine electrolysis) and the relocation of certain commodity chemicals (such as the production of toluene diisocyanate [TDI] moving to China and North America).

That said, producers will increasingly demand green, decarbonized products to reach CO_2 reduction targets, which will subsequently create opportunities for the creation of new value. In addition, new businesses, such as supplying waste heat to local district heating systems or chemical recycling and waste gasification, hold potential for chemical parks.

Adapting the commercial model

Changing market environments, production demands, and decarbonization initiatives could significantly affect the service portfolios of chemical parks. If commercial models do not adapt in turn, they will likely be unable to ensure fair attribution of saved CO_2 costs to the departments that shouldered the necessary measures to decarbonize. This is particularly true for chemical parks with multiple companies that share utility supply services, for which a fair split of the value created among the utility supplier and the chemical customer is needed.

At the same time, decarbonization offers substantial value creation potential. To capture this potential, commercial models of chemical parks can ensure the following:

— *Fair attribution of green premiums.* Decarbonizing services leads to reduced costs for CO_2 certificates, as well as potentially higher prices to end customers. This means that chemical-park operators can capture part of this benefit as green premiums.

— *Pricing based on created value.* Green power generation and heat integration are often achieved in decentralized aggregates, and third parties have lower barriers to enter the market than for central generation. Thus, chemical parks can price their services based on independent value drivers instead of "all-in-offerings," offering flexible, transparent, and competitive services to internal and external users alike

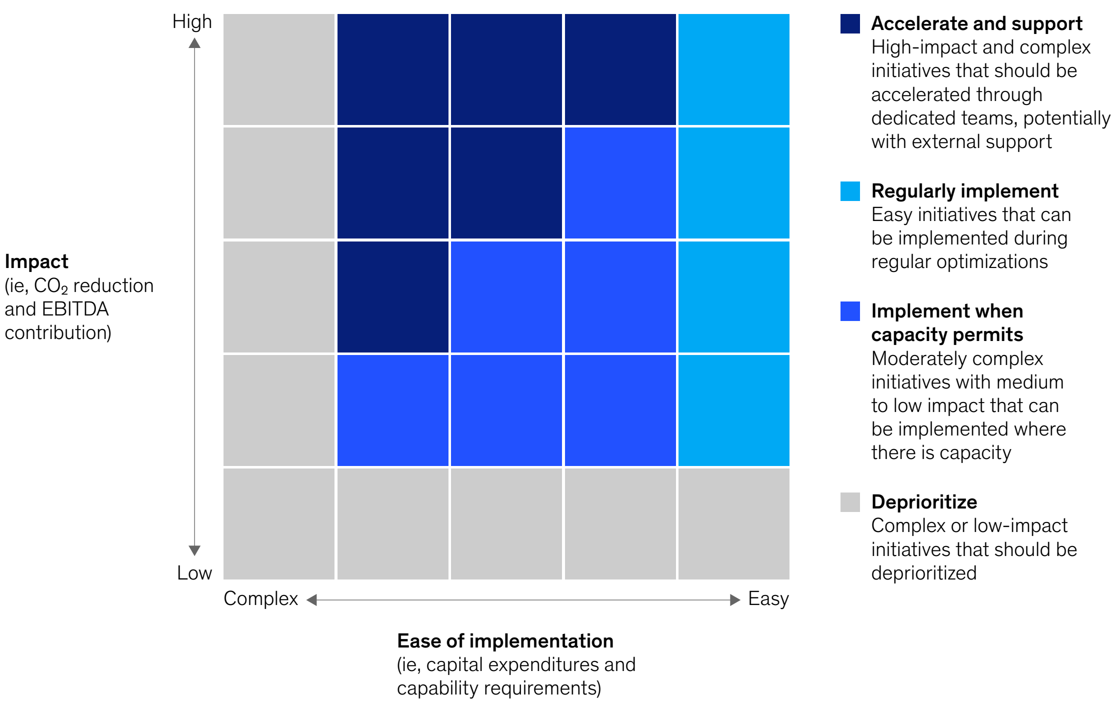
Governing decarbonization as a transformation
Shifting customer demands related to environmental impact will need to be reflected in the product portfolio, commercial model, and organizational structure. Hence, the necessary adaptions require a clear implementation plan, similar to corporate transformations.[5]

To drive comprehensive decarbonization, a full potential analysis can be conducted to determine reduction opportunities. Once the full potential is transparent, measures can be identified and prioritized based on the achievable impact and the ease of implementation, considering requirements for capital expenditures as well as the capabilities of available resources and time to implementation (Exhibit 6).

Exhibit 6

Companies can identify and prioritize decarbonization measures based on achievable impact and ease of implementation.

Prioritization matrix for decarbonization initiatives



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[5] For more on transformations, see "Digital transformations: The five talent factors that matter most," McKinsey, January 5, 2023.

That said, many transformations fail. To ensure a successful implementation, it is important to set up a full-time transformation team with a clear meeting structure and transparent tracking.[6]

Meeting the decarbonization targets of the chemical industry and keeping pace with other industries requires urgent action. Leaders can begin by making smart, well-informed decisions that prioritize the opportunities, identify resources, and adopt the right technologies.

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[6] For more on decarbonization opportunities, see "Decarbonization Transformation," McKinsey, accessed March 15, 2023.