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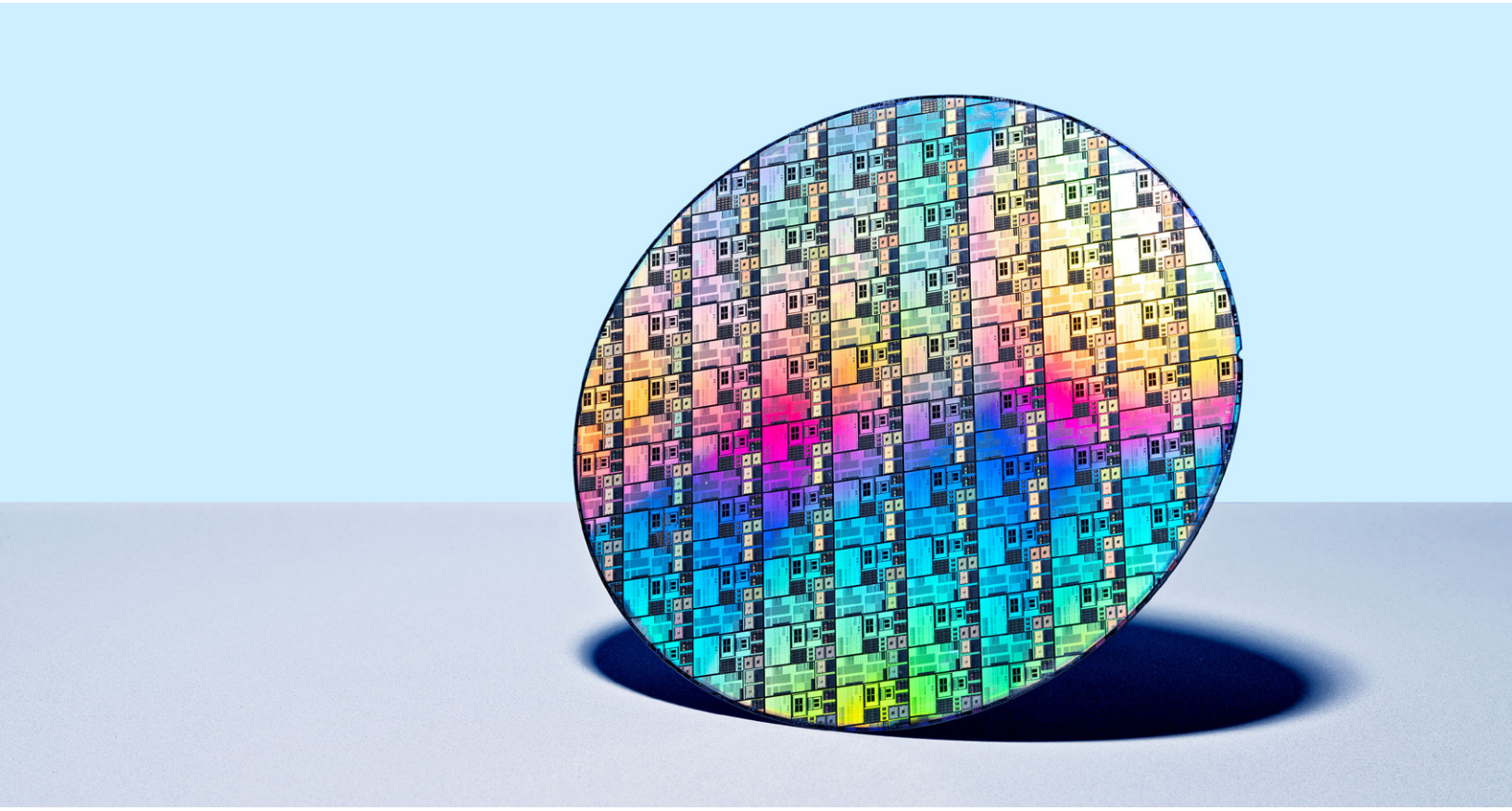
McKinsey Explainers

What is a semiconductor?

Semiconductors are the unsung heroes of the technology world: parts manufactured from pure elements that work behind the scenes to power and connect everything from smartphones to cars.



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The expression "semiconductor shortage" is one of those pandemic-era catchphrases—like "supply chain issues" or "physical distancing" or "sourdough starter"—that will probably conjure memories of deep lockdown and the dull ache of a phantom mask behind your ears for years to come. But many people have a murky understanding of what a semiconductor actually is. You might know that semiconductors have something to do with why your car was suddenly worth a lot more than you thought it was. But many of us would be hard pressed to explain what they actually are.

A first step would be to break down the word. A conductor, as you might remember from elementary-school science class, is something through which electrons freely move from one type of material to another. Ever gotten a shock in the winter after touching a doorknob? That's because metal is a great conductor of electricity. (In fact, so is the human body, which is why you can sometimes pass the shock on to an unsuspecting victim.) The opposite of a conductor is an insulator, which impedes the flow of electrons from one material to another. Rubber is a great insulator, which is why it's safe to be inside a car (with rubber tires) during a lightning storm.

A semiconductor is a substance that falls somewhere on the continuum between conductor and insulator. Manufacturers process silicon and other materials into semiconductors for all kinds of electronic devices that rely on harnessing electricity for processing power. And these semiconductors, or chips, are in greater demand than ever before: the Fourth Industrial Revolution (4IR), which is currently transforming manufacturing, production, and global business more generally, is characterized by smart computers and connected devices. Smart means connected, and connected means chips.

While semiconductors can open a wealth of opportunity for industries around the world, reliance on semiconductors has introduced some vulnerabilities when supply falls short of demand. In this *McKinsey Explainer*, we'll explore the roots of the pandemic-era semiconductor shortage, how organizations can mitigate the risks associated with reliance on semiconductors, and why semiconductors stand to dominate the next decade in global business.

What caused the semiconductor shortage? And why has it been so damaging?

About a year into the COVID-19 pandemic, a shortage of tiny silicon chips made big waves in industries throughout the world. In the first quarter of 2021, production assembly lines for everything from smartphones to home appliances to driver-assistance systems ground to a halt. The auto industry was particularly affected: major carmakers announced significant rollbacks in their production, causing revenue disruptions to the tune of billions of dollars. (This, in turn, caused an increase in the value of many used cars.)

Here are some of the factors that contributed to the semiconductor crisis:

— **An industry already at full capacity**
Known for its cyclicality, semiconductor manufacturing has historically been a boom-and-bust industry. After more than a decade of consolidation, industry conduct became more rational, with capacity additions closely matching demand growth since about 2016. When the pandemic hit, the industry's manufacturing assets were operating at close to 95 percent utilization.

— **Pandemic-related struggles**
The seeds of the semiconductor crisis in the auto industry can be traced to the early days of the pandemic, when auto sales plummeted globally—by as much as 80 percent in Europe. At the same time, demand spiked for personal computers, servers, and equipment for wired communication, driven by the shift to remote work. So while automakers' orders for semiconductors (for use in fuel-pressure sensors, digital speedometers, navigation displays, and more) dropped off sharply, personal-electronics manufacturers were ordering more than ever.

When the auto sector's demand recovered in the second half of 2020, the semiconductor industry had already shifted to meet the demand of other types of manufacturers.

— **The long road to building new semiconductor manufacturing facilities**
Semiconductor fabrication facilities, or "wafer fabs," take years to build and cost billions of dollars. From the decision to add a new fab, it takes even the most efficient manufacturers more than three years to build the semiconductor clean room, install equipment, and ramp up production to a high yield.

— **Geopolitical tensions**
US sanctions on China caused many Chinese companies to hoard chips, which led to political tensions and increased market pressure.

— **Contract terms**
Contracts for auto parts generally have shorter delivery times than contracts for parts in other industries. So when the auto industry was ready to place more orders, the semiconductor manufacturers were tied up in longer contracts serving other industries.

— **5G rollout and overlapping chip demand**
5G technology relies on the same type of semiconductor chips as automobiles. For this reason, automakers may experience continued chip shortages as 5G continues to roll out globally.

Is the semiconductor shortage over now?

In a word, no. In some areas like general-purpose microprocessors and memory chips, there is significant excess inventory. But there is still a global shortage of specialty chips used in certain automotive and industrial applications. Because the semiconductor industry was already under strain before the pandemic, COVID-19 created a spike in demand that the industry is still recovering from. According to McKinsey analysis, the shortage will likely persist for specific types of chips at least until summer 2025, if not longer.

What's the potential for the semiconductor industry?

The world of the future runs on semiconductors. Trends such as remote working, the proliferation of artificial intelligence, and soaring demand for electric vehicles are reshaping the world we live in. Accordingly, the global semiconductor industry is poised for a decade of growth. McKinsey projects industry revenues to climb to $1 trillion by 2030.

About 70 percent of this growth will be spurred by just three industries: automotive, computation and data storage, and wireless. In automotive alone, McKinsey foresees a tripling in demand, in part because of increasing demand for electric vehicles. On that basis, this segment would be responsible for as much as 20 percent of industry expansion over the coming years.

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How can semiconductor companies meet soaring demand?

Looking at the numbers, it seems like a pretty good time to be in the semiconductor business. Demand is soaring, and annual revenues increased 23 percent in 2021—far above the 5 percent increase reported in 2019. In 2021, shareholders in semiconductor companies saw an average of 50 percent return as semiconductors helped power the digital revolution.

But looking closer, semiconductor companies are facing significant challenges. The industry shortages that occurred during the pandemic pushed governments to bring chip manufacturing closer to home. Talent shortages, both in engineering-related roles and craft labor, will need to be addressed. Chips will become more expensive as they are manufactured in less economically advantaged locations. Finding the vast quantities of stable electric power and pure water needed for some semiconductor manufacturing processes also isn't easy.

McKinsey has identified several strategies that may help semiconductor companies improve productivity, as well as understand when capacity expansion can be justified. Here are six critical areas in which semiconductor companies can evaluate their strengths and weaknesses:

1. **Technology leadership**
   The race for dominance in the semiconductor industry is on, and the winner will be whichever company can manufacture the smallest, fastest, and most power-efficient devices.

2. **Long-term R&D**
   Semiconductor companies have proven that bold, long-term investments can eventually deliver substantial returns that benefit not just shareholders but also society as a whole. The creation of specialized chips for quantum computing, for example, could improve pharmaceutical development and sustainability programs.

3. **Resilience**
   The huge disruptions arising from the COVID-19 pandemic are still making serious waves in global business. One thing is clear: resilience is needed in all sectors to weather the uncertainties of the future. Semiconductor companies could work to become more agile, which would allow them to respond more quickly to changes in the market.

4. **Talent**
   Semiconductor manufacturing facilities are being developed in new regions, which requires new sources of talent. In addition to increasing their efforts to recruit talent, companies in the semiconductor industry can also address workplace attractiveness issues reported by employees.

5. **Ecosystem capabilities**
   Increased collaboration with other semiconductor companies could prove useful in addressing challenges related to complex chip design and competition for talent. For example, one company could develop intellectual property and license it to others.

6. **Greater capacity**
   Finally, capacity expansion could deliver benefits for some semiconductor companies. But these aren't easy decisions to make: construction for a new semiconductor fabrication plant takes up to three years and can cost as much as $5 billion. Companies should closely examine the pros and cons of accepting government subsidies, partnering with equipment manufacturers, and other potential cost-saving measures before proceeding.

If semiconductor companies can meet demand, they could sail through the next decade.

How can the semiconductor industry keep its emissions in check as it grows?

Powering the 4IR is a critical imperative. But it's not the only one. Customers are increasingly demanding that their suppliers step up efforts to reduce greenhouse-gas emissions to achieve a 1.5°C carbon pathway. Semiconductor companies have made climate commitments, but at present these commitments are not enough to limit emissions as required

by the 2016 Paris Agreement. Getting the industry to net zero will require more comprehensive, collaborative action.

Here are some steps the industry could take in the short term:

— *Gas abatement systems* could be installed to transform harmful gases into ones with less global-warming potential.

— *Heat-transfer fluids* could be replaced with ones with lower global-warming potential.

— *Fuel supplies* could be substituted with clean options like hydrogen or biomass.

In the longer term, semiconductor companies will need to shift toward a more innovative approach, making greater investment in decarbonization and showing a willingness to experiment with innovative solutions. Collaboration will be helpful here: companies could develop early-stage decarbonization technologies with start-ups and academic labs, then share with a consortium of companies.

Learn more about McKinsey's Semiconductors Practice—and check out semiconductor-related job opportunities if you're interested in working at McKinsey.

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