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Translating into action the ambitious climate targets that have been put in place by governments and companies depends on accelerating the deployment and adoption of several interrelated technologies. These include renewable energy sources (RES), electrification technologies such as electric vehicles (EVs), and heat pumps--as well as comparatively less mature technologies, such as carbon capture, utilization, and storage (CCUS), green and blue hydrogen, and sustainable fuels.

These decarbonization technologies (alongside many others, such as nuclear, long-term duration energy storage, battery energy storage systems, and energy efficiency investments) are the cornerstone of efforts to reduce greenhouse gas (GHG) emissions in all McKinsey energy scenarios. The period until the end of this decade is a critical one to put in place a trajectory of accelerated adoption to meet 2030 and 2050 targets set by countries and companies.

The gap between what is needed and what has been achieved in the deployment of low-emissions technology is large--to date, only about 10 percent of the deployment of low-emissions technologies globally by 2050 required for net zero has been achieved, mostly in less challenging use cases. Closing the gap would require building a new, high-performing energy system to match or exceed the current one, which would entail developing and deploying new low-emissions technologies, along with entirely new supply chains and infrastructure to support them.

Given the size and complexity of today"s energy system, this is no easy task. The physical challenges that would need to be overcome to successfully transform the energy system are significant and would require concerted action to solve. McKinsey"s recent report, "The Hard Stuff: Navigating the physical realities of the energy transition," identifies 25 physical challenges across seven domains of the energy system that would need to be addressed for the energy transition to succeed.1The hard stuff: Navigating the physical realities of the energy transition, McKinsey Global Institute, August 14, 2024.

Addressing these physical challenges would involve improving the performance of low-emissions technologies, addressing the interdependencies between multiple challenges, and achieving massive scale-ups, even in technologies where a strong track record has not yet been established. And, of course, this is only one side of the equation. To overcome these physical challenges, significant firm investment into low-emission technologies needs to be unlocked.

While significant progress has been made in developing and deploying some of these technologies, notably solar and wind, for which installed capacity has risen sharply over the past 15 years, a significant gap has emerged between the actual results and the expected ones. The at-scale deployment of all these technologies is still not happening as fast as needed to reach 2030 targets (see sidebar "The technology gap"). Moreover, the technologies are at risk of facing raw material and labor shortages and long permitting procedures.

We have identified three major issues that threaten the necessary deployment of capital: first, the business case--that is, the economic returns and policy predictability for developers--often remains weak; second, many technologies are increasingly but not yet cost-competitive for consumers, given the lack of at-scale manufacturing capacity or learning rate driven by deployment; and third, several technologies have not been tested at scale and need multiyear product, project, and supply chain development, thereby creating uncertainty about their effectiveness and efficiency. Ultimately, technology-focused enablers have not yet managed to address the challenges posed by macroeconomic shocks, geopolitics, and what it takes to enable tech ecosystems.

To shed light on the current status of the energy transition and provide a rigorous, fact-based assessment, we conducted an extensive analysis involving several steps.

Scope: We identified the key singular technologies that together account for the bulk of decarbonization potential (onshore and offshore wind, solar PV, clean hydrogen, sustainable fuels, CCUS, electric vehicles, and heat pumps). This means we excluded several other decarbonization technologies, including energy storage and battery energy storage systems (BESS) because these technologies are already in vast supply, with very healthy pipelines, and numerous players not only announcing projects but committing to them. We also excluded energy efficiency, low-carbon thermal generation, and nuclear because these are very fragmented markets with limitations due to regulation.

Data collection: We gathered comprehensive data from various sources, including proprietary and commercial project-tracking databases. This allowed us to obtain up-to-date information on the status of numerous projects across different decarbonization technologies.

Policy and historical capacity review: We reviewed existing policies, historical capacity deployments, and growth trends to understand the broader context and the trajectory of different technologies. This helped us benchmark current progress against historical data and policy targets.

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