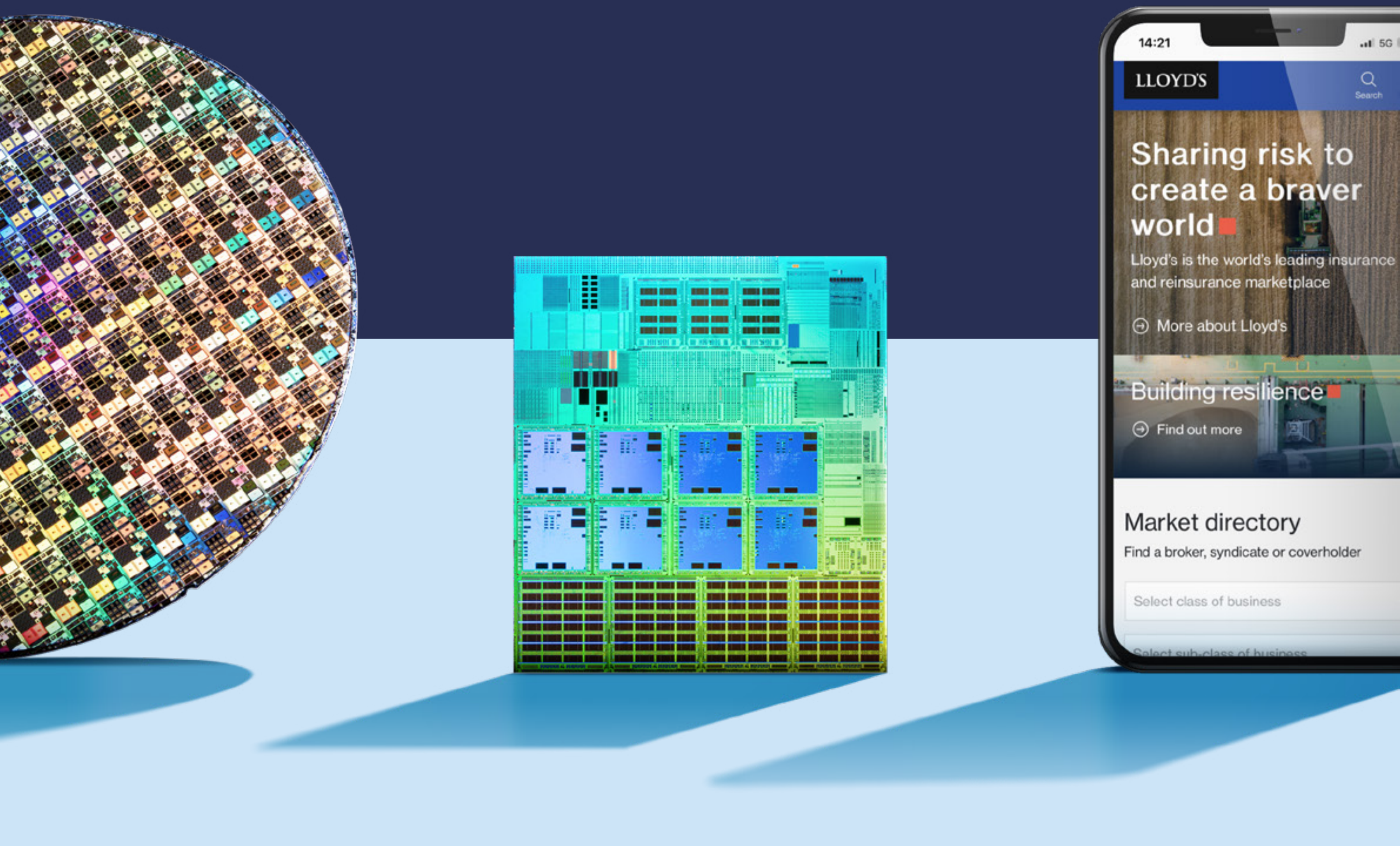
LLOYD'S | wtw

Loose connections:
Rethinking semiconductor supply chains

Part 2: The semiconductor industry

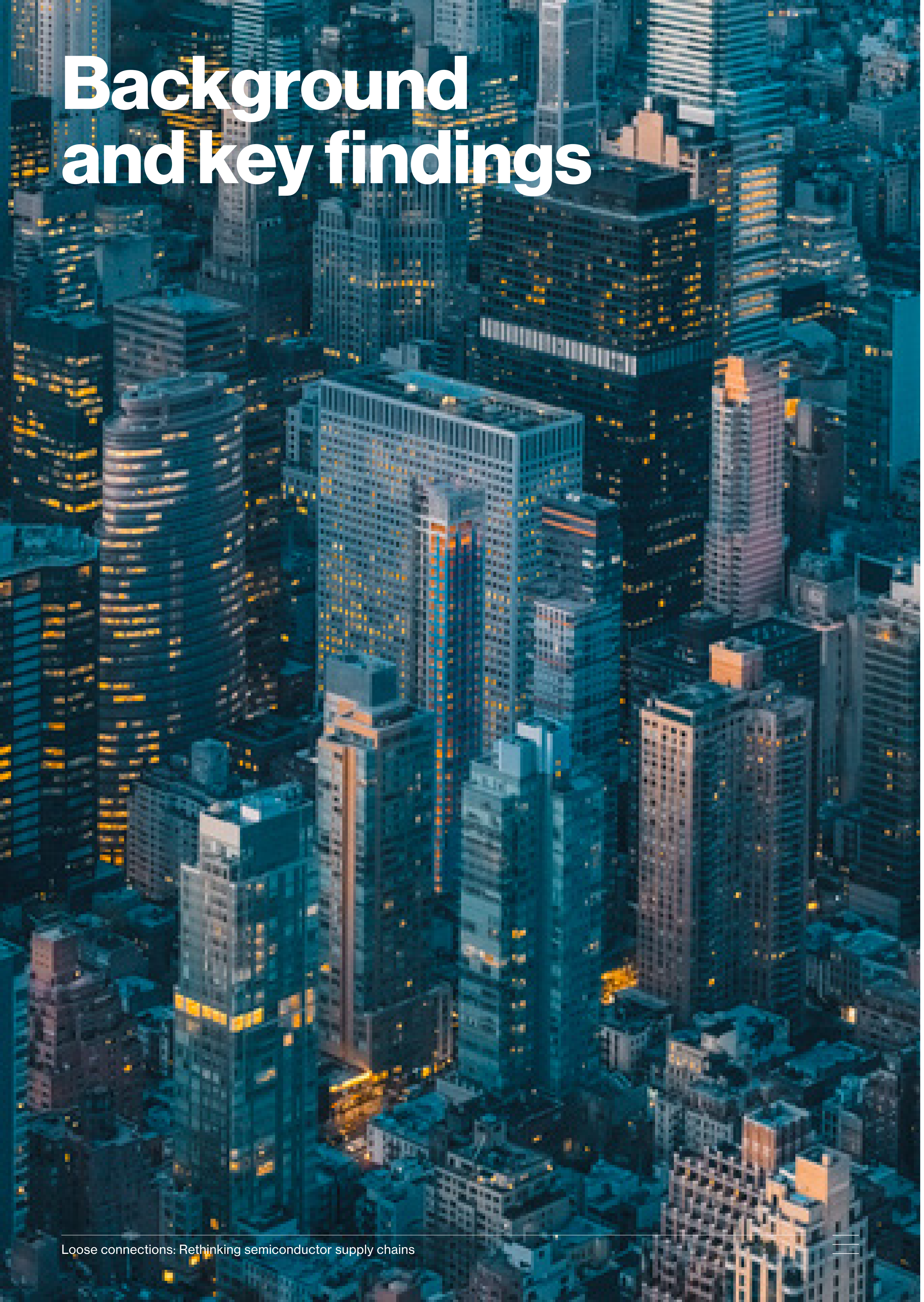


Lloyd's Futureset

Key:

- Client quotes
- Insurance case studies
- Acceleration opportunity with industry partners
- General sector insights

Background and key findings



Background and key findings

In November 2022, Lloyd's and WTW published a joint report "From farm to fork: Rethinking food and drink supply chains", the first in a series of three reports exploring supply chain risk. The report examined the food and drink sector's risk challenges with the aim of sparking product innovation.

Our second report in the series explores the semiconductor industry. Global technology businesses have always relied on a wide range of components and suppliers to get their final products from factory to customers, and in the past three decades semiconductor chips have become integral in the interconnected world of products and services. As the semiconductor industry has grown in size, volume and complexity, the associated risks have also increased.

Understanding the semiconductor industry and where it touches every sector through enabling digitisation is important to every class of business. Whereas the food and drink industry supply chain can be considered relatively linear, the semiconductor supply chain is multi-dimensional and contains several potential bottlenecks. Some are within an organisation's control and others – like geopolitical risks – have systemic elements that go beyond the balance sheet of any one institution.

This report examines those risks through a survey and interviews with over 100 semiconductor businesses to provide the insurance industry with a greater understanding of customer needs, protection gaps and potential insurance solutions (see **Section 3**). This section of the report provides a solid foundation of knowledge on the semiconductor industry and its needs.

Key findings include:

- The semiconductor sector will become even more important to the world in the coming decades, reflecting a significant and continuing demand for chips and the fact that various governments are making serious policy moves as they classify the sector as a 'critical national infrastructure'. The insurance industry will be hugely relevant for the protection of the billions of dollars' worth of investment being made in the sector and represents a real growth opportunity for insurers to demonstrate the value of insurance and develop new solutions
- Our research has shown that the majority of the sector's players are advanced in terms of their supply chain resiliency measures and have a strong willingness to do more. Semiconductor companies have invested heavily in risk management practices, including partnering with third parties to provide new data sources in the face of ongoing global change. Our interviews have shown an interest among semiconductor businesses in working with their insurance partners to increase underwriters' understanding of the industry
- Most companies that we spoke to had well-established and effective business continuity teams or arrangements in place, or were in the process of updating arrangements. Supply chain risk within the semiconductor industry, whether it relates to changes in a critical supplier or is due to international conflict, benefits from close monitoring of events and the ability to react accordingly, i.e., a blend of proactive and reactive response capability
- Increased collaboration creates opportunities to innovate and therefore develop solutions that will allow insurers to grow in partnership with the sector. This is where Lloyd's, through initiatives such as Futureset, the Lloyd's Lab, and brokers who advise the industry as risk partners can convene stakeholders, support conversations, and enable new partnerships to be forged

An introduction to the semiconductor industry

An introduction to the semiconductor industry

Semiconductors are essential enablers of all modern technologies and electronic systems. The industry fuels global progress and has registered a total market size of over $580bn worldwide in 2022[1].

The components are used as switches and transistors and are the building blocks of computer chips. The manufacture, sale and transportation of semiconductors has grown exponentially as global use and demand for computing technology has skyrocketed. Around 1.3 trillion semiconductor devices were expected to be purchased in 2022[2], with that figure boosted by increased demand for digital services, e-commerce infrastructure, and tools for remote working.

Box 1: The semiconductor basics

A semiconductor is a physical substance designed to manage and control the flow of current in electronic devices and equipment. There are two basic types of semiconductors, with most semiconductor chips and transistors created using silicon. An N-type semiconductor is used when its conductance is higher, or there is a large number of free electrons. A P-type semiconductor is used when its inductance is higher, and there are fewer free electrons.

Applied semiconductors differ significantly in each sector, but one creed holds true – their application has exploded. In 1978, a Porsche 911 GSeries had approximately eight semiconductors. By 2022, electric vehicles have an estimated 5,000–7,000 semiconductors[3]. Electronic products often hold multiple types of semiconductors, as different compounds and designs are required for the different functions involved in processing, display, facial recognition and communication (e.g. 5G) capabilities[4].

Semiconductors are used in communications, power generation, artificial intelligence, electric and autonomous vehicles, robotics, healthcare, military technology, and quantum and cloud computing. If there is a disruption or slowdown to the manufacturing process, the material implications are felt globally.

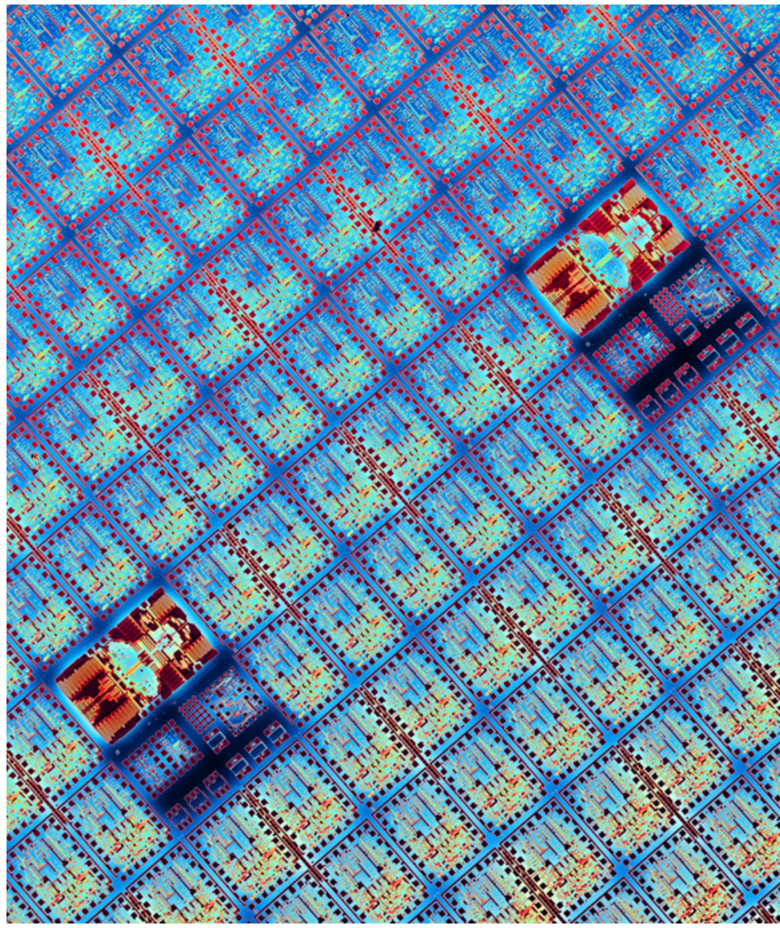
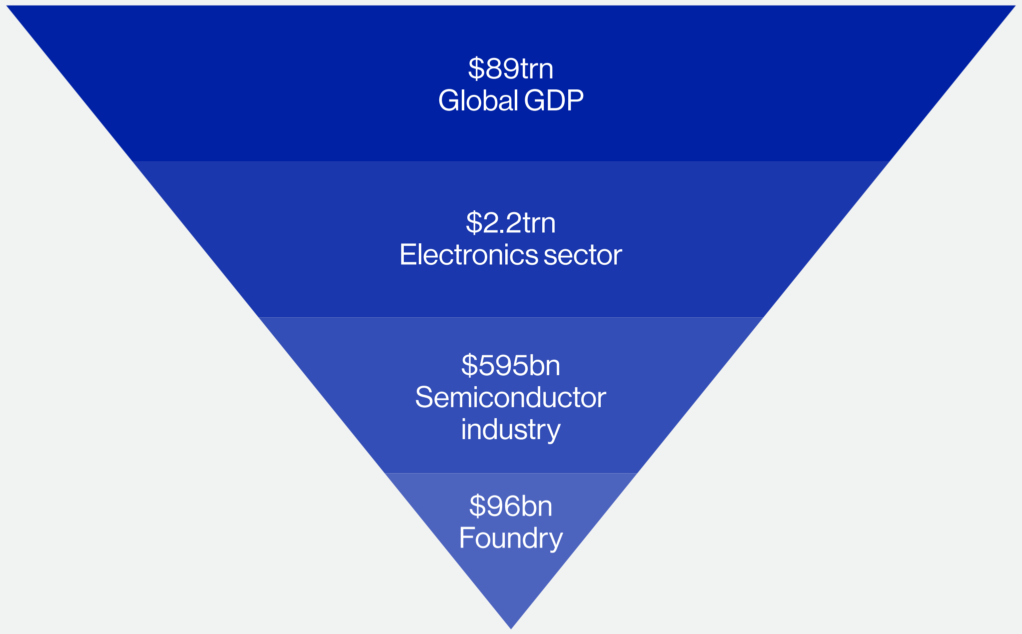


Figure 1: Underpinning global growth



Source: AMD SEC filing[5]

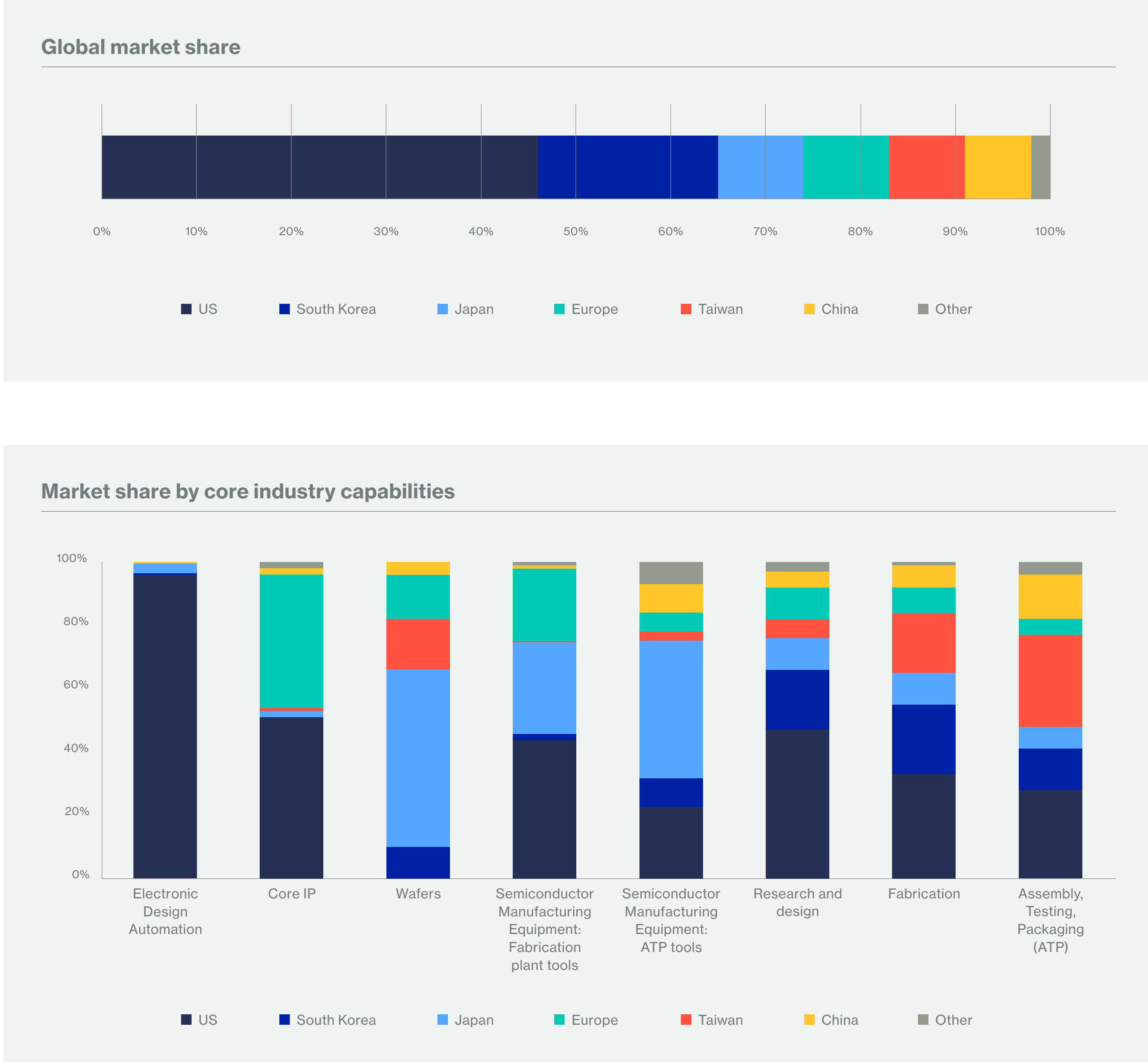
As one of the most capital and planning-intensive industries, semiconductor supply chains have been designed to be extra efficient using lean manufacturing. As the value chain extends globally, however, it is faced with key bottlenecks in geographies such as the U.S. and Asia (see **Figures 2-4**), where the risk of supply chains being impacted by sudden natural or manmade disruptions is high.

Understanding the sector and the risks involved therefore presents an area of interest for insurers across every class of business, and for everyone from underwriters to claims professionals to explore.

Industry research forecasts that global semiconductor revenue may total $596 billion in 2023, down from the previous forecast of $623bn[6], the first annual contraction since 2019. While 2022 saw the sector's market cap shrink, the global semiconductor industry is anticipated to grow to $1trn in revenues by 2030[7], almost doubling in size this decade.

This makes the sector relatively small when compared to food and drink, but long-term industry success relies on a stable political and business environment that enables collaboration globally and among all ecosystem players. No single country has end-to-end dominance over the production and supply segments that result in finished semiconductor chips, with different key countries each leading separate market segments that rely on one another (see **Figure 2**, to the right).

Figure 2: Understanding market dynamics
2021 data which includes all subsectors of the value chain



Source: Adapted from Centre for Security and Emerging Technology[8], SIA[9]

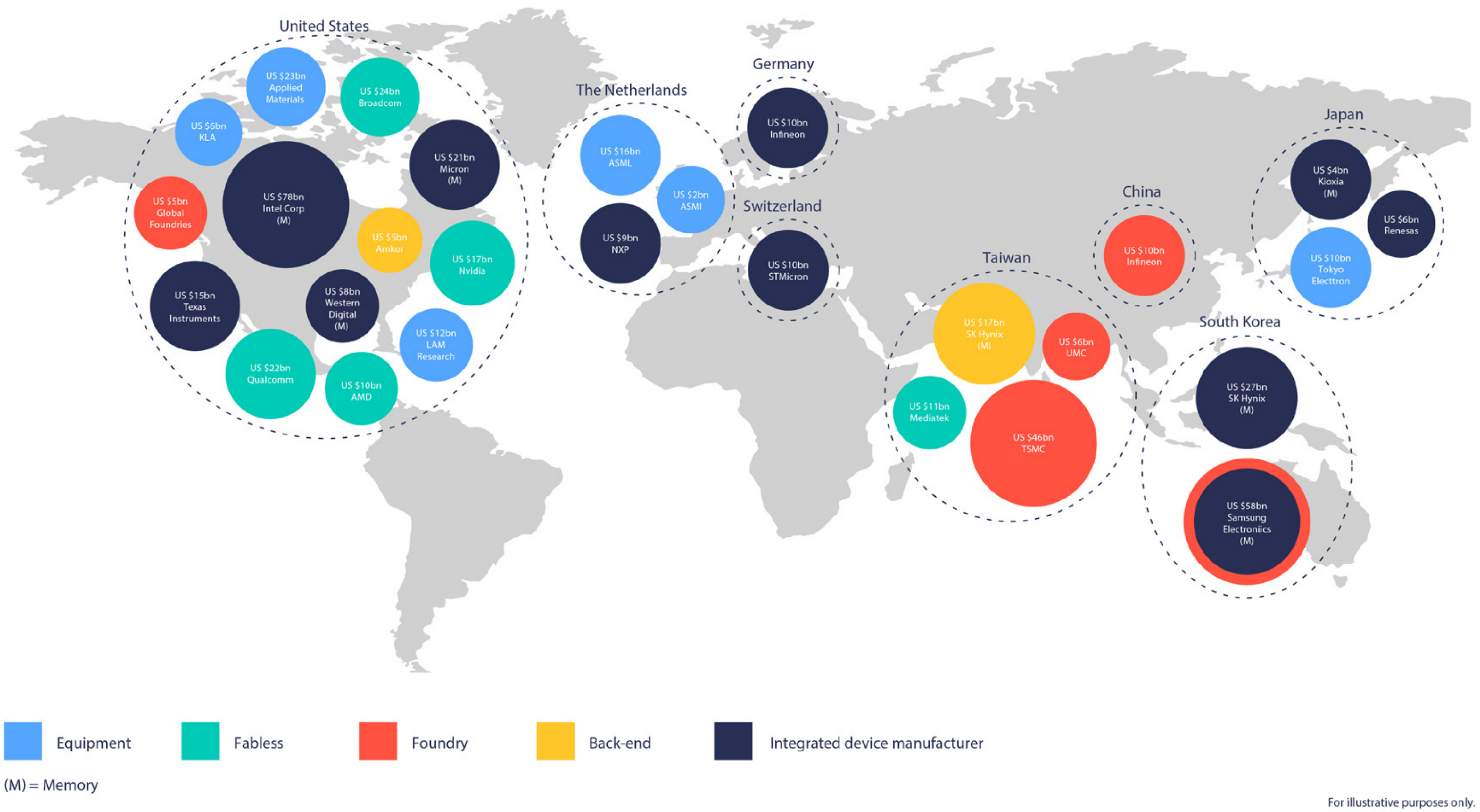
The semiconductor industry's global revenue is dominated by the U.S.[10], which has held the lead market share since the 1990s. While demand drivers in the short term are still responding to societal and economic change from COVID-19, over the next decade further innovation in semiconductors will enable a host of transformative technologies, including artificial intelligence (AI), autonomous electric vehicles, and the internet of things (IoT).

Global production is highly concentrated in East Asia, mainly Taiwan and South Korea, a region significantly exposed to high seismic activity and geopolitical tensions[11].

As well as geographical variations, the natural progression towards specialisation in the semiconductor industry is the result of ever-increasing technical complexity and rising costs, with companies splitting activities based on geographical centres of excellence.

East Asia hosts the bulk of capital-intensive activities such as wafer fabrication and production of materials. This is due to the availability of the required infrastructure, cost efficiencies, a skilled manufacturing workforce and government subsidies. Intel estimates[12] it can cost 40%–50% more to operate a semiconductor fabrication plant - known as a “fab” - in Europe compared to other areas of the world, where governments may subsidize manufacturing.

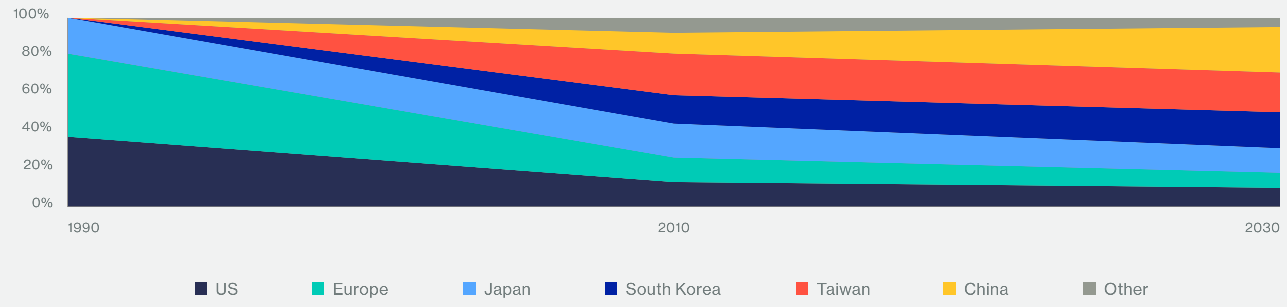
Figure 3: Key global semiconductor business model companies by country



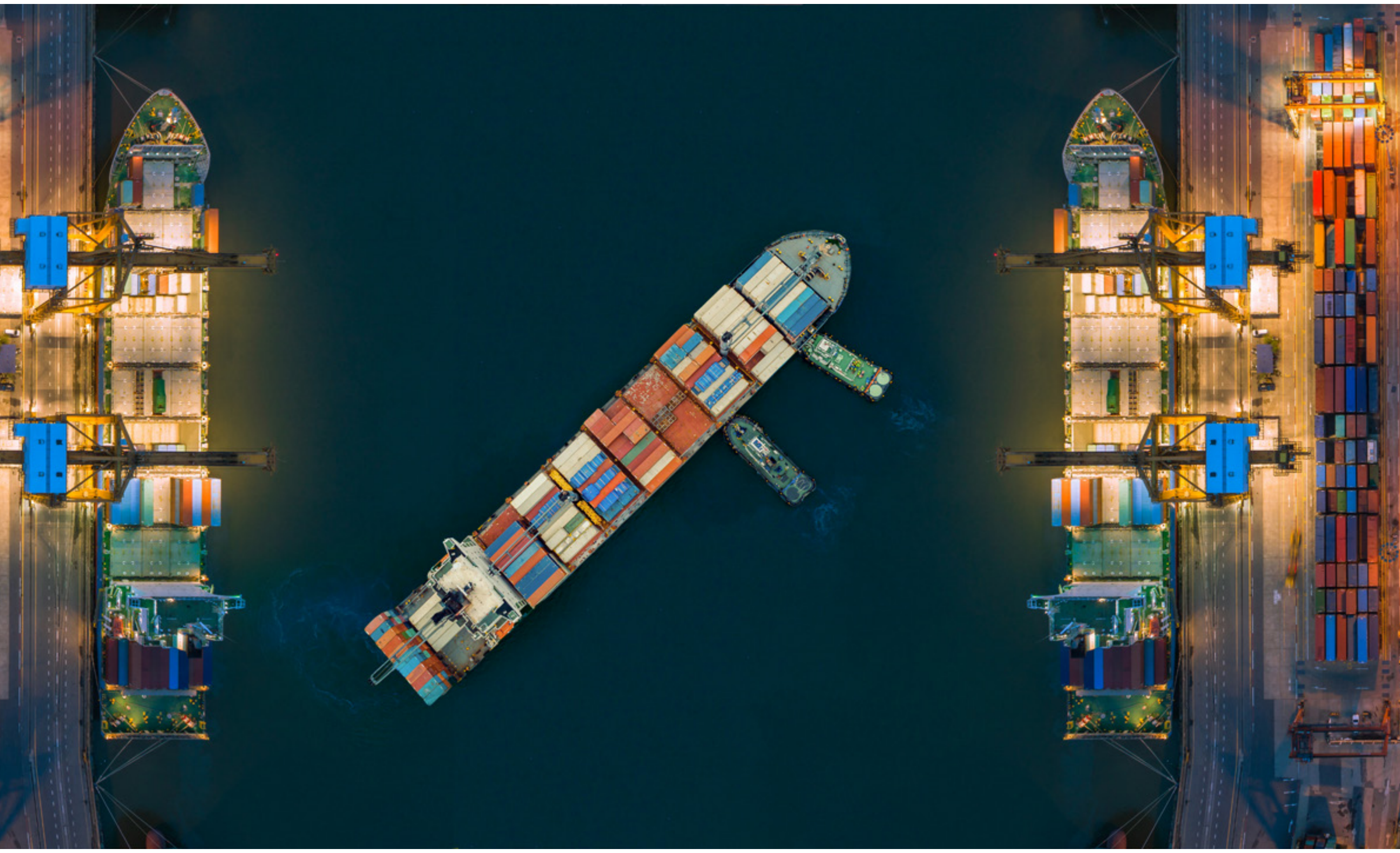
Source: ING[13]
Note: All revenues are for 2020. Samsung revenue figures are for its semiconductor segment. Western Digital revenue figure is only for Flash memory segment. List of companies is for illustrative purposes, and should not be considered exhaustive.

Looking forward, industry research estimates that while the U.S. and Europe will look to hold on to expertise in certain fields, the rise of investment and manufacturing centres in South Korea, Taiwan and mainland China since the 1990s will continue to shift the market. Geopolitical dynamics are increasing the stresses on an industry that relies on segmenting an incredibly complex process.

Figure 4: Global manufacturing capacity by location (%)



Source: Adapted from SIA and BCG[14]



Attributes of the semiconductor industry

Highly competitive

- The semiconductor industry is highly cyclical, subject to periodic booms and busts. High consumer expectations for innovation in electronics puts constant pressure on price, quality and, more recently, sustainability
- While there are pressures both upstream and downstream, capital investment (e.g., for new machines or factories) is very intensive and takes considerable time to complete. Geopolitical tensions and national security concerns are also pushing countries to explore ways of enticing semiconductor companies to onshore and to establish bases to help protect intellectual property
- Efficiency is increasingly important, with growing use of technology for operational gains, and increased sustainability an industry-wide priority
- As more electronic products require one or more chips to be integrated into their design, average annual semiconductor sales have typically trended upwards since the 1960s. However, the industry has experienced periods of both growth and contraction in past decades, making investment decisions tricky for the industry and its capital providers

Highly specialised

- The semiconductor industry relies on a simple creed: smaller, faster, cheaper. The benefit of being small is that more power can be placed on the same chip. The more transistors there are on a chip, the faster it can do its work. This creates fierce competition in the industry and drives new technologies which lower the cost of production per chip
- Semiconductor businesses and products are highly specialised, according to whether they are used in communications infrastructure, power generation, artificial intelligence, electric and autonomous vehicles, robotics, healthcare, military technology, quantum and cloud computing, or everyday consumer devices
- The industry's record of steady technological improvement has created a 'winner-takes-all' dynamic that makes leading-edge capabilities vital within several segments. While there are signs of industry consolidation, this is not happening at pace and the supplier ecosystem remains fragmented, with interdependence continuing to be a significant challenge. There is fierce competition for specialised talent and labour demand at all levels, from design, to engineers, to management
- The semiconductor supply chain is complex and has barriers to entry (for example, capital intensity, highly specialised know-how and vertically integrated competitors). Industry estimates[15] suggest each chip factory takes a minimum of $10 billion and five years to build, from breaking ground to production of chips

Fast moving

- Adaptability, flexibility and speed are key to survival. However, the time from design to completion, or for the construction of a new semiconductor fabrication plant, is often considerable, making capex investments risky for the industry
- Constantly changing consumer behaviours and preferences in the consumer and corporate electronics end-market is making forecasting, and therefore design and investment decisions, difficult for semiconductor companies
- There is constant pressure on chipmakers (as well as other companies in the value chain) to develop and produce something better, and at an even lower price, than before. What was defined as state-of-the-art only a few months beforehand may be redundant in the next few months. Therefore, semiconductor companies need to maintain large research and development budgets
- The buyer market is experiencing its own growth, with chips rising in their importance and capabilities for specific products where they are embedded. For example, the number of semiconductors used per automobile is expected to double between 2013 and 2030[16]

Highly integrated and global

- The semiconductor industry is a hugely important sector for many of the world's major economies, with semiconductor components found in a wide range of consumer and commercial products – from vehicles to computers, to mobile devices and personal electronics
- The microchip manufacturing process is complex and completely global in nature, involving a competitive and highly integrated international supply chain. With each link in this complex supply chain controlled by a different entity, and potentially in a different geography, there is little conformity across the risks and levels of preparedness
- The semiconductor supply chain is multi-dimensional and contains several potential choke points. Some are within an organisation's control and others, like geopolitical risks, have systemic elements that go beyond the balance sheet of any one institution
- The semiconductor industry is increasingly classified as a critical national infrastructure industry in key geographies globally. The industry is increasingly facing additional political and regulatory pressures

> "One of the most striking developments has been the rise, fall and rise again of the semiconductor industry of the United States, which is, once again, the dominant player in the most advanced semiconductor product-markets
>
> **Peter Dicken[21]**

> "The chips industry has one of the highest R&D margins across all industries – semiconductor companies easily spend on average more than 18% of their revenue on R&D
>
> **Technology industry thinktank leader**

> "Data is today's new business currency, and memory and storage are a critical foundation for the data economy. Memory and storage innovations will help transform society and enable significant value for all
>
> **Global Semiconductor company executive**

> "There is no digital without chips. And while we speak, whole production lines are already working at reduced speed - despite growing demand - because of a shortage of semiconductors
>
> **EU President von der Leyen, 2021 State of the Union address[22]**

Loose connections: Rethinking semiconductor supply chains

The subsectors of the semiconductor industry: How they work, market drivers and trends

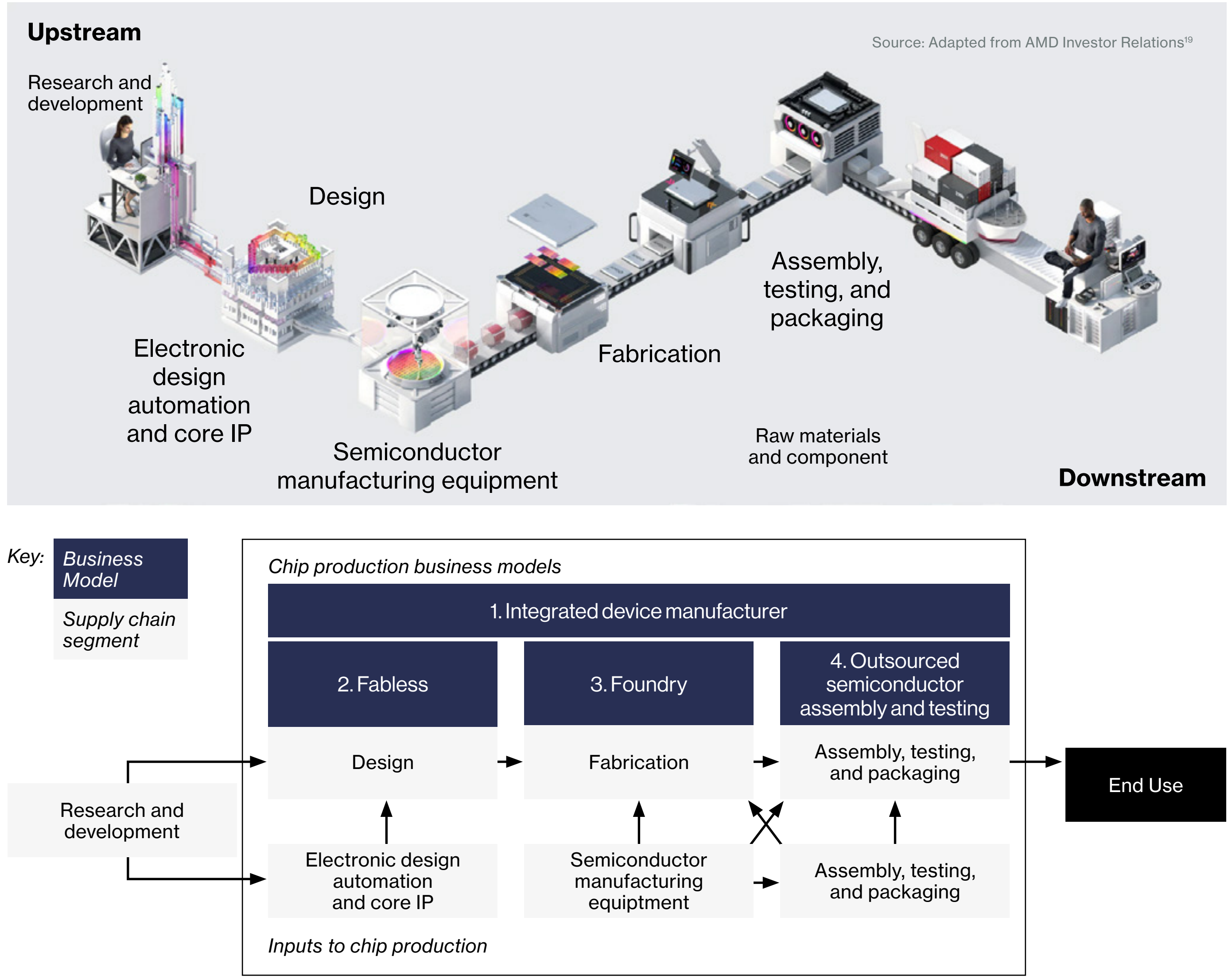
The subsectors of the semiconductor industry: How they work, market drivers and trends

The market and supply chain for semiconductors is global and complex. Multiple companies across the world, each specialising in one or more steps of the process, make up the supply chain.

Each business contributes its components or resources into specific parts of production until finally a chip factory has all the designs, equipment, and materials necessary to manufacture a chip. Intellectual property and trademarks are the lifeblood of the industry and protecting these is essential to a company's success.

The semiconductor industry can be divided into a series of different business models and capabilities, responsible for different steps from factory to consumer (see **Figure 5**).

Figure 5: Semiconductor subsectors



The semiconductor production process is often multi-layered; most companies specialise in certain steps within the value chain, but may also outsource some activities, including printed circuit board assembly, to a sub-contractor or fabrication partner.

The four key business models are integrated device manufacturers, fabless, foundry, and outsourced semiconductor assembly and testing companies:

- **Integrated device manufacturers (IDMs):** IDMs design, manufacture, and sell integrated circuit (IC) products. In the early days of the semiconductor industry, when IC complexity was low and IC design, fabrication and test processes were forming, the IDM business model worked well. In a mature semiconductor industry in which product complexity is high, it is increasingly impractical and cost prohibitive for one company to handle all the processes[20]
- **Fabless companies:** Fabless chip makers are companies that design and produce semiconductors for use in various types of electronics, such as digital cameras, smartphones, and the new technologically sophisticated “smart” cars. The term "fabless" means that the company designs and sells the hardware and semiconductor chips but does not manufacture the silicon wafers, or chips, used in its products. Instead, it outsources the fabrication to a manufacturing plant
- **Foundry:** A semiconductor foundry (a fab) is a factory where devices such as ICs are manufactured. Foundries are expensive and complicated to construct/operate and are geographically are concentrated in just a few places.They are mainly located in Asia, with Korea and Taiwan leading the way in fabrication. The operating environments at foundries are vast and complex. Depending on the design, each chip might require anywhere between 1,000 and 2,000 steps to produce it. Fabs are very expensive to build due to their requirements around cleanliness, typically needing to have ~1,000 times cleaner air quality compared with normal factories
- **Outsourced semiconductor assembly and testing (OSAT):** OSAT companies remove chips from the wafers produced by foundries, and add the electrical contacts required to enable integration with printed circuit boards and electrical systems. They also provide a wide range of semiconductor test services for foundries, including final system-level, wafer, and strip testing along with the complete end of line services, up to and including final shipping to the end customers

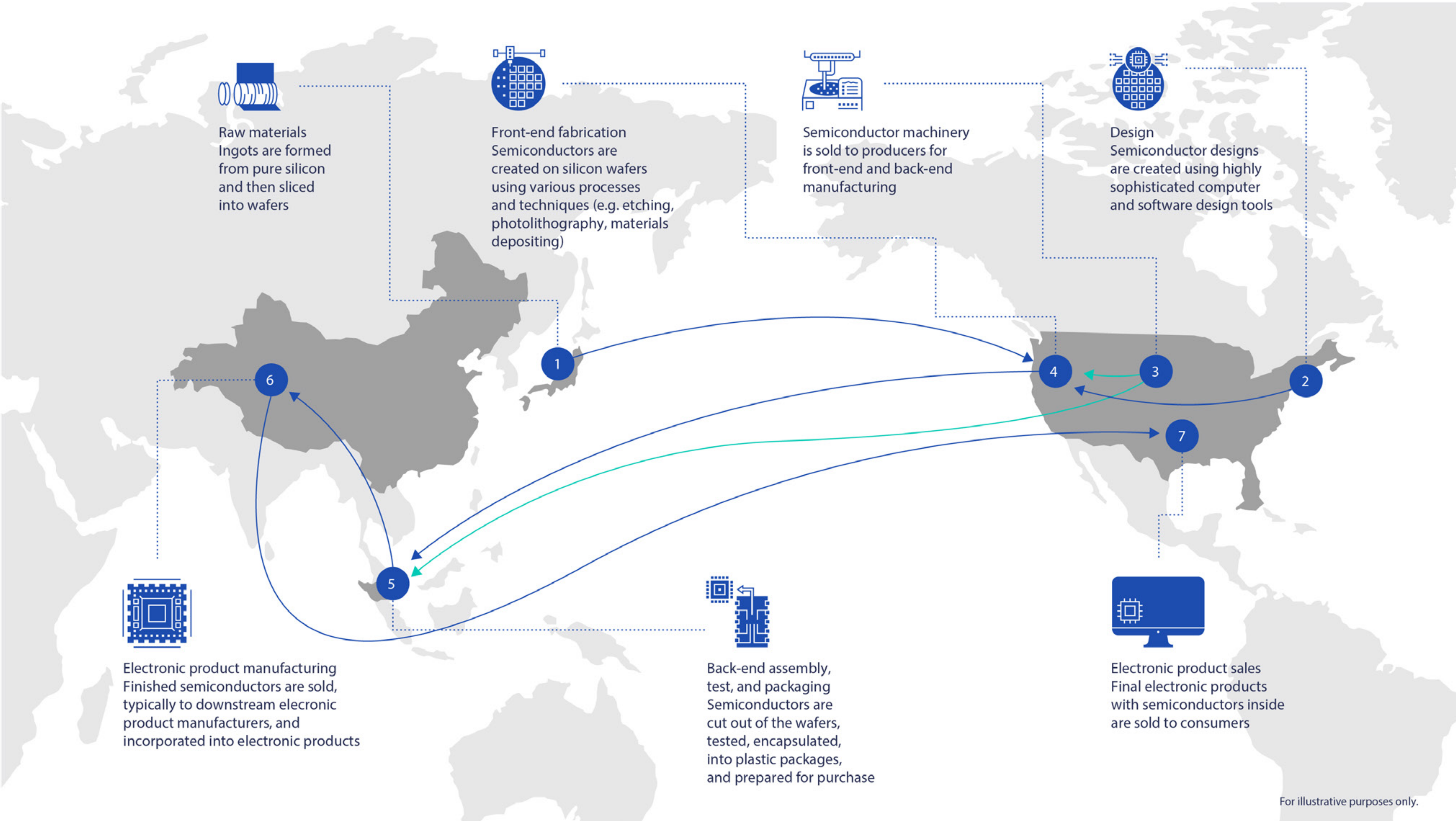
These business models are made up of – and rely on – key subsectors:

- **Research and development, and design companies:** The semiconductor industry is one of the most intensive industries in the world for research and development (R&D), and companies in this space develop future designs for semiconductors and new manufacturing and material techniques. A typical spend of between 15-20% of sales on R&D is not uncommon
- **Electronic design automation (EDA) companies:** This subsector consists of (primarily) software, hardware, and other specialised services with the collective goal of assisting in the definition, planning, design, implementation, verification, and subsequent manufacturing of semiconductor devices, or chips. The cost of an error in a manufactured chip can be catastrophic. Chips errors cannot be “patched.” The entire chip must be re-designed and re-manufactured. The complexity of design chips is high and the need to do it flawlessly has resulted in highly specialised software tools
- **Semiconductor equipment manufacturers, capital equipment companies:** The semiconductor capital equipment industry markets and manufactures the key equipment used in processing, production and packaging of semiconductors and other electronic components. Without, production lines do not move. The industry is facing ever-higher demands for key manufacturing equipment, and with a limited supply of specialists the ability to fulfil demand and keep pace with capacity expansions is restricted
- **Raw materials:** Semiconductor materials vary in price and availability, from abundant silicon to difficult-to-source rare-earth elements like scandium. Raw materials are supplied from Europe, the U.S., Russia, Japan, and Mexico, as well as many other countries. Without raw materials chips cannot move off the drawing board into production

In our conversations with semiconductor companies, many felt that the wider insurance market has been slow to meet the needs of the sector and its robust management; highlighting the value of this report in sharing more information between the industry and insurers and opening up understanding of the sector to new underwriters. To support this, detailed profiles of these business models and key subsectors can be found at the back of this report in the appendix.

When all production phases are considered, the entire process extends from material procurement to back-end manufacturing and multiple international journeys take place before the final chip is available (see **Figure 6)**.

Figure 6: Example of value chain flows



Source: Congressional Research Services Report[21]

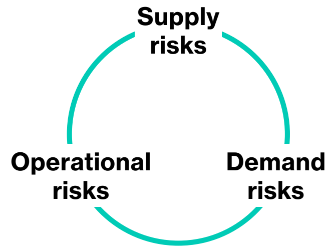
Supply chain risks in the semiconductor industry

Supply chain risks in the semiconductor industry

The microchip manufacturing process is complex and completely global in nature, involving a competitive, and highly integrated international supply chain that contains several potential bottlenecks. Some supply chain risks are within an organisation's control and others – like geopolitical risks, or extreme weather – have systemic elements that go beyond the balance sheet of any single institution.

Supply risks:	Impact inbound supply (critical raw materials, specialised packaging and/or components etc.), meaning that a chain of suppliers cannot meet the demand in terms of quantity and/or quality of finished goods
Operational risks:	Impact elements within a supply chain, impairing its ability to supply service or finished goods within the standard requirements of time, cost, and quality. With a truly global supply chain, one needs to review potential operational risk disruptions across a wide spectrum of companies
Demand risks:	Impact elements of the outbound supply chain where the extent or the fluctuation of the demand is unexpected. Semiconductors, as end products, are used by a wide range of industries so demand analysis and forecast are complicated

Figure 7. Supply chain risks and drivers



Factors

Environmental	Geopolitical	Economic	Technological
– Natural disasters – Extreme weather – Pandemics and epidemics	– Political instability – Trade restrictions – Terrorism – Theft and illicit trade – Piracy	– Demand shocks – Price volitility – Border delays – Currency fluctuations – Energy shortages	– ICT distruptions – Infrastructure failures

The global structure of the semiconductor industry creates enormous value for consumers, businesses, and governments. The industry is highly reliant on its global value chain and will continue to be so for the foreseeable future, with key semiconductor dependencies such as TSMC (Taiwan Semiconductor Manufacturing Company) chips, and ASML (Advanced Semiconductor Materials Lithography) equipment. To give a sense of the scale of potential asset accumulation across the industry, in 2016, RMS estimated $319bn of insured value at the Hsinchu Science Park[22] - a key centre of semiconductor production in Taiwan.

Box 2: Recent trends impacting semiconductor supply chains

- **Early 2020 - The pandemic:** The COVID-19 pandemic caused massive disruption in supply chains and logistics. This was coupled with a 13% increase in global demand for PCs as people worked from home. Chips were suddenly unavailable for the manufacture of a broad range of products.
- **Late 2020 - Trade war between US and China:** As part of the economic conflict between China and the United States, the US Department of Commerce imposed restrictions on China's largest chip manufacturer, Semiconductor Manufacturing International Corporation (SMIC), which made it harder for them to sell to companies with American ties.
- **2021 - Cryptocurrency sees chip demand soar:** The increased use of cryptocurrencies requires a huge amount of data mining, all done with specialised computers. The high demand for cryptocurrency mining machines reduced the availability of chips for other uses. The collapse of cryptocurrencies since then has eased the problem.
- **Summer 2021 - Severe weather in Taiwan:** Taiwan is the leading producer of chips. Severe droughts in the summer of 2021 affected output[23]. The droughts affected production due to the lack of available ultra-pure water needed to clean the silicon wafers used in microprocessors. The Taiwanese government was reported[24] to have re-routed water supplies from 20% of irrigated farmland and limited water access in three cities two days per week to help TSMC. The company is reported to have taken further steps[25] to truck water in and explore its own desalinisations plants to secure future water access.

Examples of supply chain losses and drivers

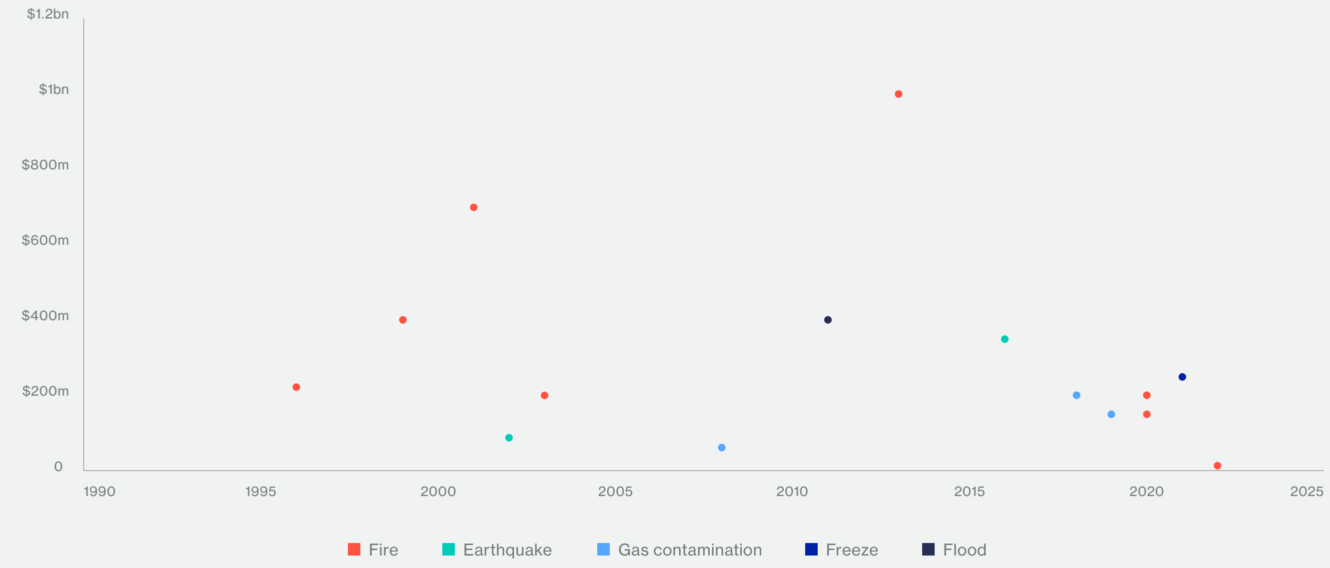
Not all risks can be mitigated, and when supply chain disruption events occur and impact physical assets, the resulting losses can be high for both the industry and those who depend on semiconductor chips. As a result, supply chain risks are at the forefront of semiconductor companies' minds. Regardless of the source, an interruption to a supply chain can cause an array of problems; from loss of market share and revenue to reputational damage, breach of contract and damage to stock price. Semiconductor companies are aware of and are actively managing their supply chain risks.

Examples of supply chain losses within the semiconductor industry

- **Freeze:** In 2021, a freeze event in Texas forced three major semiconductor plants to close, exacerbating a global pandemic-triggered semiconductor shortage and further slowing production of microchip-dependent cars[26]. The outages also forced railroad closures, severing heavily used supply chain links between Texas and the Pacific Northwest for three days. Cooling units and the energy supplier 'failed', with no power to keep the manufacturing, including clean rooms running. Further supply chain cascades included Honda in the U.S. and Canada coming to an almost total standstill.

  Texas is a self-governed power state with an open market. As the freeze worsened, Austin Power had to shut down all power or risk overloading the entire system. The event is estimated to have caused economic losses up to $155bn[27], and an estimated $15bn[28] of insured losses nationwide.
- **Drought:** During 2022, Europe and Asia saw extreme heatwaves that led to the drying of key reservoirs and crucial waterways, threatening companies' ability to operate. Taiwan experienced its worst drought in over 50 years[29], highlighting semiconductor manufacturers' exposures to water shortages. Taiwanese companies had to resort to trucking in tanks of water to maintain production.
- **Fire:** In 2018, a fire caused a 30-minute power failure, which resulted in all wafers in production at a Samsung plant being discarded. Approximately $45m worth of assets were lost in production. In 2021, a fire in one of Renesas' Japanese factories caused a 100-day return to normal production and an estimated $200m sales loss[30].
- **Cyber:** In 2020, Tower Semiconductor in Israel was the target of a ransomware attack that held its servers hostage. Forced to shut down production, Tower Semiconductor was reported to have paid[31] the ransom demand to return production to full capacity.
- **Key supplier failure:** In Japan in 1993[32] a fire and resulting explosion destroyed a Sumitomo Chemical plant that at the time supplied 65% of the world's epoxy resin used in manufacturing semiconductor housings and packaging, highlighting a key supplier vulnerability that had not been identified within the industry. Global chip production slowed while companies looked to establish new sources.
- **Downstream impacts:** Ericsson lost €400m after their supplier's semiconductor plant in New Mexico caught fire in 2000[33] when a lightning bolt hit its electricity source and induced a short power outage. In the absence of an alternative power generator, fire sparked; it was extinguished 10 minutes later but affected some critical equipment. Two production lines were stopped for three weeks and were unable to reach normal capacity for months. The disrupted process was extremely specific, and Ericsson failed to find an alternative supplier promptly[34].

Figure 8: Global semiconductor losses



Source: Compiled from various sources[35]

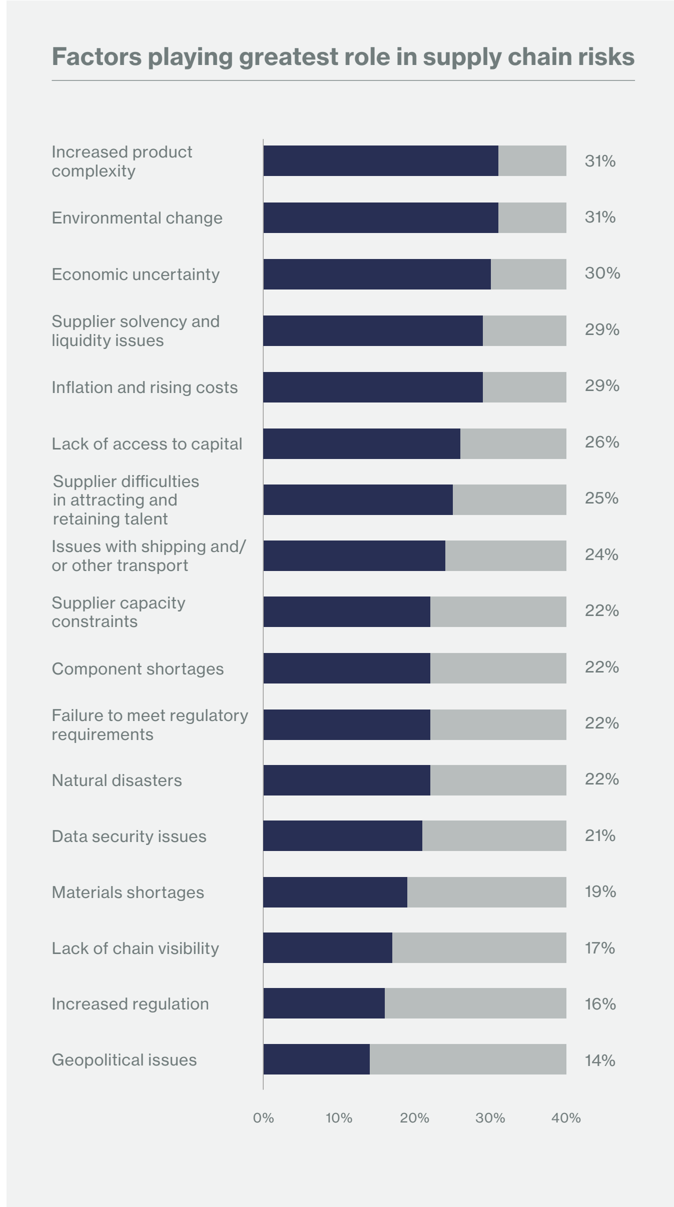
WTW Global Supply Chain Survey 2023

To gain a view on the risk factors playing the greatest role in supply chain risks, what's driving them, and what they expect to face in the short term, as part of this research series, WTW surveyed 100 risk leaders in global semiconductor companies.

- Pandemics and health-related risks to supply chain were cited by 7-in-10 companies as a top three concern
- Cyber risks emerged as a high priority issue affecting the supply chain for almost 1-in-4 businesses
- 1-in-5 businesses are concerned about data security risks
- Increased product complexity, environmental change, economic uncertainty and supplier solvency and liquidity issues feature at the top of semiconductor companies' agendas when managing supply chains
- Inflation and rising costs currently concern only 3-in-10 companies

Business leaders are optimistic that, with the foresight to respond to and manage these risk factors, long-term risk can be more than halved.

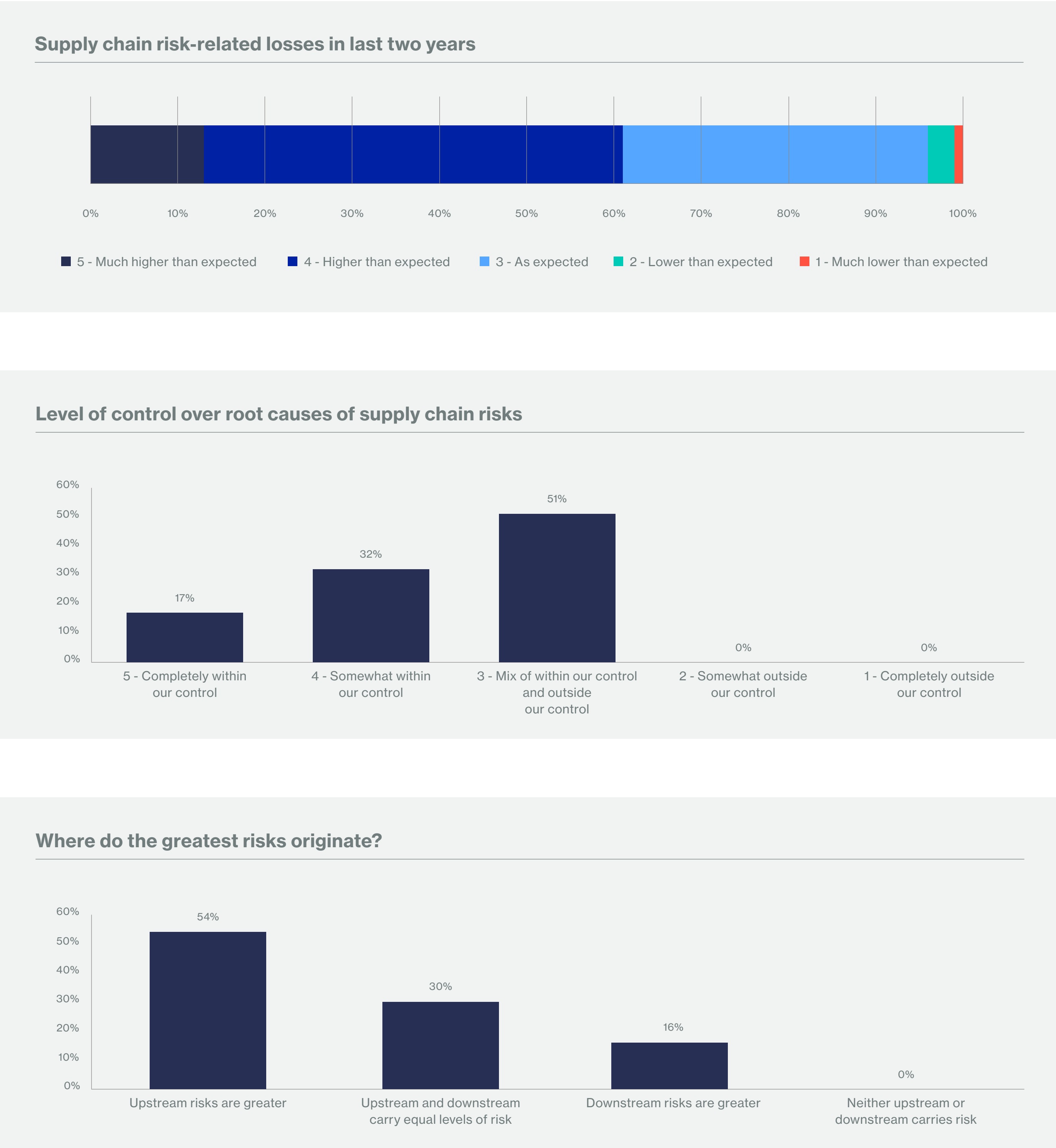
Figure 9: WTW Global Supply Chain Survey 2023 key trends, factors and risks for the semiconductor industry



Source: WTW Global Supply Chain Survey 2023

Greater emphasis was placed on supply chain risk originating upstream, although 1-in-3 feel that both up- and downstream carried equal levels of risk. At least half of the companies feel confident that they have the ability to manage root causes of risks to supply chain, and 7-in-10 have at least some influence over the quality of supply chain risk management.

Figure 10: Where do the greater risks to your organisation come from in your supply chain?



Source: WTW Global Supply Chain Survey 2023, semiconductor companies

Looking forward, semiconductor companies were also asked what supply chain challenges they expect to face in the next two years.

Figure 11: Semiconductor supply chain challenges companies expect to face in the next two years

Raw material shortages 43%	Energy or other service interruptions 40%	Shipping container shortages 35%	Just-in-time operating models 34%	Component or ingredient shortages 34%
Shortage of talent 34%	Logistics and warehousing shortages 33%	Regulation changes 32%	Construction delays 26%	Shortage of drivers 25%
Transport issues 23%	Natural disasters 22%	Cyber security 19%		

Source: WTW Global Supply Chain Survey 2023, semiconductor companies

What supply chain risks are semiconductor companies concerned about?

Table 1 (below) highlights the key strategic and operational supply chain risks facing the semiconductor industry across its global value chain/key subsectors. Notable risks stem from dependence upon other critical factors, such as water, energy, transportation, governments, labour, key inputs (raw materials and components), and technology/data communications. Location (of a fabrication facility or key supplier), and the concentration into a single or limited number of sites, is a crucial pinch point for vulnerability in the supply chain, particularly if those sites rely on a sole source utility such as water or are susceptible to adverse weather.

Some of these key supply chain risks have potential insurability challenges, highlighted in *italics* and darker row colouring. These include potentially systemic risks such as pandemics, macroeconomic factors (e.g. inflation), currency fluctuations, or environmental factors (e.g. climate change, resource, and water loss). Other commercial trading risks like fines or penalties, movement restrictions, or labour availability are also often excluded from cover, as are non-damage supply chain risks like fuel shortages.

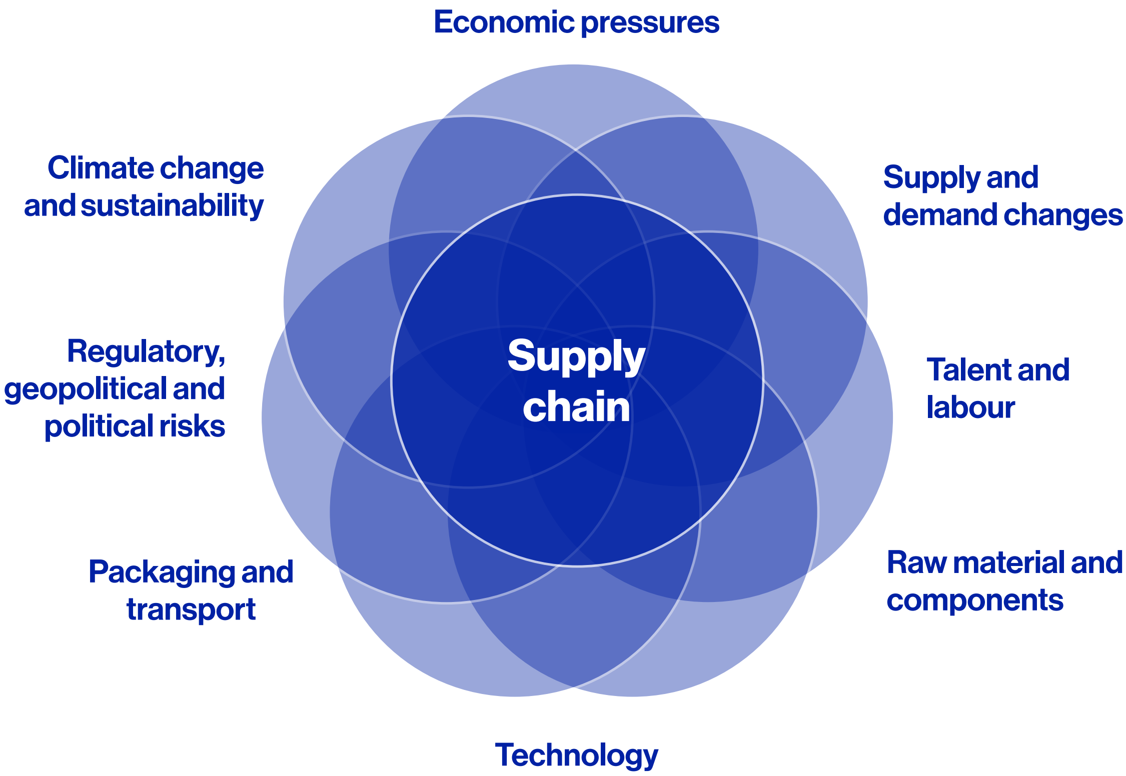
Category	Risk Description	Raw materials and chemicals	Research and design	Fabrication	Assembly, test and packaging	Semiconductor capital equipment and tools	Electronic product manufacturing and sale
Financial	*Currency fluctuation*	X		X	X	X	X
Financial	*Financial penalties (e.g. fines, litigation costs)*		X	X		X	X
Financial	*Profit reduction due for example to global recession and sharp decline in demand (e.g. Decline in stock price following wrongdoing/failures/conflicts within supply chain due to semiconductor producer/processor/retailer/ buyer)*	X	X	X	X	X	X
Financial	*Cost inflation, raw materials and inputs (e.g. disproportionate rise in transport costs due to changing business model in transport industry)*	X	X	X	X	X	X
Financial	Loss of a key customer (e.g. payment default, customer business model failure)	X	X	X	X	X	X
Operational - adverse weather	*Climate change - negative effect of climate change on supply chain*	X	X	X	X	X	X
Operational - adverse weather	Adverse weather e.g. Texas freeze, Thai floods, storm surge	X	X	X	X	X	X
Operational - adverse weather	Drought/water shortage/availability of water	X		X		X	
Operational - inputs	*Pandemic - global and systemic (e.g. affects supply continuity/employees/ reduces demand)*	X	X	X	X	X	X
Operational - inputs	Epidemic - regionalised or localised (e.g. affects supply continuity/employees/ reduces demand)	X	X	X	X	X	X
Operational - inputs	*Shortage of a key raw material or input (e.g. silicon, gallium arsenide, germanium)*		X	X	X	X	X
Operational - inputs	Failure of utilities/critical supplies (e.g. electricity, water, liquid nitrogen)	X	X	X	X	X	X
Operational - inputs	Loss of a key supplier (due to hub distribution failure, technology issue, property damage, solvency or reputational issue)	X	X	X	X	X	X
Operational - inputs	Intellectual property (e.g. source code security, chip design and testing)		X	X	X	X	X

Category	Risk Description	Raw materials and chemicals	Research and design	Fabrication	Assembly, test and packaging	Semiconductor capital equipment and tools	Electronic product manufacturing and sale
Operational - inputs	*Labour availability (national and transnational, talent mobility, retention, recruitment, law changes)*	X	X	X	X	X	X
Operational - outputs	Product defect/contamination (e.g. could be as a result of system defect or malicious activity that results in recall, integrity and traceability)	X	X	X	X	X	X
Operational - outputs	*Failure to forecast future demand results in supply chain delay*	X	X	X	X	X	X
Operational - property damage	Denied access/egress (e.g. regulatory or otherwise), at owned or third-party premises	X	X	X	X	X	X
Operational - property damage	Significant property damage event at own business location (e.g. fire, flood, access to water impaired), that may destroy/damage buffer stocks	X	X	X	X	X	X
Operational - property damage	Damage to third party premises (e.g. warehouse, supplier premises, customer premises, systems disruption)	X	X	X	X	X	X
Operational - property damage	Natural catastrophe event(s). (e.g. earthquake, volcanic eruption), affects key supplier(s) and/or transportation	X	X	X	X	X	X
Operational - technology	Cyber issues (e.g. attack on suppliers or logistics parties, data loss, ransomware, denial of service)	X	X	X	X	X	X
Operational - technology	Breakdown or unavailability of key equipment, and consequent business interruption	X	X	X	X	X	X
Operational - transportation	*Fuel shortage prevents transportation of semiconductors upstream or downstream/employee access*	X	X	X	X	X	X
Operational - transportation	Loss in transit (e.g. raw materials, including temperature-controlled)	X	X	X	X	X	X
Operational - transportation	Theft of stock in transit or goods from warehouse(s)	X		X			X
Operational - transportation	Bottlenecks or delays at port or warehouse negatively affect supply chain and stock throughput (e.g. delay such as volcanic eruption prevent flights or delay, resulting in deterioration of stock)	X	X	X	X	X	X
Operational - transportation	Movement restrictions (national and transnational, people or goods)	X	X	X	X	X	X
Strategic - inputs	*Change in regulatory requirements (e.g. environmental legislation, financial disclosure requirements for suppliers/supply chain)*	X	X	X	X	X	X
Strategic - inputs	*Political/geopolitical risks (e.g. sabotage, war, expropriation, Brexit, trade embargoes/sanctions/restrictions)*	X	X	X	X	X	X
Strategic - inputs	*Innovation / research and development (e.g. inability to keep up with industry appetite for new and faster semiconductors)*		X	X	X	X	X
Strategic - inputs	*Ethical supplier conduct (e.g. one or more suppliers involved in fraud, ethical wrongdoing, such as poor working conditions, child labour exploitation resulting in reputational damage)*	X	X	X	X	X	X
Strategic - outputs	*Reputation risk (e.g. failure of semiconductor - chip, design, testing - leads to industry blacklisting the company)*		X	X	X	X	X

Key risks and drivers

From the wide range of risks mentioned, the categories outlined in **Figure 12** below are the key supply chain risks and drivers of most concern to the semiconductor industry.

Figure 3: Supply chain risks and drivers



Economic pressures

Economic pressures dominate business risks in the current climate. An unstable economic situation and market volatility are both major concerns for supply chains, hence on the mind of every semiconductor business that we spoke to across this research. The necessity for improved resilience is also driving increased costs; e.g. additional inventory and storage for raw materials, components and finished product as a result of the increased need for nearshoring.

Inflation is impacting semiconductor manufacturers in every aspect of their operation; increased wages and energy, raw material, packaging and capital equipment costs. Current uncertainties are further exacerbated by unfolding conflicts, such as in Ukraine or parts of Asia in which there are long-running tensions. While the short-term impacts from the conflict in Ukraine are expected to be manageable, the war's effects on raw material prices, supply chain constraints, and overall uncertainty will continue to affect chipmakers and their customers by impacting prices all the way to end-consumers.

Semiconductor risk managers are also proactively planning for impacts, together with their business continuity and procurement teams and with their suppliers, including increasing the levels of inventory held for key raw materials, components and finished products. One global semiconductor company we spoke to had increased its inventory capacity from 85 days to nearly 200 days over the past three years to be better prepared for disruptions and responding to increased demand.

Regarding resilience, some semiconductor companies have added their own gas production facilities and increased storage at key sites. Companies in the sector are also reviewing their business continuity plans, seeking alternative sources of critical raw materials such as palladium, and exploring neon gas recycling.

Semiconductor businesses are already planning for scenarios like the restricted energy power supplies and three-day working weeks experienced during the 1970s in the UK[36]. Multiple ingress points for power lines and on-site water supply are also being implemented, with some companies we spoke to also considering building their own power plants on site and/or acquiring high-power generators as a further back-up.

A further consideration relates to economic pressures on their workforce and their salary costs. Semiconductor companies are facing a critical talent shortage, leading to upward pressure on wages, and many operate in countries in which the COVID-19 pandemic led to shutdowns and impaired access for workers to key sites. Many employees are also facing personal economic challenges leading to some of the semiconductor companies we interviewed upgrading the quality of their benefits programmes to help retain and attract employees.

Quotes from interviewed semiconductor practitioners

> “Inflation is impacting our risk and has added substantial cost to our insurance as well as production process.
>
> **Group Insurance & Risk Manager – European semiconductor company**

> We recognise that there are a few “super-dependencies” on a few key Asian semiconductor fabrication facilities that impacts the global industry. On one key Fab in the region alone, we recon there is a global dependency worth well beyond US$50 billion. Only really small parts of that are insurable currently, because of the cumulation (and lack of knowledge by the market). This makes quite a few clients that are dependent on that particular fabrication company nervous and they are be looking at alternatives (big investment plans). The industry should work to come up with some sort of financial solution for this risk. Such a solution is currently aspirational, but achieving this could mean a lot to the owner's commercial position in the market.”
>
> **WTW Semiconductor Taskforce Leader**

Supply and demand changes

Growth in semiconductor-dependent sectors, combined with cyclical factors, has resulted in an extraordinary demand over the past few years for vendors, designers, manufacturers and the companies that supply chips. During the current cycle, the sector's own supply chains face unusual and systemic difficulties ranging from challenges in obtaining raw materials to capacity constraints in the shipping/logistic sectors.

Semiconductor companies we spoke to told us that they are considering not only the challenges of meeting demand right now, but are also facing a significant future risk; if they invest heavily in capacity to meet shortages today, will they find themselves selling into a glut tomorrow? While the latter is a longstanding risk for this historically cyclical industry, the intensity of today's supply shortfall, and the high costs that may be needed to address it, make it imperative to chart a careful course.

Even with semiconductor fabrication plants operating at full capacity, semiconductor companies have been unable to meet demand, resulting in product lead times of six months or longer . Supply chain challenges downstream have been considered so critical that it is prompting several large technology companies and major automotive makers to move chip design in-house. This is a trend that could have major implications for both supply and demand in the future. In other industries, manufacturers often respond to shortages by increasing output.

In the semiconductor industry however, construction of new semiconductor fabrication plants and the ramping up of production are both very costly and time consuming, often requiring at least a year for significant expansion, or more than three years to build a new facility. These factors make it difficult to increase semiconductor volumes quickly.

The impact of broader economic contraction on customer demand for electronic products was also highlighted through our interviews. The concerns are that, just as semiconductor companies complete massive capital investments allowing them to ramp up production, their end customers may no longer require the same volume of chips. It is worth noting that in July 2022 there were signs that end user demand for semiconductor products might be slowing down.

Sectors with greater reliance on semiconductors, such as technology equipment, automobiles and consumer electronics, saw new orders fall during July 2022 due to worsening economic conditions for consumers, highlighting the 'dual-front' difficulties these industries are facing if the supply of semiconductors fails to improve and prices remain high.

Looking ahead, other factors like environmental, social and governance (ESG) considerations and evolving consumer tastes are also likely to influence future demand volumes. Consumer demands may have changed by the time capacity for chip production has been adequately ramped up. Electronics, whether for use by businesses or the consumer, typically have a low lifespan with innovation and new products often changing the direction of customer preferences and requirements.

To plan for this, several manufacturers have been looking at new ways to manage product supply, such as additional storage of components and raw material and staged supply. Several semiconductor businesses we spoke to are also planning for better re-tooling (recycling up or down) of older technology/equipment, potentially giving manufacturers a quicker response.

Quotes from interviewed semiconductor practitioners

> Semiconductor firms, prompted by political and regulatory requirements, are increasingly looking for their suppliers (and suppliers' suppliers) to manufacture components on their own shores to reduce their supply chain exposure.
>
> **Sector Expert at a law firm**

> Consumer demand for the latest gadgets means that semiconductor firms, regardless of where in the value chain they operate, will have to continuously innovate to ensure they can meet the latest demand. With that comes the need to plan for and secure products from different areas of the world to those currently considered.
>
> **WTW TMT Industry subject matter expert.**

> Semiconductor companies need to work towards becoming more agile and responsive to their supply chain challenges. They can achieve better resiliency by increasing their raw material and inventory levels, ensuring a broader supplier base, strengthening their pricing strategies and improving redundancy in chip allocation to customers. Factors outside their immediate control, such as access to logistics, power or water also needs to be better addressed.
>
> **Group Risk Manager – North American semiconductor company**

Talent and labour

While investment in new manufacturing fabrication plants will be welcomed by the industry, its impact will be limited if steps are not taken to also address labour shortages. Estimates in the U.S. suggest that companies across industries will face a shortfall of 300,000 engineers and 90,000 skilled technicians by 2030[38].

Wage inflation and rising labour costs, due to both labour supply and demand challenges and the broader economic pressures, are key issues for the semiconductor industry. A rise in social unrest also presents risks to labour forces across an increasing number of sectors such, as seen with the rail and postal strikes in the UK in 2022. The global haulage sector, which is essential for the transport of both components and finished goods across semiconductor supply chains, has been particularly affected, with industry bodies estimating a shortage of 80,000 drivers in the U.S. alone[39].

Amid intense competition, semiconductor companies are finding it harder than ever to attract and retain personnel. As semiconductors become ever more critical to product differentiation, some electronics companies, automotive manufacturers, and other fast growth companies are beginning to move chip design in-house. Primary rationales for doing so are to eliminate supply chain bottlenecks and to allow for increased specialisation in design.

These moves are making competition for already-scarce semiconductor talent even tougher than usual[40] and have the potential to undermine semiconductor companies' expansion plans. Simultaneously, as chip design is becoming more of talent and more labour – especially for some of the latest and smaller generations of chips where the manufacturing process is complicated.

Against this background, semiconductor manufacturers recognise that they must acquire the skills they need to be able to effectively put their significant and promised capital investments to work. They are struggling in three areas in this regard - talent acquisition, talent retention, and organisational health – potentially presenting significant threats to the effectiveness of the billions of dollars being invested in securing the industry's future. As a result, the semiconductor industry is putting considerable effort into ensuring it has a strong talent pipeline and is increasing its efforts to recruit talent, including staff with expertise in process technology and operations management.

That said, the industry still faces an image problem. Typically, semiconductor products receive less attention from employees than the end products (e.g. Apple's iPhone), and prospective employees may enter the market with little knowledge of the many strong and innovative companies within the sector.

In many recent surveys of employees, the semiconductor industry consistently ranked lower than other industries across multiple dimensions of workplace attractiveness. Companies in the sector are increasingly reviewing compensation, learning, and development strategies to ensure that they compare more favourably with businesses in other industries – and especially against other technology industries.

One possible solution being explored is the formation of partnerships with other semiconductor companies or with academic institutions, especially in markets where talent is in very short supply, to meet short term needs and ensure that the skills of the future will be available.

Quotes from interviewed semiconductor practitioners

> **"Everything revolves around people: the right amount, the right training, the right qualifications, the right culture, but the labour market is the worst it's been since, probably, the 1970s.**
>
> **CRO, semiconductor company**

> **The industry must do a better job to identify, recruit, and develop the necessary workforce.**
>
> **CHRO, semiconductor company**

> **As we enter 2023, the semiconductor worker shortage shows no signs of getting better. The competition for talent is only intensifying. We are struggling to see how companies in the sector can effectively address the semiconductor worker shortage. But it needs to happen!"**
>
> **Journalist, semiconductor trade journal**

Raw materials and components

Computer chip fabrication takes a long time – three months or longer on average – and requires raw materials and supporting material (such as rare or precious metals and special gases) to complete. Specialised equipment for fabrication and packaging are also adding to a complex process with many steps.

Rare and precious materials used in the semiconductor fabrication process are required to design, create, and augment a chip, ranging from the material used to produce the core computer chip to the soldering used on its surface to create electrical flow. Such raw materials include tantalum, palladium, and ruthenium, and are in many cases the primary reason for supply chain and shortage issues because of where the materials are sourced from[41].

Typically, these materials are relatively abundant, but only available from countries that experience regular conflict and unrest, where access issues can be compounded throughout the entire operation if there are disruptions in supply of these materials.

Since chipsets are used in nearly everything related to modern electronics, this supply chain disruption has impacted chip-dependent industries such as automotive, manufacturing, logistics, computing, and construction. Fortunately, measures are being taken to remedy these complications and lessen the burdens of the industry overall such as increasing stockpiles of critical components and raw materials on site, as well as moving manufacturing operations closer to home. But for some of the more difficult components and/or raw materials needed, this will only serve as a short-term stop-gap measure if a truly disruptive event takes place.

Semiconductor companies have also moved to shore up supply chains amid the upheaval, in some cases adding alternative suppliers to gain options. Companies stocked up on neon and other important chip-making materials, and now typically have a six-week to three-month reserve[42]. Some companies have gone even further – as seen recently with neon gas.

Box 3: Neon gas supply chain concerns

Production of vital raw materials for chip making is concentrated in Russia and Ukraine. The countries are a major source of both neon gas[43], needed to feed lasers that print minute circuitry onto silicon, and the metal palladium, used in later manufacturing stages.

About a quarter-to-a-half of the world's semiconductor-grade neon comes from Russia and Ukraine, while roughly a third of the world's palladium comes from Russia, analysts and industry consultants estimate. A potential shortage of those materials sparked concern among some analysts that an industry already struggling to meet increased demand could suffer a blow to production. Those worries were not realised, at least not in the near term, in part because the industry has reset how it operates after facing the last three years of non-stop global disruption. Leading semiconductor companies began to ensure that they secured alternate supplies of neon shortly after Russia amassed military force along the Ukrainian border.

Quotes from interviewed semiconductor practitioners

"... [we see] that firms have now stocked up on neon and other important chip-making materials, and now typically have a six-week to three-month reserve.

Managing Partner, semiconductor industry advisor

We have gained valuable learnings from the Ukraine – Russia conflict and are trying to put these lessons to bear on how we plan for other potential conflicts, such as for example China vs Taiwan. We are adjusting our inventory levels upwards for example.

Managing Partner, semiconductor industry advisor

We need to get a much better understanding of our supply chain at Tier 2, 3 and 4 level."

Vice President Global Supply Chain, automotive industry

Technology

Current technology supply chain concerns focus on coming up with the next generation of leading-edge chips and the machinery required to make them. For semiconductor manufacturers, creating smaller node sizes has traditionally been the path to success. For decades, the number of transistors on a chip doubled every two years—the rate predicted by Moore's law[1] —as semiconductor companies constantly decreased the size of technology nodes.

In recent years, however, the rate of doubling has slowed because technological challenges increase as the industry approaches the physical limits for the number of transistors that can be included on a single chip. Nevertheless, companies will still attempt to push the technology, because average demand growth for chips with the smallest nodes —seven nanometres (nm) and below—will be higher than forecast supply growth through 2025.

The importance of node size varies by device segment, and the demand for leading-edge chips will grow much more in some categories than in others. Since customers expect high performance for computer-intensive applications, semiconductor companies that design chips in the smallest available technology node may have a distinct advantage in these areas. Equipment manufacturers are also looking to capture growth by creating the next-generation machinery required to enable leading-edge innovations in fabrication.

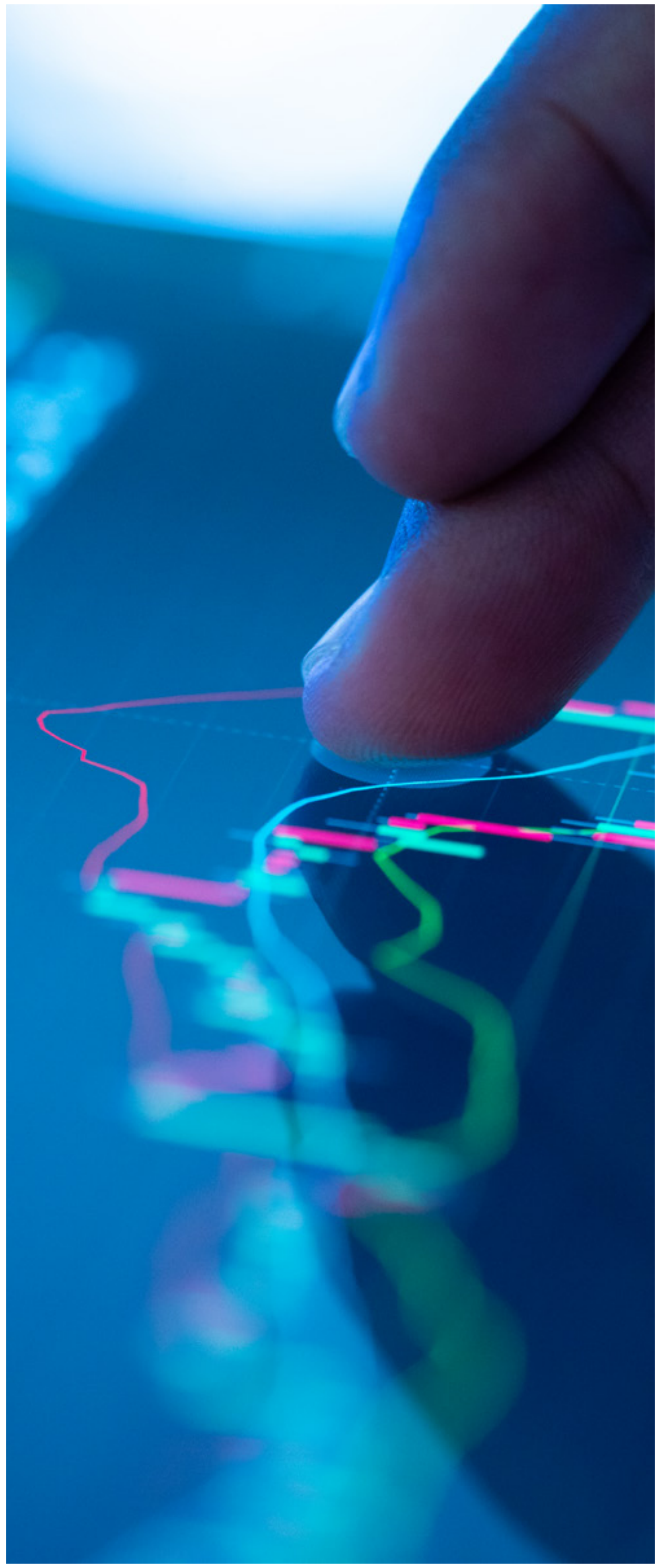
Although many investors may be sceptical of providing funding over an extended period, semiconductor companies have proven that bold, long-term investments can eventually deliver substantial returns. A leading capital equipment maker (a firm which produces manufacturing equipment for the semiconductor industry) spent 17 years and about $7bn developing its extreme-ultraviolet lithography technology, including the ability to produce the technology at volume[44]. Similarly, a fabless company spent six years developing a 64-bit computing processor that is now a significant source of the company's revenue.

Other companies that invest heavily in long-term R&D projects could help promote technological leaps–often far more than node reduction–that could prove helpful for society. In 2021, IBM announced[45] that it had developed the world's first 2nm node chip, which is projected to achieve 45% better performance, or 75% more energy efficiency, than leading 7nm chips. The creation of specialised chips for quantum computing, for example, could improve pharmaceutical development, sustainability programmes, and other initiatives across industries.

The semiconductor industry continues to see wider automation, the harnessing of artificial intelligence (AI) and the deployment of internet of things (IoT) devices. Technological advances are also being explored by some in the sector in an attempt to address labour shortages and rising labour costs. Such moves widen the cyber security challenge for the sector. As the industry is heavily reliant on third-party outsourced suppliers, further consideration for resilience therefore lies in improving its IT infrastructure. If not carefully coordinated, these can lead to disruption or failure of existing systems and to loss of valuable intellectual property, such as the latest chip design.

The evolving nature of cyber-attacks is also adding to the pressure on companies in the sector to ensure that their cyber security solutions are up to date, or risk facing a widening range of undesirable consequences. This is changing the risk profile, increasing the demand for cyber security technology professionals and adding to ongoing recruitment needs. WTW global cyber claims data shows the manufacturing sector overall is the second highest sector in terms of both cyber insurance claims frequency, and the impact of claims. Several of the world's leading semiconductor companies have faced ransomware attacks, extortion attempts and other malicious activity in 2022.

[1] Moore's law is a term used to refer to the observation made by Gordon Moore in 1965 that the number of transistors in a dense integrated circuit (IC) doubles about every two years.



Quotes from interviewed semiconductor practitioners

> The move toward data and service-based business models is an ambitious shift with a lot of potential for growth. But companies are likely to bite off more than they can chew without highly efficient and cohesive software ecosystems.
>
> **Analyst, semiconductor industry advisor**

> We are seeing innovations ranging from artificial intelligence (AI), the Internet of Things (IoT), and 5G to advanced packaging and in-house production – all of which is requiring the even more advanced chip. The industry is also accelerating the adopting of the latest operational and process related technologies that will increase efficiency and meet environmental requirements. Innovation that is more essential than ever before!
>
> **WTW GB technology industry leader**

Packaging and transport

Transport-related risks were raised in the majority of the conversations with key players in the industry, and for some have resulted in significant changes to inventory levels held, manufacturing timescales and, at times, delays in delivery to customers.

Stress on the global supply chain started during the trade war between the U.S. and China. Several tariffs and sanctions were bilaterally imposed by the two countries, creating volatility in demand and supply. The crisis further unfolded as industries around the world were forced to shut down amid the pandemic, and weak links across the global supply chain began to surface. The lack of workers across the supply chain resulted in congested ports, stalled ships, overloaded warehouses, delays, empty shelves, and eventually higher prices.

As pandemic-induced lockdowns are easing, issues in the logistics sector continue to create problems, further impacted by the fact that consumer demand is expected to continue to increase. The shipping industry continues to experience issues ranging from ongoing dislocations in the container market, shipping routes, air cargo, roads, rail lines and warehouses, to a shortage of logistics workers. All of these factors have strained the global semiconductor ecosystem and supply chain. Added to this, silicon chips are extremely fragile microelectronics that can be irrevocably damaged by excessive vibration, temperature fluctuations, or even static electricity.

Advanced packaging provides for better environment conditions during operations, allowing companies to place semiconductor components closer together. In addition, advanced packaging allows semiconductor companies to combine mature and leading-edge chips in an integrated system for applications that need both types, which lowers costs. This trend, called heterogeneous integration, enables companies to combine multiple smaller chips instead of making one large chip. Larger chips often have lower yield, with the drop typically scaling with chip size, so heterogeneous integration may deliver profound cost benefits.

Since the sector's inception, semiconductor packaging has largely been the domain of China, Taiwan, and other East Asian countries. However, emerging national security concerns have led to a re-evaluation of the role of packaging and best location for its manufacture in the global semiconductor supply chain. The National Advanced Packaging Manufacturing Program in the U.S., along with other similar initiatives, serves as an example of where this issue has made it onto the political and regulatory agenda.

Quotes from interviewed semiconductor practitioners

> “Over the past 2 years, we have been impacted by logistic sector capacity constraints (including lack of qualified personnel) leading to difficulties in terms of us getting raw materials and components to sites as well as in distributing finished semiconductor products to electronics manufacturers or our end users
>
> **Risk and Insurance Manager – global semiconductor firm**

> Advanced packaging has increasingly become essential for us to be able to better ensure the quality of our product as well as to help us ensure that we improve our environmental profile. Therefore, access to specialised packaging suppliers and solutions have become very important”
>
> **Supply chain and logistics manager – global semiconductor company**

Regulatory, geopolitical and political risks

Given the recent global conflicts and political events which have dominated both domestic and international news channels, it is unsurprising that geopolitical and/or political risk was mentioned by every semiconductor executive interviewed. More widely, some risk leaders were preparing for rolling blackouts in winter 2022 winter/spring 2023 as a result of the threat of reduced energy supply linked to the conflict in Ukraine (covered in depth in our recent report Ukraine: A conflict that changed the world).

Technology and market trends over the past decade have concentrated cutting-edge semiconductor manufacturing capabilities among a handful of companies located in global hotspots, including China, US, South Korea and, most importantly, Taiwan.

As the U.S., and to a lesser degree the EU, presses ahead with stricter and broader controls over semiconductors and related technologies, it will hasten the decoupling of the two blocks' technology sectors while further spurring China's attempts to establish a separate R&D and production system. Maintaining an edge in semiconductor innovation and supporting the resilience of supply chains have become key strategic priorities for both Beijing and Washington[46].

Two aspects are worth noting[47] in this regard. Firstly, neither China nor the U.S. is independent enough to sustain the whole semiconductor supply chain on its own. The U.S. currently enjoys a clear advantage in manufacturing capacity compared to China and particularly so in areas such as intellectual property, chip design, manufacturing, and non-wafer materials. China, on the other hand, is the key supplier of raw materials, such as silicon needed for manufacturing. In other key areas, such as contract manufacturing, both the U.S. and China are heavily dependent on Taiwan, South Korea, and Japan. Contract manufacturers, in turn, need capital equipment, with one of the most prominent companies located in The Netherlands.

Secondly, because of the regionally fragmented nature of microchip production, companies from third countries are often pulled into geopolitical conflict. Due to increased U.S. pressure, the Taiwanese company TSMC stopped supplying chips to Huawei[48]. China, on the other hand, considers Taiwan part of mainland China that will be reintegrated into the People's Republic. In a further interesting dynamic, while China is responsible for only 10% of TSMC's sales, it relies on the company to provide 70% of the wafers it needs for its consumer electronics industry[49].

In response to these developments, policy makers around the world have unveiled plans to bolster their domestic manufacture of semiconductors to mitigate the worst effects of supply chain breakdowns (see **Box 4**).

Quotes from interviewed semiconductor practitioners

> “Fallout is likely for Taiwan as the US attempts to drive a wedge between “red” and “blue” supply chains. This could potentially impact our suppliers in Asia, and is therefore of increasing importance to our Board.
>
> **Semiconductor CFO**

> Semiconductors are a strategic vulnerability for China and its most important tech company, Huawei, which relies on cutting-edge manufacturing facilities in Taiwan to make the chips it needs to remain globally competitive.
>
> **Commercial technology research firm**

> The semiconductor firms we work with are increasingly spending money, resources and planning efforts to improve their visibility when it comes to the ever changing geopolitical risk landscape. They use advanced scenario planning to better anticipate the impacts of potential geopolitical tensions on their operations.”
>
> **WTW GB technology industry leader**

Box 4: Future centres of semiconductor excellence

Policy moves are being made around the world to entice semiconductor businesses to establish new production bases[50]. These efforts, while they have yet to take effect, will be the first steps in strengthening regional and national resiliency against future crises and, in some cases, companies have responded with statements of intent to take these offers up. This may reshape the future centres of semiconductor excellence and secure production, and at the same time further shakeup the delicate balance of cooperation the industry has been used to (see **Figure 14**).

- South Korea: In May 2021, South Korea unveiled the “K-Semiconductor Belt” strategy, aimed at building the world's largest semiconductor supply chain by 2030. The initiative offers investment tax credits for semiconductor R&D to attract more private sector investment.
- Japan: In November 2021, Japan approved $6.8bn in funding for domestic semiconductor investment as a part of its goal to double domestic chip revenue by 2030. In November 2022, Japan proposed an additional $8bn in funding for a joint research hub with the U.S., including advanced semiconductor manufacturing lines, and semiconductor materials.
- The European Union: In February 2022, the European Commission began formal consideration of the “EU Chips Act,” which includes up to 43 billion in targeted support for Europe's semiconductor sector. This includes incentives aimed at bolstering the EU's front-end manufacturing for “first-of-a-kind” technologies and new investments in cutting-edge research and development.
  - Intel responds: In May 2022, Intel announced[51] it was investing up to 80 billion in chip manufacturing across Europe, including the construction of a new 17 billion “megafab” production plant in Germany for high-end chips. A further announcement was made in August 2022 of a $30bn funding package with Brookfield Asset Management to aid the construction of two new foundries in Arizona.
- U.S.: In July 2022, Congress passed the CHIPS Act, a $52.7bn package which provides investment and incentives for semiconductor manufacturing in the United States. It should be noted that large-scale fab construction has not occurred in the U.S in more than 20 years, and few builders within the country possess the experience, capabilities, and expertise required to deliver these specialised projects.
  - Micron responds: In October 2022, Micron Technology announced it would spend $20bn to build what it called the largest ever US semiconductor factory in New York, and it may spend up to $100bn over 20 years to expand it.
  - Taiwan Semiconductor Manufacturing Company (TSMC) responds: In December 2022, TSMC announced[52] the opening of the company's second chip plant in Arizona, raising its investment in the state from $12bn to $40bn.
- Taiwan: In October 2022, Taiwan said it was mulling additional tax incentives for the semiconductor industry. The new incentives may include proposals to attract overseas semiconductor talent and semiconductor materials and equipment suppliers.
- Southeast Asia: Thailand in November 2021 approved a preferential tax policy for news semiconductor investments. Vietnam also recently announced semiconductor-specific incentives, such as zero percent corporate income tax for chips businesses. India: In December 2021, the Government of India rolled out a $10bn semiconductor incentive package to, among other things, attract investments in chip manufacturing, assembly test, packaging, and chip design.
- Mexico: In September 2022, the Mexican federal government began to draft a new incentives package to attract semiconductor investment, particularly focused on assembly, test, and packaging. Several Mexican states have also begun to develop similar incentives at the local level.
- Canada: In 2022, Canada announced a desire to offer incentives for new investments in chip design, manufacturing, and associated critical materials. In addition, Canada is aiming to increase its talent development through educational partnerships between universities and design or manufacturing companies.

Climate change and sustainability

The industry is dealing with a paradox. Green technology, essential for the world to be able to meet global climate goals will, in large part, rely on semiconductors. Electric vehicles, solar arrays and wind turbines are a small number of the key transition technologies that require semiconductors to function. However, semiconductor manufacturing requires huge amounts of raw materials, energy and water – a chip fabrication plant, or fab, can use millions of gallons of water a day. The global supply chain required to build chips also adds to global carbon footprints through other parts of the value chain. It is worth noting that researchers[53] suggest that it is chip manufacturing, rather than energy consumption or hardware use, that accounts for most of the carbon output from electronics devices.

On top of this, climate risk is driving extremes and increasingly affecting key manufacturing locations such as Taiwan, which is experiencing chronic periods of drought. This impacts not only the water supply for chip manufacturing sites on the island, but also its power supply running on hydroelectric power. Such power outages weigh heavily, since the production process of chips must take place in clean rooms with stable temperature and pure air. Disruptions of any kind render the product unusable.

Climate change is understood as a risk impacting the external landscape, from procurement to supply chain, as well as internal operations such as warehousing, energy, production, and business continuity within the supply chain. Also of note is the complexity of the production process, where weather-related power outages or droughts can have severe consequences on manufacturing capacity. Access to renewable energy will be a major factor as companies decide where they should build new semiconductor fabrication plants – something that is becoming more common as they try to increase capacity to alleviate the chip shortage.

As the semiconductor industry finds itself increasingly under the spotlight, it is starting to grapple with its climate impacts. The pressure to act when it comes to improving the industry's carbon footprint may soon increase further. Customers and policymakers are scrutinising emissions along the entire supply chain – and in many cases, semiconductor companies will account for a substantial amount of these. Achieving substantial emission reductions will require new technologies, innovative thinking, collaboration with peers and suppliers, and the complete re-design of semiconductor fabrication plants that will require major investment. These factors are driving the push for datasets and tools in the industry (see **Box 5**), an area where the Lloyd's market can look to support their efforts.

Quotes from interviewed semiconductor practitioners

> I believe that customers want to know how companies can help them live more sustainably. That means greening the supply chain.
>
> **Social Impact Manager – Global hardware manufacturer**

Box 5: Datasets and tools

If you can't measure, you can't manage. As more and more companies analyse and report on their greenhouse gas emissions, supply chain emissions have grown in both focus and importance.

Initiatives: The Responsible Business Alliance (RBA) is the world's largest industry coalition dedicated to corporate social responsibility in global supply chains. Beginning with eight members in 2004, the RBA's core membership has grown to over 200 electronics, retail, and auto companies. The RBA's Code of Conduct is a set of ESG standards in line with international norms and treaties, as outlined in the International Labour Organisation's International Labour Standards and the OECD's Guidelines for Multinational Enterprises. The RBA's three main initiatives – Responsible Minerals Initiative, Responsible Labour Initiative, and the Responsible Factory Initiative – provide an architecture encompassing nearly every stage of the semiconductor supply chain from sourcing of natural resources to final production lines.

Sustainable supply chains: As insurers consider emissions across whole insurance portfolios, access to data and being able to share their views during risk conversations is an opportunity to support the transition to a sustainable future. An example of where insurers are putting this into practice is a partnership explored in the Lloyd's Lab, where Tokio Marine Kiln and CarbonChain have gone on to pilot a methodology framework to measure customers' emissions and compare them with their industry and regional peers. This can then be translated into a 'carbon risk rating' to be taken into account when considering underwriting of each policy[54].

The future risk landscape

As well as the shorter-term risks and drivers facing businesses now, there are four key areas where change is expected to increase.

Figure 13: A forward look at drivers, trends and risks

1. Business model

- The chip industry is increasingly focusing on the fallouts from a complex and unpredictable market environment that has affects its business functions and supply chain
- Semiconductor companies are increasingly recognising the need to change their business and operating models to monetize more of the value their IP, chips, and solutions provide (e.g., silicon as a service)
- The industry players are increasingly planning to construct fabs outside their traditional locations, including in the United States, Europe, China, Singapore and Israel – in response to capacity constraints and from geopolitical pressures
- The ongoing talent shortage will be made even more severe by the addition of increased semiconductor manufacturing facilities outside Taiwan, China, and South Korea and the emergence of fast growth market requiring chips (EVs, green energy, etc.).

Near-shoring/construction of Semiconductor fabrication plants	Skills shortage
New products and Scale	Trade disruptions and restrictions
Digital transformation and cyber security	The economic cycle
Critical raw materials and longer component lead times	Hyper-demand from products requiring the 'chip'

"The chip shortage of the past two years resulted in revenue misses of more than $500bn worldwide between the semiconductor and its customer industries, with lost auto sales of more than $210bn in 2021 alone."
Source: Deloitte 2021

2. Sustainability

- Semiconductor production is water-and-energy-intensive, with the cost of power being a major component of the overall cost
- Achieving substantial emission reductions will require new technologies, innovative thinking, collaboration with peers and suppliers, as well as the complete re-design of fabrication plants
- Rare and precious materials used in the semiconductor fabrication process leave a considerably negative ecological footprint.

Water shortage	Circular economy
Power insufficiency	Advanced packaging
Recycling of scarce materials	Sustainable fabs
Toward net-zero production	Life-threatening disruptions
Maintaining a 1.5°C pathway	Specific net zero emissions targets

"We observed that while some semiconductor companies have created ambitious targets for reducing their emissions and remaining on a 1.5°C pathway, many others have been less ambitious. This needs to change!"

3. Consumer demand

- The last few years have seen consumer spending on electronics reducing overall due to financial worries and so the demand for semiconductors in consumer electronics, which has a big market share, has been lower than usual and will continue to be so. Looking forward, as new technologies mature, consumer demand will shape the growth of new semiconductor developments, and be shaped by them in turn
- Customers (individuals, across industries, as well as governments) are now scrutinising the industry's impact along the entire supply chain – and in many cases, semiconductor companies will account for a substantial amount of these.

Consumer preferences and buying power	Consumer electronics, automotives, healthcare
5G capable devices	Increased use of cloud infrastructure
AI and connected devices	

"We see a strong demand for semiconductors in specialised areas, such as electric vehicles, healthcare and work-from-home technology. The demand for our products has surged and is benefiting the industry."

4. Technology and politics

- The digital transformation within the industry will continue and accelerate. Semiconductor companies are increasingly bolstering their collaboration with extended supply network partners so that they can better implement integrated AI, edge computing, 5G communications, and internet of things (IoT) solutions
- Semiconductor manufacturers and other high-tech companies are at the cutting edge of some of the most advanced technologies in the world. Despite that fact, many are still lagging in critical components of their digital transformation, namely supply chain management, the shift to data and services, and integration from mergers and acquisitions.

Moore's law limitation	Effective use of big data
Short term vs long term memory demand	Infrastructure bottlenecks and failure
Regulation limiting access to foreign technology	Semiconductors as a foundational technology
Growth in CAPEX	US–China technology rivalry
Self-reliance, digital sovereignty, and strategic autonomy	Geo-concentrations at the technology level

"The move toward data and service-based business models is an ambitious shift with a lot of potential for growth. But companies are likely to bite off more than they can chew without highly efficient and cohesive software ecosystems."

The future risk landscape: Business models

Shifts in global industry collaboration may shape future supply chains and transnational partnerships. Industry analysis[55] suggests a series of potential pathways that may shake up the current collaborations (see **Figure 14**) and therefore the geographic footprint of exposure. The strategic importance of semiconductor centres of excellence is forcing countries and regional power blocs to make significant investment and policy moves that will attempt to rebalance supply chains.

Hurdles to moving manufacturing capacity of advanced chips outside of Asia include high requirements for utility infrastructure, slow deliveries of extreme ultraviolet lithography systems and the lack of local supply-chain support from photomasks and wafer materials to experienced engineers. The mismatch of downstream market demand is also a key issue. Personal computers and handsets, the two largest end-markets for chips, are still largely produced in China and Southeast Asia.

Figure 14: Global industry collaborations – current and future scenarios

Today - global collaboration		Potential future - self sufficiency/ally		
			Collaboration with non-allied countries	Western ally
USA, UK, India	Design	China	India	USA, UK
USA, Japan, Russia	Semiconductor equipment	China ↔	Japan ↔	USA, Russia
Chile, Korea, Japan, USA, Germany, Singapore	Materials (wafer, substrate, chemicals)	China ↔	Japan, UAE, Korea, Chile, Singapore ↔	USA, Germany, Russia, UK
USA, Chile, Korea, Israel, Ireland, Germany	Front-end manufacturing	China	Chile, Korea, Israel, Germany ↔	USA, Germany
China, Malaysia, Vietnam, The Philippines	ATP Assembly, test, and packaging	China	Malaysia, India, Vietnam, The Philippines, Ireland ↔	USA

Source: Kearney[56]

Leaders in innovation are looking to create equipment that includes advanced technologies to optimise process control, as well as yield monitoring and enhancement. The below areas may bring further changes to the business models and subsectors that make up the industry:

- **Improved features:** A focus on innovative features is being explored as they may be particularly valuable in high-growth segments, such as the internet of things, and, because such features may help better differentiate products from competitors
- **Specialised applications:** Application-specific integrated circuits (ASICs) look to integrate well-defined algorithms and functions into their chip design and are customised for specific purposes, such as for use in artificial intelligence and cloud computing. The customer base for ASICs includes many different companies, such as automotive original equipment manufacturers (OEMs) and other fast growth companies, and their needs will vary. Some customers may decide to design their own ASICs in-house as Luminar has[57] to improve customisation, differentiate their products, and reduce lead times
- **Packaging:** Innovations in chip packaging can raise the performance of electronic devices as well as lower the power consumption of chips. A focus on driving innovations in advanced packaging rather than just chip density could help make the key semiconductor players more competitive

The future risk landscape: Sustainability

Every industry is seeing a focus on environmental regulations and reporting frameworks, with specific requirements for the semiconductor industry (see **Figure 15**). Such regulations are necessary to minimise the environmental impact of a wide variety of operations, and specifically when it comes to proposed semiconductor fabrication plants.

Figure 15: Sustainability frameworks and reporting initiatives

Task Force on Climate-Related Financial Disclosures	83% of technology companies now report on sustainability. While similar to other industries, technology companies lag behind the benchmark set by the world's 250 largest companies (96%). For comparison, 50% of food and drink companies reported on their Risks and Opportunities and 48% on their Climate-Related Metrics.
Carbon Disclosure Programme	A majority (55%) of companies worldwide (by market cap) now report environmental data, according to CDP, yet some of the biggest companies that withhold environmental information such as their greenhouse gas emissions are a number of the global technology giants.
Sustainability Accounting Standards Board now IFRS Foundation	Requirements for identifying, measuring and disclosing information related to significant climate-related risks and opportunities for 6 technology industry sub-sectors can be reviewed in Appendix B – Industry-based disclosure requirements within the IFRS' Climate Related Disclosures.
UN Global Compact	Under the UN Global Compact principles, technology companies work within the Business and Industry Associations framework. As part of this association, technology companies are well equipped to offer sector-specific advice and guidance on key sustainability issues, by developing tools and promoting best practices. In the UK, the Technology Code of Practice is a set of criteria to help government design, build and buy technology. In the U.S., the Environmental Protection Authority has issued similar guidelines. Both will have an impact on technology firms in terms of requiring more sustainable technology solutions as governments are typically among the largest purchasers of technology in the world.
Global Reporting Initiative	GRI reporting is developing a new global benchmark for sustainability reporting. The draft work program 2020-2022 proposed a total of 40 sectors categorised by four priority groups. Communications, media, software and packaging falls within CRI's Group 3: Transport, infrastructure and tourism and is down as a future Sector Standards project for GRI. Until then, technology companies are expected to follow the Universal Standards.

Traceability and transparency are two of the biggest market forces driving digitisation and are seen as essential in building consumer loyalty and trust. The technology sector has a dual role to play in sustainability – to transform its own organisation and ecosystems, and to use its role as a digital enabler to drive sustainability for its customers. To reduce sources of waste and pollution throughout the entire supply chain, semiconductor companies (and their customers) are increasingly adopting long-term targets and an externally oriented approach to extend their green initiatives beyond their organisational frontiers. They are looking to build more sustainable semiconductor fabrication plants and are also increasingly looking at how to recycle components, including those made from rare earth minerals. Future water demand is a key area of exploration, with immediate effects being felt today that are projected to worsen going forwards.

Box 6: Industry action – Managing water use

The semiconductor industry consumes an estimated 264 billion gallons of water per year, a resource likely to become scarcer in a changing climate. An individual fab can use tens of millions of gallons of water per day, with the largest use of water in a fab (about three-quarters) being process related. Much of that is converted to ultra-pure water (UPW) needed for production itself, followed by the facility scrubber and cooling tower.

Water access and availability vary from region to region, with some water-stressed areas taking proactive approaches. All wafer fabrication plants in Singapore practice some form of water recycling, and recycling rates range from 23% to 65%, with an industry average of 45%. For semiconductor plants, the situation is more variable, with the recycling rates ranging from 0% to 80% and an average of 23%. Water demand is expected to double from 430 to 860 Mg/day (1.6 to 3.2 billion litres per day) by 2060 and the industry plans to meet 85% of that demand with desalination and recycled NEWater.

Source: Semiconductor Digest[58]

The future risk landscape: Consumer preferences

Sustained demand for consumer tech is in part driven by the integration of digital services such as video streaming or remote fitness classes into devices and equipment. Looking forward, transportation, space, sustainability, and health are key areas experiencing innovation.

Specific technologies such as the internet of things (IoT) are also shaping this trend. In the coming year, 15 billion devices will be connected into the IoT, and this number is expected to double by 2030[59]. A principal driver of this trend will be the rapid expansion of 5G coverage in 2023, which will allow devices to communicate faster and improve their overall performance. These areas will open up new services, technologies and innovation opportunities that will support and drive consumer preferences.

Corporate and individual consumers of technology solutions and electronics are becoming increasingly aware of the impact that the technology industry has on the world's carbon footprint and therefore expect the sector to do more to reduce their impact. They are increasingly going to expect the sector to 'act' using their knowledge and innovation to create greener alternatives to the current products offered.

Consumer demand may further influence the capital investors are prepared to put up, by redirecting their purchases or investments to greener alternatives if the industry does not respond adequately[60].

The future risk landscape: Technology

The world of semiconductors is always changing. The quest for smaller, denser, and more powerful chips continues at pace, and new technologies are also coming to the fore. For many years, OEMs have outsourced the production of key components to independent suppliers. Companies are finding it more economical to customise, design and develop their own chips that are essential to their most integral business lines. Both Ford and General Motors have entered strategic partnerships and MOUs with GlobalFoundries to create a direct-to-foundry pipeline to reserve capacity in order to minimise future shortages.

To support these efforts, advanced materials are being leveraged that offer high voltage resistance and higher operating temperatures. Recognising the limitations of silicon's efficacy on circuitry demands has resulted in an intense search for a viable replacement that may shape the future of the industry. Silicon's two main drawbacks are its less accommodative nature to "holes"—electrons' positively charged counterparts—and its weakness at conducting heat.

Researchers at RMIT University in Melbourne, Australia, believe a metal-based field emission air channel transistor (ACT) they have developed could maintain transistor doubling for another two decades[61]. The ACT device eliminates the need for semiconductors. Replacing silicon with metal means these ACT devices could be fabricated on any dielectric surface. Machines could be built on ultra-thin glass, plastics, and elastomers so that they could be used in flexible and wearable technologies.

Elsewhere, a team of researchers at a collection of universities that includes Boston College and the University of Houston have demonstrated that a material known as cubic boron arsenide (c-BAs) can overcome these limitations, providing high mobility for both electrons and holes and possessing ten times more thermal conductivity than silicon.

Supply chain risk management approaches

Supply chain risk management approaches

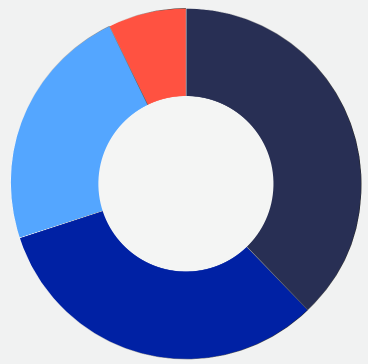
Semiconductor companies take risk very seriously and invest heavily in ensuring they have robust contingencies in place. Moreover, companies in the semiconductor industry appear to learn very quickly from events and adapt accordingly.

Examples of disruptive incidents include: the 2011 Thai floods during which many chip manufacturers were flooded; the 2021 winter storm in Austin Texas which shut down manufacturing operations in several semiconductor companies; and, more recently, a fire that hit the ASML factory in Berlin, which is the world's largest and only supplier of extreme ultraviolet lithography (EUV) photolithography machines used to manufacture the most advanced chips.

These events serve as constant reminders of the vulnerability of the semiconductor industry to supply chain disruption and the need to improve their resilience. The risk concerns related to these events were reflected in the comments of 100 semiconductor risk leaders that were asked about the influence of the last two years on how they are responding to risk with management.

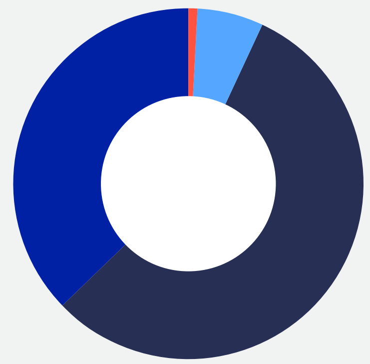
Figure 16: Responding to supply chain risks

How would you describe the extent of any changes you have made in the last two years?



Complete overhaul to our supply chain	23%
Significant changes to our supply chain	38%
Some fine tuning to our supply chain	32%
No change to our supply chain	7%

How would you describe the extent of any changes you intend to make to your supply chain in the next 12 months?



Complete overhaul to our supply chain	6%
Significant changes to our supply chain	56%
Some fine tuning to our supply chain	37%
No change to our supply chain	1%

Source: WTW Global Supply Chain Survey 2023, semiconductor companies

The view of supply chain risk from the inside

Are these actions reflective of thinking within the semiconductor industry? We asked several key companies to talk to us about their view of supply chain risk and how they are managing it.

Views on the biggest supply chain risks varied but there was unanimous agreement on the concentration of risk, both business and natural peril, in key areas—for example, contract semiconductor chips from TSMC in Taiwan and chip making machines in ASML Germany.

Smaller companies are also at greater risk, partly because they may be fabless (they do not own manufacturing plants in which raw silicon wafers are turned into integrated circuits) and therefore rely on third party foundries, or due to the fact that a large part of their revenue is reliant on one factory. In some cases, the lack of product lines presents a further threat to small companies given their inability to shift emphasis to alternative products in the event of a disruption.

> If TSMC 14 fab goes, the whole industry goes.
>
> **Risk and insurance manager, global semiconductor company**

There was recognition that the full exposure of the supply chain is not insurable. It is a risk/exposure that companies can only hope to manage. Furthermore, many of those interviewed acknowledged the unusual degree of dependency on specific suppliers but also underlined their confidence in the resilience of such suppliers given their dominance in the sector.

Broadly speaking, semiconductor businesses do not consider logistics relating to supply to be a high risk, although there were still some concerns in respect of access to markets such as China, particularly in the light of COVID-19 and the potential impact of continued carrier capacity shortage, due to a lack of drivers, pilots, etc. That said, the size and quantity of semiconductor products are such that alternative modes of transport such as air freight always remain a viable option. As one manager put it: "[our] products are very small. So it is easy to rent a plane and airports are always open".

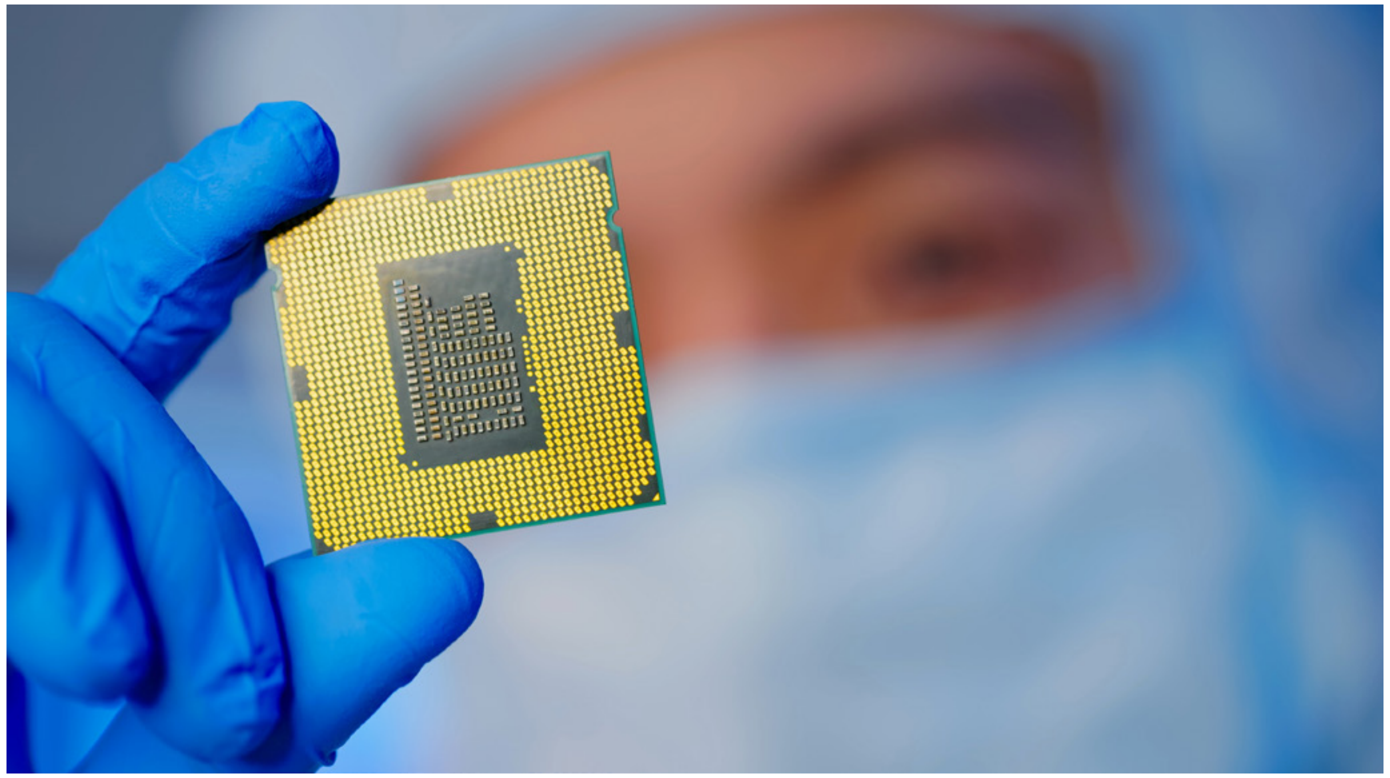
The view on supply chain risk is also not static. As one risk director explained: "It changes from year to year, moment to moment". This sentiment was echoed to varying degrees by other companies. Supply chain risk within the semiconductor industry, whether due to changes in a critical supplier or from international conflict, can be mitigated by increased attention to event monitoring and response. This was evidenced in the surveys, where semiconductor manufacturers said:

- At least half of the companies feel confident that they have the ability to manage root causes of risks to supply chain, and 7 in 10 have at least some influence over the quality of supply chain risk management
- 6 in 10 companies are still planning to make significant improvements and revamping their supply chains in the next year
- Lack of suitable supplier alternatives is a major obstacle for 8 in 10 companies who wish to spread the risk or switch away from unsuitable suppliers

In the absence of supplier choice, better understanding of existing supplier networks and supply chain partners, and relationship building, are seen as key measures for safeguarding against supply risks. The second group of measures that are deemed impactful involves technology and data: using supply chain mapping software and improving data quality and sharing.

Figure 17: Which of the following measures do, or would have, the greatest impact on managing your supply chain risks?

When asked to select their top three



The view of supply chain risk from the inside

Some businesses that have invested in supply chain risk management systems have fared well in the current risk environment. One company claimed they had not been adversely impacted by COVID-19 and were able to grow their market share through supplying the automotive industry. Moreover, their own supplier base maintained robustness thus it was able to keep its factories running. Part of the success was attributed to an effective continuity plan which continued to evolve during the pandemic. In interviews with semiconductor leaders, further insights emerged on common themes, which varied from business to business.

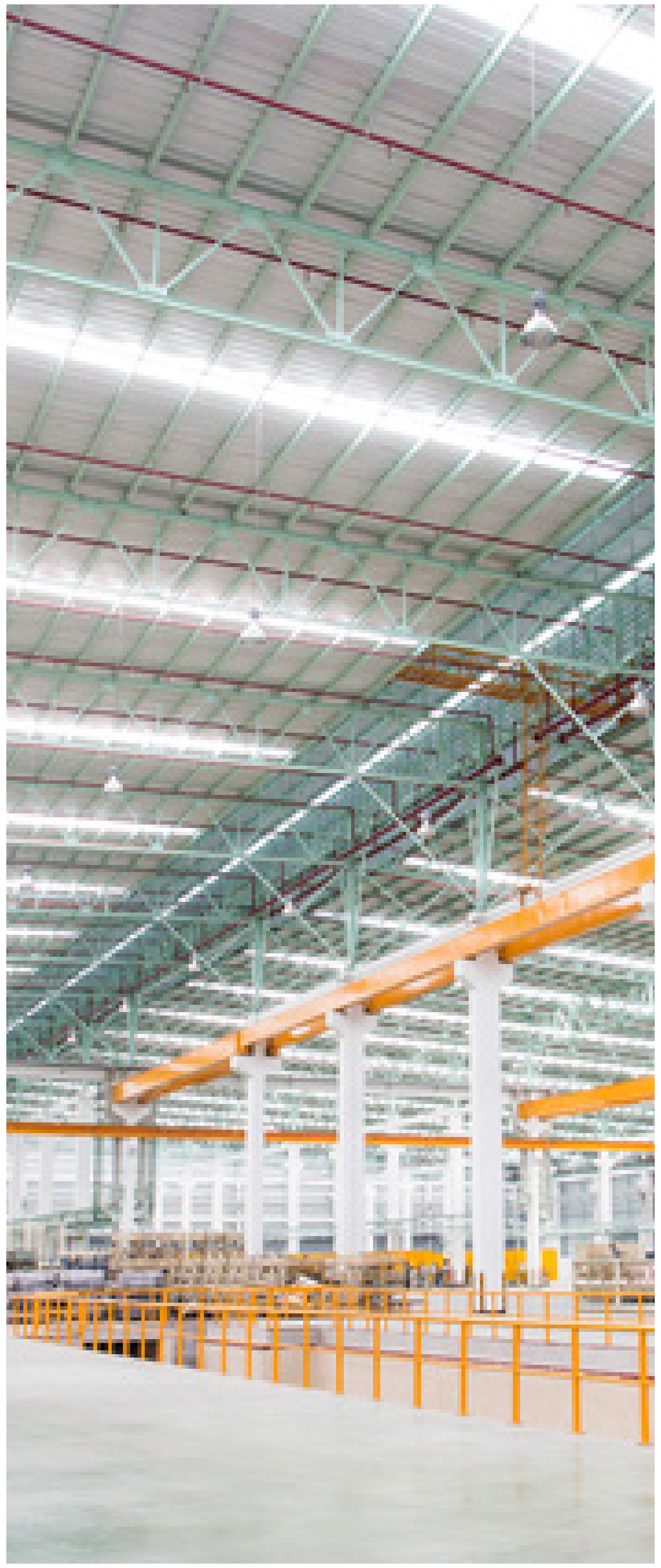
- **Business models:** The quest for greater resilience has led some companies to work towards a business model that is more adaptable to changing circumstances. Examples of this include taking steps to reduce their exposure downstream by negotiating terms with customers so that they own goods bought from the distribution centre onwards, thus mitigating risk, or exploring new production sites in other countries for diversity.
- **Reviewing and keeping higher inventory levels:** Inventory levels cover not only finished product but also raw materials and components. One company, for example, reported that demand issues had led to increasing their inventory target from 150 to 195 days. Another is evaluating inventory level increases, but not for all product ranges. A further example relates to a semiconductor producer that held two months of inventory pre-Covid. During the crisis it fell to a lower-than-comfortable level which drove the company to restock to a higher level. Today, two-thirds of their order book is now in their inventory, and they operate to two quarters of inventory on hand now. Other companies are also looking at further in-advance ordering of raw materials and consumables, retooling old equipment, and finding ways to improve ‘buffer stocks’.

> “We have always kept some (inventory) level but gone from 85 days before Covid to more than double that today.
>
> **Risk management director, global semiconductor manufacturer**

- **Increasing equipment contingency:** There is an increasing view towards mothballing equipment on a just-in-case basis, or purchasing multiple stocks of equipment (critical components) and building equipment redundancy.
- **Business continuity:** Most companies we spoke to had well-established and effective business continuity teams or arrangements in place or were in the process of updating arrangements. Perhaps unsurprisingly, most companies also placed a great deal of trust in the continuity capability of sole suppliers, for example, praising the level of preparedness TSMC appears to have, aided also by their modular facilities which help prevent disasters from spreading. Collaboration on business continuity also extended to exchanging/sharing business continuity plans (BCPs) with trusted partners and working with third parties to vet and improve supplier BCPs.
- **Greater emphasis on risk identification:** Among the companies we spoke to, risk identification was broadly spread out across the organisation. In one company, responsibility for managing supply chain risks is devolved to individual site level. Interestingly, some risk leads indicated a preference for preventive actions rather than a BCP, which speaks to concerns over lack of utilities. For one company the risk of an electric yard being wiped out is critical, therefore multiple yards and lines into sites have been created. Other examples include the creation of on-site gas plants for key gases. The use of on-site generators, primarily to support life/safety systems and protect assets if there is a power interruption, was also quoted. If the interruption is caused by damage to equipment at one of the electrical yards, the mitigation plan would include keeping spares for long lead-time equipment.

- **Multi-sourcing:** Most semiconductor companies do not dual source at fab level, as design costs are too high. In fact, the more advanced the node the less dual sourcing is possible and costs of $10m upwards can be incurred to design one pattern. However, subject to appropriate controls, companies were more inclined to multi-source for other product stages, where this was possible, to increase supply resilience. One company, for instance, imposes multi-sourcing where multiple suppliers of equipment are available, and may buy material/equipment years ahead in anticipation of forecasted/expected demand.

  Pre-qualification of alternative suppliers is considered, but due to the demanding nature of specifications this can be a complex and lengthy process and it is sometimes difficult to always see value. One workaround is for companies to switch to an alternative supplier at short notice but with significantly less vetting. One company reported that a supplier could be brought on board without a contract in an emergency situation, estimating the risk of yield damage to be only 1-2%.
- **Intra company collaboration:** Collaboration and effective business continuity planning across internal teams is another area where progress is being made. This approach encourages cross fertilisation of initiatives for resilience across functions such as procurement, commercial, operations and risk management and promotes a more joined-up way of addressing the resilience challenge. One example given was a supply chain risk management team hosted within a procurement function, but working closely with the finance department and sharing their findings with each other.



Supplier vetting

Companies mostly mentioned they had minimum acceptable supplier standards and audits were usually conducted annually, led by, in most cases, procurement or business continuity functions. Semiconductor companies are understandably cautious when bringing on new suppliers and initial supplier vetting is an in-depth process/exercise with due diligence and scrutiny of suppliers, especially during the onboarding stage, increasing at Tiers 1-3.

Key factors examined during the vetting stage include:

- quality of product and services and supplier's balance sheet;
- an expectation that their suppliers have strong business continuity plans and verification of such arrangements;
- identifying which other notable companies place their trust in the supplier e.g., Apple is a major customer of TSMC and it is assumed they will provide close checks.

Downstream activities such as back-end/testing and packaging also require control and assurance. One company defines these companies as their 'Tier 2' providers and ensures a very active dialogue with these suppliers, facilitates review by their insurer, and maintains a 'healthy' book of alternative suppliers able to step in should failure occur.

Semiconductor company key insights

- Lack of suitable supplier alternatives is a major obstacle for 8 in 10 companies who wish to spread the risk or switch away from unsuitable suppliers.
- In the absence of supplier choice, better understanding of existing supplier networks and supply chain partners, and relationship building, are seen as key measures to safeguard against supply risks.
- The second group of measures that are deemed impactful involve technology and data; using supply chain mapping software and improving data quality and sharing. Among the top 2 greatest challenges in addressing risk in the future for 8 out of 10 companies is lack of data and knowledge and insurance for risk transfer, closely followed by lack of internal risk management tools and insight (6 in 10 companies).

Source: WTW Global Supply Chain Survey 2023, semiconductor companies

Third-party data control

The use of third parties to carry out specialised supplier vetting, supply chain analysis and control was referred to several times. Resilinc, for example, was quoted as a highly credible supplier data control agent, able to audit suppliers and gather valuable supply chain data, map it out and determine Tier 2 and 3 suppliers and what they do in terms of COPE, natural catastrophe risk, business continuity planning, etc. The supply chain risk management team within one company manages the relationship with Resilinc directly and receives 'event watches', which are made up of about 50–100 reports of events per day, to proactively track events, evaluate potential impacts and then adjust inventory process/levels accordingly.

> If we find that business continuity plans are not that solid, we will work with Resilinc and supplier to improve.
>
> **Risk manager, global technology company**

Appendix

Appendix

In our conversations with semiconductor companies, many felt that the wider insurance market has been slow to recognise the needs of the sector and its robust risk management—highlighting the value of this report in sharing more information between the industry and insurers and opening up understanding of the sector to new underwriters. To support this, detailed profiles of these business models and key subsectors have been created.

Research and development: Intellectual property, patents, trademarks and trade secrets

The semiconductor industry is one of the most intensive industries in the world for research and development (R&D). A typical spend of between 15-20% of sales on R&D is not uncommon[62]. Innovations take place over several phases to get to the final technology solutions, including development, extraction of materials, electrical properties, circuitry, manufacturing (both for process and capital equipment) or user applications.

Intellectual property (IP) is the lifeblood of the semiconductor industry, with effective IP protection being key to ensuring and encouraging innovation across the entire value chain. The continued success of the industry and further improvements in semiconductor design and manufacturing (and as end products require even more sophisticated and smaller chips) depends on a company's ability to rely on an effective patent system and strong protections for trade secrets.

Trademarks and patents define the origin of a product and form the legal basis for fighting counterfeit products and challenging perceived IP theft. Counterfeits are an issue for the industry and can erode the economic basis of the companies that have invested in new products but are also not subject to the same quality requirements, leading to substandard products in the supply chain of the end customers. IP protection – for patents, trademarks or trade secrets – is not consistent across global geographies, making the environment difficult and potentially costly to navigate.

State-backed funding of China's semiconductor industry has emerged as a focus of the trade tensions between China and the U.S.. Both the U.S. and Europe have expressed concerns about the loss of IP to China[63] and are exploring further legislative options. IP experts that WTW has spoken with as part of this research have expressed concerns that the CHIPS and Science Act passed by the U.S. Congress in July 2022, to increase semiconductor R&D and manufacturing in the U.S., may increase IP litigation. The CHIPS Act could also make semiconductor trade secret protection more important and potentially result in more innovative start-up businesses that can increase employee mobility and the possibility of trade secret leaks, therefore boosting the number of IP litigation cases in the U.S.

Market drivers

Companies are constantly searching for new and better ways to make semiconductors, resulting in valuable IP. Semiconductor IP is a potential revenue stream, and a company that invents unique semiconductors (secured via patents) can leverage semiconductor IP as unique revenue. Productivity improvements in the chip itself, as well as for the essential components and equipment needed to produce chips, is a key contributor to the semiconductor's economic performance and its competitiveness.

Trends

The global market for semiconductor (silicon) intellectual property (SIP) was estimated at $6bn in the year 2022. The market is expected to register growth of over 7% between 2020 and 2027[64]. Semiconductor IP can remain proprietary to the company that invented the design, or the inventing body might license their designs to other companies.

- Driven by geopolitical and national security fears over their digital infrastructure and the resiliency of supply chains, governments and companies all over the world are fighting for dominance in the semiconductor market. This is likely to result in constraints on who semiconductor companies are allowed to sell IP to
- Increased U.S. production could drive more International Trade Commission complaints by making it easier for businesses to meet domestic industry requirements
- Semiconductor production-self-sufficiency is becoming a top priority for China. The government-backed China Integrated Circuit Industry Investment Fund will be central to improving China's ability to design and manufacture advanced processors and GPUs. Western governments are worried about the threats this might pose to IP owned by companies in their geographies

Example companies (Global HQ):

- Synopsys (U.S.)
- Cadence (U.S.)
- Arm Holdings (U.K.)
- Nordic Semiconductor (Norway)
- CEVA (U.S.)

Raw materials: specialised raw materials and components

Semiconductor materials is one subsector that can offer significant innovation opportunity to the electronics industry, with variations in price and availability of materials, from abundant silicon to difficult-to-source rare-earth elements such as scandium[65]. By employing key raw materials, electronics manufacturers have been able to replace traditional thermionic devices that made electronic items heavy and non-portable. Since the inception of semiconductor elements, there has been a high degree of miniaturisation, making electronic equipment more compact and mobile.

Lack of access to critical raw materials has the potential to significantly hamper chip fabrication. Also, since chipsets are used in nearly everything related to modern electronics, events that could interrupt raw material supply could also subsequently impact chip dependent industries such as automotive, manufacturing, logistics, computing, and construction.

The market is segmented by[66]:

- **Materials:** Silicon Carbide, Gallium Manganese Arsenide, Copper Indium Gallium Selenide, Molybdenum Disulfide, and Bismuth Telluride
- **Fabrication:** Process Chemicals, Photomasks, Electronic Gases, Photoresists Ancillaries, Sputtering Targets, and Silicon
- **Packaging:** Substrates, Lead Frames, Ceramic Packages, Bonding Wire, Encapsulation Resins (Liquid), and Die Attach Materials
- **End user industry:** Consumer Electronics, Telecommunication, Manufacturing, Automotive, and Energy and Utility.
- **Geography:** The semiconductor business has also become one of the most interlinked sectors in history, including when it comes to raw materials. Raw materials are supplied from Europe, U.S., Russia, Japan, Mexico, as well as from many other countries

Example companies (Global HQ):

- BASF (U.S.)
- LG Chem Ltd (South Korea)
- KYOCERA Corporation (Japan)
- Indium Corporation (U.S.)
- Showa Denko Materials Co. Ltd (Japan)

Market drivers

The semiconductor materials market was valued at $58.3bn in 2021[67], and expected to register a compound annual growth rate (CAGR) of 4.71% from 2023-2028[68]. While 2022 saw the sector's market cap shrink, the global semiconductor industry is anticipated to grow to $1trn in revenues by 2030, doubling in this decade. To turn silicon powder into chips, the material is melted in a furnace at 1,400°C and formed into cylindrical ingots. These are then sliced into discs called wafers, like chopping up a cucumber. Finally, several dozen rectangular circuits – the chips themselves – are printed onto each wafer in factories, such as that run by GlobalFoundries in New York state. From here, chips make their way to every corner of the planet.

Trends

- In the absence of an effective response, Europe may fall increasingly behind and become dependent on China for raw materials including chemicals, and even technology. Silicon wafers are thin slices of semiconductor that are used for the fabrication of integrated circuits, and to manufacture solar cells. In 2020, the global demand for silicon wafers was about 12.4 billion square inches[70].
- Semiconductor materials have specific characteristics related to electrical conductivity. The future of semiconductors depends on whether new materials with these characteristics can be mass-produced at a cost similar to that of silicon.

Electronic design automation

Electronic design automation (EDA) consists of software (primarily), hardware, and other specialised services with the collective goal of assisting in the definition, planning, design, implementation, verification, and subsequent manufacturing of semiconductor devices, or chips.

The cost of an error in a manufactured chip can be catastrophic. Chips errors cannot be "patched." The entire chip must be re-designed and re-manufactured. The complexity of designing chips is high and the need to do it flawlessly has resulted in highly specialised software tools. Another market segment that is closely associated with EDA is intellectual property[71]. Due to the strong dependence of IP use and reuse on EDA tools, these markets are typically viewed as one.

These highly complex and costly facilities are either owned and operated by large, vertically integrated semiconductor companies or operated as independent, "pure-play" manufacturing service providers. This latter category is the dominant business model. While EDA solutions are not directly involved in the manufacture of chips, they play a critical role in three ways[72]:

1. EDA tools are used to design and validate the semiconductor manufacturing process to ensure it delivers the required performance and density. This segment of EDA is called technology computer-aided design (TCAD).
2. EDA tools are used to verify that a design will meet all the requirements of the manufacturing process. Deficiencies in this area can cause the resultant chip to either not function or function at reduced capacity. This area of focus is known as design for manufacturability (DFM).
3. Silicon lifecycle management (SLM) is the growing requirement for monitoring the performance of the device from post-manufacturing test to deployment in the products where the chip is embedded. The purpose of SLM is to ensure the device continues to perform as expected throughout its lifetime and to ensure the device is not tampered with.

Hardware is used when extremely high performance and shorter timescales are required (hours to days vs. weeks to months). The two primary delivery vehicles for EDA hardware are emulation and rapid prototyping. Many new tools incorporate both analogue design and mixed systems—a trend towards placing entire electronic systems on a single chip.

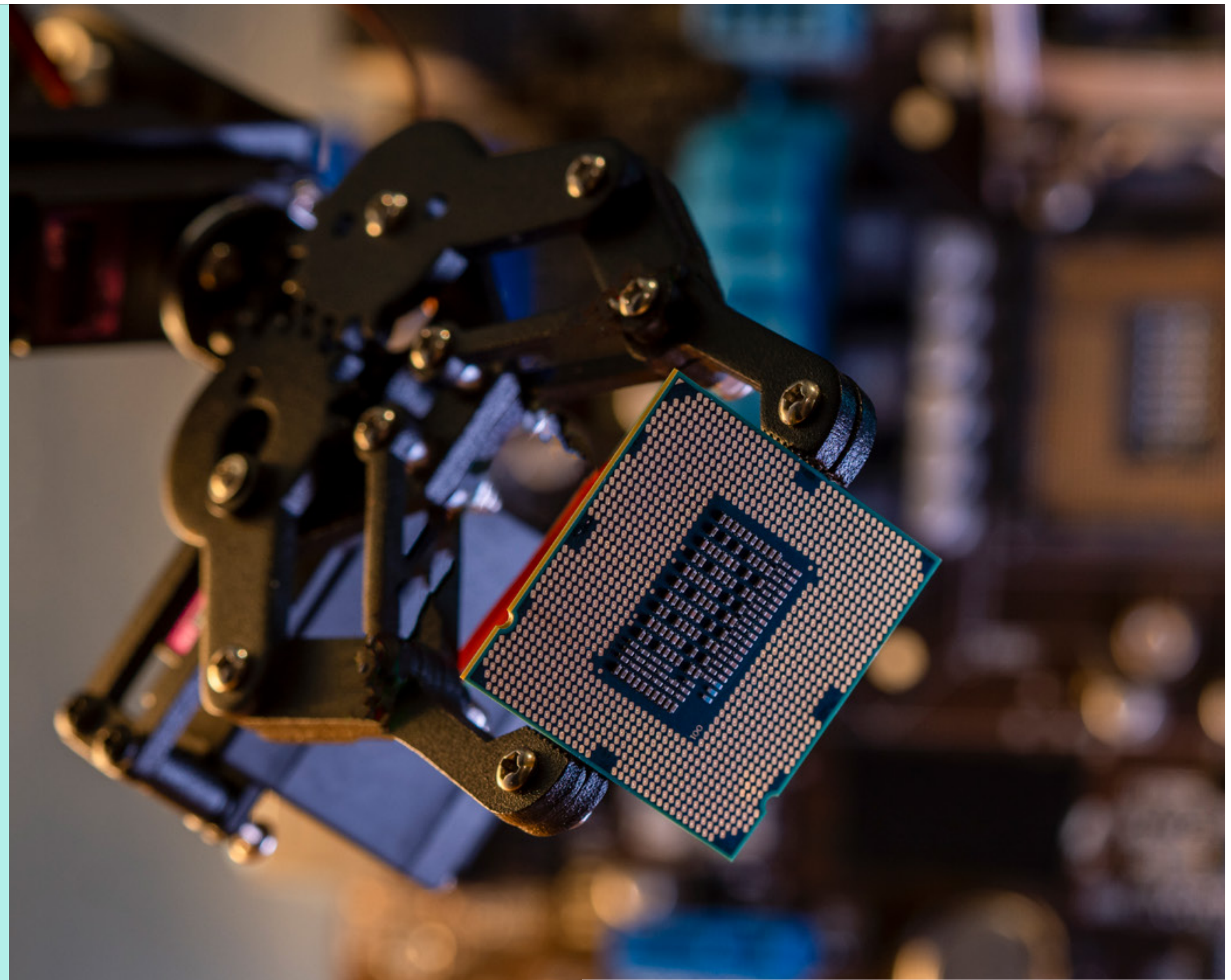
Market drivers

The global electronic design automation software market is set to surpass a valuation of $11.2bn in 2023 and to further expand at a CAGR of 8.6% to reach $25.6bn by the end of 2033. Revenue generation from electronic design automation software accounted for 77% of the global electronic automation market in 2022[73].

As designs are growing increasingly complex, EDA software is becoming crucial for developers engaged in the manufacturing of printed circuit boards (PCBs) and other circuit boards. EDA software helps developers in designing, modelling, simulating, testing, and analysing circuit designs to catch potential issues before they can enter production.

Trends

- EDA for electronics has rapidly increased in importance with the continuous scaling of semiconductor technology. Simulations are increasingly important as errors in the chip cannot be addressed once embedded in a product.
- Many EDA companies grow by acquiring smaller companies with niche/unique software or other technology that can then be adapted to and enhance the acquirer's core business. Most of the market leaders today are an amalgamation of many smaller companies and this trend is helped by the tendency of software companies to design tools as accessories that fit naturally into a larger vendor's suite of programmes.



Example companies (Global HQ):

- Cadence Design Systems (U.S.)
- Zuken (Japan)
- Altium Limited (U.S./Australia)
- Codasip (Germany)
- Rambus (U.S.)
- Shanghai Hejian Industrial Software Group (China)
- Cognidox (U.K.)
- Innoda (Chengdu) Electronic Technology (U.S.)

Semiconductor equipment manufacturers: Capital equipment

The semiconductor capital equipment industry markets and manufactures the key equipment used in processing, production and packaging of semiconductors and other electronic components. While the industry contracted somewhat in 2022, the overall demand for semiconductor-powered devices is expected to rise significantly over the coming decade owing to the rapidly advancing dynamics of electronic devices, which in turn will fuel the growth of the semiconductor capital equipment market.

Semiconductor capital equipment is classified as back- or front-end, and plays an important role in the manufacturing of integrated circuits (ICs) in semiconductor fabrication plants:

- Front-end semiconductor capital equipment involves various functions such as etching, photolithography, ion implantation, deposition, cleaning, chemical and mechanical polishing, and silicon wafer fabrication. The front-end semiconductor capital equipment segment accounts for majority of industry sales
- Back-end semiconductor capital equipment encompasses packaging, assembling and testing of integrated circuits

To better compete in the market and to make increasingly complex chip designs, semiconductor capital equipment manufacturers need to constantly innovate and produce leading-edge tools. Advancements in the circuitry board technology and the planned increased construction of semiconductor fabrication plants intended to improve global production, are both influencing the sector—a trend that is likely to continue over the coming years.

The industry is facing ever-higher capital intensity and significant investment requirements to maintain growth. However, such growth is under pressure given the limited agility in parts of the semiconductor supply chain, and particularly when it comes to key manufacturing (capital) equipment, restricting the ability to fulfil demand and keep pace with capacity expansions.

Market drivers

Geographically, the semiconductor capital equipment market can be segmented into North America, Western Europe, Latin America, Eastern Europe, Asia Pacific excluding Japan (APEJ), the Middle East and Africa (MEA) and Japan. The Global Semiconductor Capital Equipment Market is expected to grow by over $17bn from 2022-2026, accelerating at a CAGR of 5.18% during the forecast period[74].

ASML has a 90%[75] share of the total market for lithography systems that make semiconductors. When it comes to the most advanced type of chipmaking lithography machine, known as extreme ultraviolet lithography (EUV), that market share surges close to 100%.

Trends

- Asia Pacific is anticipated to be the major revenue generating region in the global semiconductor capital equipment market, owing to the increasing usage of semiconductor capital equipment in consumer electronic industries. Countries such as China, Japan and India are expected to drive the growth of the semiconductor capital equipment market in this region.
- The semiconductor capital equipment market in North America is expected to grow at a significant rate owing to the increasing usage of semiconductor capital equipment in the telecommunications industry in this region and as a result of the US government-driven legislation to support market growth
- Environmental impact, and in particular a reduction in carbon footprints, is becoming a key driver for this water and energy-hungry sector. The drive for more environmentally-friendly process is also increasingly becoming a key battleground.
- Raw material and input costs, labour shortages and other supply chain challenges are high on the agenda.

Example companies (Global HQ):

- Hitachi High Technologies (Japan)
- Applied Materials (U.S.)
- Tokyo Electron (Japan)
- ASML (The Netherlands)
- Lam Research (U.S.)

Foundries

A semiconductor foundry (fab) is a factory where devices such as integrated circuits (IC) are manufactured. Fabs are expensive and complicated to construct and operate. Fabs are concentrated to just a few players and mainly located in Asia, with Korea and Taiwan leading the way in fabrication. As well as this geographical concentration, fabrication capacity is located in regions facing a multitude of potential supply chain risks and challenges, including geopolitical, natural disasters (wind, flood, earthquakes, etc.) and logistical exposures.

The operating environments at foundries are vast and complex. Depending on the design, each chip might require anywhere between 1,000 and 2,000 steps to produce it[76]. Fabs are very expensive to build due to their requirements around cleanliness, typically needing air quality that is approximately 1,000 times cleaner than normal factories. Chips are so tiny that dust particles or hairs could ruin their complex circuitry. To avoid contaminating the microelectronics, the vast factory floor must be sterile and lit by a dim yellow light to prevent ultraviolet radiation from damaging some of the chemicals used in the production process. Lab workers and factory technicians operate in clean rooms, with increasing operations carried out automatically by vacuum-sealed robots.

Given the extended time frames required to build fab infrastructure and enhance workforce skills, semiconductor companies deploy a long-term strategy for achieving design and manufacturing excellence – one that simultaneously considers construction issues, equipment costs, university partnerships, employee training/retention and the need to enhance internal capabilities.

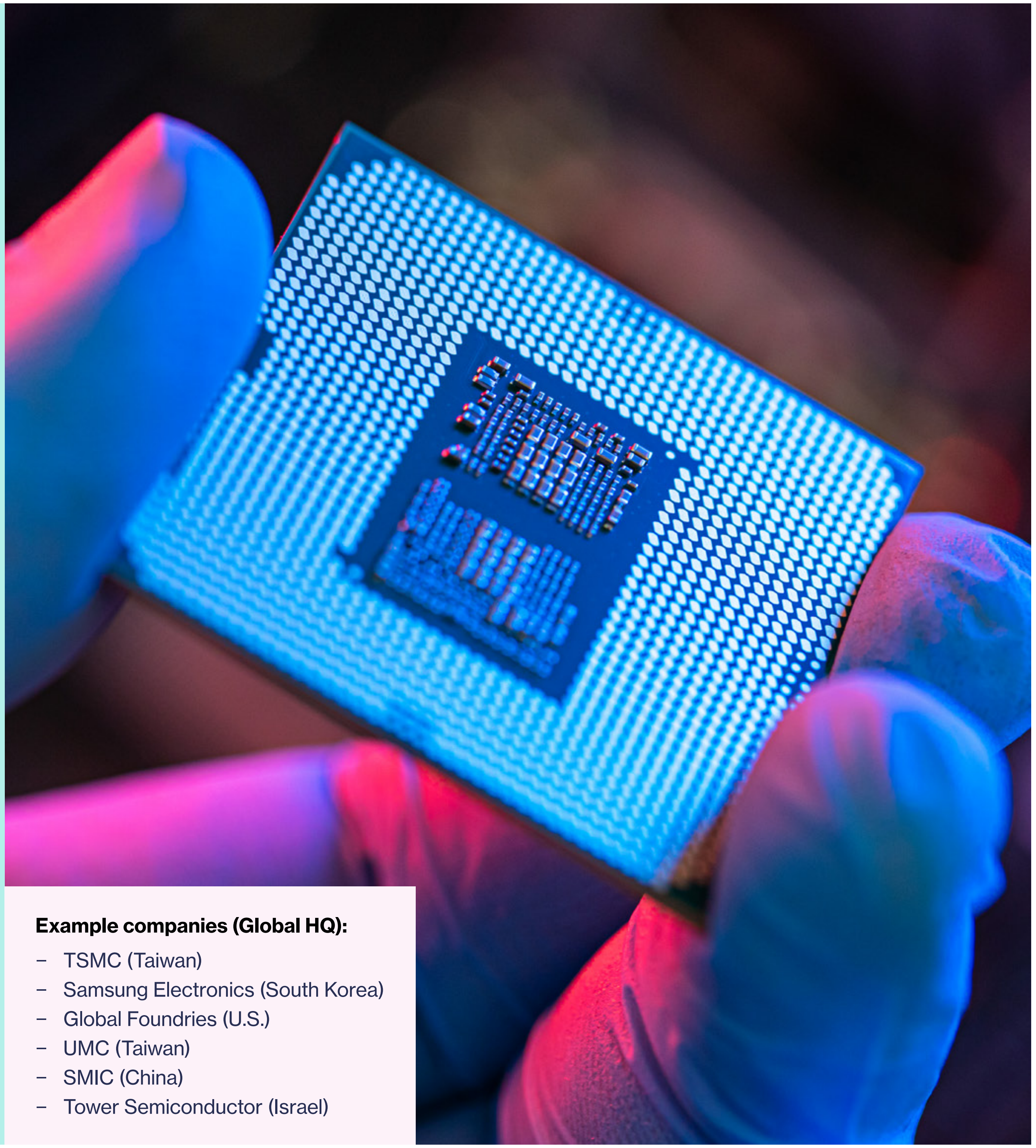
Market drivers

According to market research[77], the global semiconductor foundry market was estimated at $77.8bn in 2022. In late 2022, market analysts expect the market to reach $112.9bn by 2028, exhibiting a growth rate (CAGR) of 6.2% from 2023-2028[78]. Softening consumer demand in 2023 along with high IC inventories are expected to see revenues to decline by 5%-7% in 2023. The world's top ten semiconductor foundries generate the majority of the global revenue[79].

Semiconductor manufacturing is subject to demand that is largely driven by consumer appetite for electronics, including for products whose performance continues to be enhanced by incorporating 'smart' features. The industry is highly capital-intensive, with high costs stemming from construction and expensive machinery. Given the lengthy construction time frames for new foundries, investment decisions often need to be made years in advance and despite the cyclical nature of the industry.

Trends

- Growing demand for more advanced consumer electronics, including portable and network-enabled devices is continuing to push up demand.
- Rising demand for high-performance computing products for many industries, including cars and other transportation solutions, is creating supply challenges with shortages expected to continue for the foreseeable future.
- Sustainability, and in particular a reduction of carbon footprints, is a key driver for an energy-hungry sector. The drive for more environmentally-friendly operations, with a particular focus on reducing the sectors high dependency on water and energy, is high on the agenda.



Example companies (Global HQ):

- TSMC (Taiwan)
- Samsung Electronics (South Korea)
- Global Foundries (U.S.)
- UMC (Taiwan)
- SMIC (China)
- Tower Semiconductor (Israel)

Fabless chip companies

Fabless chip makers are companies that design and produce semiconductors for use in various types of electronics, such as digital cameras, smartphones, and the new technologically sophisticated “smart” cars.

The term "fabless" means that the company designs and sells the hardware and semiconductor chips but does not manufacture the silicon wafers, or chips, used in its products; instead, it outsources the fabrication to a manufacturing plant. The business model works by making use of the design, research, development skills (and distribution networks) of the fabless company, and the specialised manufacturing skill of the chip foundries. Many of the foundries contracted by the fabless chip makers are located in Taiwan and China.

The fabless business model is popular in the semiconductor industry because it allows companies to invest profits in the research and development of new technologies while outsourcing the high production volumes needed to maintain sales to the specialist foundries.

Example companies (Global HQ):

- Qualcomm (U.S.)
- Broadcom (U.S.)
- Nvidia (U.S.)
- Nordic Semiconductor (Norway)

Market drivers

In 2021 the world's 10 biggest fabless chip designers grew their collective revenue to $127.4bn, a 48% increase over the previous year[80], with 2022 figures not yet available. While there is a relatively close relationship between the annual market growth of the fabless IC suppliers and foundries, the sales growth of fabless IC suppliers has increasingly become better than those of IDMs.

Trends

- The world's 10 biggest fabless chip designers grew their collective revenue to $127.4bn in 2021, a 48 percent increase over the previous year[81].
- With a 36% surge in fabless company IC revenue in 2021, fabless companies have achieved a record 34.8% share of global IC sales after having a 2011-2021 CAGR of 10% – double that of the IDMs[82].
- Global silicon wafer shipments are projected to increase 4.8% year-over-year in 2022 to a record high of nearly 14,700 million square inches[83].
- Persistent inflation, impacting everything from the cost of raw materials, energy costs, wages and transportation, and resulting in the lowest ever consumer confidence, is translating into a reduced demand for gadgets and other consumer electronics.

Outsourced semiconductor assembly, testing and packaging, and logistics

Outsourced semiconductor assembly and test (OSAT) companies provide a wide range of semiconductor test services for foundries, including final system-level, wafer, and strip testing along with the complete end-of-line services. up to and including final shipping to the end customers.

Customised semiconductor logistics is an important link in the value chain and OSATs often provide customers with total supply chain solutions that encompass everything from semiconductor shipping to packaging to warehousing and distribution. They offer outsourced services, which are typically more cost-effective than if chip manufacturers were to have these operations in-house. As chips grow even smaller, testing and packaging solutions will become even more extensive, expensive and important to get right. The OSAT stage of the manufacturing process is the most labour-intensive and is often performed in countries that have lower labour costs such as China and Malaysia.

Companies in this part of the market are also essential in ensuring that the design and delivery of flexible, end-to-end logistics solutions keeps pace with the changing chip designs and logistics requirements. The benchmark for the industry is a fulfilment accuracy rate of close to 99.999%, with careful planning of solutions important down to the smallest detail. Disruptions experienced when the logistics sector faced a shortage of qualified personnel (such as during the COVID-19 outbreak) were felt across the entire value chain, causing processes across the semiconductor industry and electronics manufacturing to grind to a halt.

Market drivers

OSAT market sales totalled $34.6bn in 2021, and are projected to reach $60.3bn by 2031, growing at a CAGR of 6.3% from 2022 to 2031[84].

Just as semiconductor market revenues have increased over the last decade, so too have total unit shipments. In 2021, about 1.15 trillion semiconductor units were shipped all over the world – a 40% jump from the figure recorded in 2010[85]. New market drivers and applications continue to emerge, contributing toward a rise in semiconductor shipments and the importance of securing transportation.

Trends

- Green logistics and sustainability, moving to alternative fuels.
- Stringent regulatory landscape with protectionist behaviour on both the regulatory and political agenda globally.

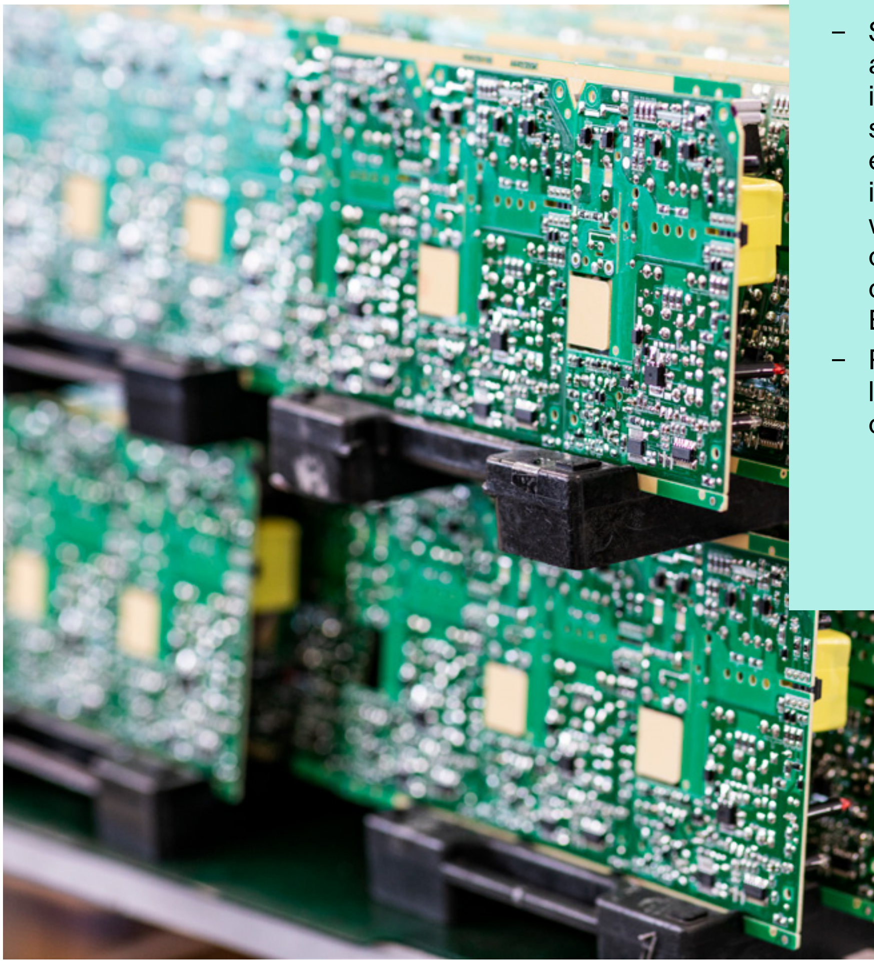
Example companies (Global HQ):

- ASE Group (Taiwan)
- Amkor Technology (U.S.)
- JCET (China)
- Siliconware Precision Industries Co Ltd (Taiwan)
- ChipMOS (Taiwan)

Integrated device manufacturers

An integrated device manufacturer (IDM) is a semiconductor company which designs, manufactures, and sells integrated circuit (IC) products. IDMs are large-scale semiconductor companies that have the means to do everything from designing to producing products, controlling every process from planning to manufacturing and sales. In comparison, a foundry may only oversee production, and a fabless only has the resources to design semiconductors.

Covering activities across the value chain makes the supply chain challenges more complex for IDMs and can conversely give them greater oversight and control of suppliers allowing them to monitor important parts of their supply chain more actively. This model, while still important, has becoming less relevant as sector companies increasingly specialise in a particular part of the supply chain to achieve better efficiencies and cost improvements for the particular part.



Market drivers

Integrated device manufacturer (IDM) companies sold $257.4bn worth of integrated circuits in 2020, up from the $251.8bn in 2019[86]. In the early days of semiconductor industry, when IC complexity was low and IC design, fabrication and test processes were forming, the IDM business model worked well. In a mature semiconductor industry where the product complexity is high, it is impractical and cost-prohibitive for one company to handle all the processes[87].

Trends

- Sustainability, and in particular a reduction of carbon footprints is a key driver for an energy-hungry sector. The drive for more environmentally friendly packaging is also increasingly a key battleground, with decisions being made by investors, customers, consumers and employees on the basis of a manufacturer's ESG credentials.
- Raw material and input costs, labour shortages and supply chain challenges are high on the agenda.

Example companies (Global HQ):

- Samsung (South Korea)
- Texas Instruments (U.S.)
- Infineon (Germany)
- Intel (U.S.)
- Fujitsu (Japan)
- Sony (Japan)

References

1. https://www.statista.com/statistics/266973/global-semiconductor-sales-since-1988/#:~:text=In%20 2022%2C%20semiconductor%20sales%20reached,in%202022%20reached%204.4%20percent
2. https://news.metal.com/newscontent/101720424/ic-insights-expects-global-semiconductor-sales-to-grow-by-another-11-this-year
3. https://www.porsche-consulting.com/en/media/insights/detail/white-paper-strategic-semiconductor-management/
4. https://www.iqsdirectory.com/resources/everything-you-ever-wanted-to-know-about-semiconductors/ https://publications.parliament.uk/pa/cm5803/cmselect/cmbeis/291/report.html#heading-0
5. https://www.sec.gov/Archives/edgar/data/1709048/000170904822000021/a6-kex993businessupdate.htm
6. https://techhq.com/2023/01/semiconductor-revenue-expected-to-contract-for-the-first-time-in-four-years-in-2023/#:~:text=%E2%80%9CGlobal%20semiconductor%20revenue%20is%20forecast,of%20 around%20the%20same%20level
7. https://www2.deloitte.com/us/en/pages/technology-media-and-telecommunications/articles/semiconductor-industry-outlook.html
8. https://cset.georgetown.edu/wp-content/uploads/The-Semiconductor-Supply-Chain-Issue-Brief.pdf
9. https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_Nov-2022.pdf
10. https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_Nov-2022.pdf
11. https://www.cliffordchance.com/insights/resources/blogs/talking-tech/en/articles/2022/08/semiconductors-increasing-governmental-and-regulatory-scrutiny.html
12. https://www.weforum.org/agenda/2022/09/a-revitalized-semiconductor-industry-will-drive-europes-digital-future/
13. https://think.ing.com/articles/eu-chips-act-to-strengthen-europes-economy/
14. https://www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf
15. https://www.marketplace.org/2022/08/23/what-does-it-take-for-chip-manufacturers-to-get-a-new-plant-up-and-running/
16. https://www.newelectronics.co.uk/content/interviews/strong-chip-growth-forecast-through-to-2030/
17. Dicken, Peter. 2003. Global Shift: Reshaping the Global Economic Map in the 21st Century,. Fourth Edition. Guilford Press.
18. https://ec.europa.eu/commission/presscorner/detail/en/speech_21_4701
19. https://www.amd.com/system/files/2020-02/378203_semiconductor-production-chain-1920wide_0.jpg
20. https://semiengineering.com/knowledge_centers/manufacturing/integrated-device-manufacturer-idm/
21. https://crsreports.congress.gov/product/pdf/R/R46581
22. https://www.rms.com/blog/2016/12/19/understanding-risk-accumulations-in-taiwans-science-parks
23. https://supplychaindigital.com/top10/timeline-causes-of-the-global-semiconductor-shortage
24. https://www.nytimes.com/2021/04/08/technology/taiwan-drought-tsmc-semiconductors.html
25. https://www.bbc.com/news/world-asia-56798308
26. https://www.preventionweb.net/news/how-climate-change-disrupting-global-supply-chain
27. https://www.accuweather.com/en/winter-weather/damages-from-feb-snowstorms-could-be-as-high-as-155b/909620
28. https://www.swissre.com/media/press-release/nr-20211214-sigma-full-year-2021-preliminary-natcat-loss-estimates.html
29. https://www.msci.com/www/blog-posts/how-climate-change-affected/02841370014
30. https://www.reuters.com/article/us-japan-renesas-taiwan/renesas-says-normal-production-at-fire-hit-chip-plant-to-take-100-120-days-idUSKBN2BM09M
31. https://www.calcalistech.com/ctech/articles/0,7340,L-3848490,00.html
32. https://www.imua.org/Files/reports/Underwriting%20Semiconductor%20Manufacturing%20Exposures.html

33. https://www.tandfonline.com/doi/pdf/10.1080/13675560500405584
34. https://pure.iiasa.ac.at/id/eprint/18260/1/CC_SHS_SCMIJ_AAM.pdf
35. https://www.edn.com/ase-loss-widens-on-impact-of-may-fire/ https://www.swissre.com/dam/jcr:8aa200e8-1ee2-4204-a1e2-017bfa30282c/pub_fire_protection_on_building_sites_en.pdf https://icrt.co/wp-content/uploads/2019/12/1997_10_8-UICC-fab-fire-causes-%EF%BF%BD416-million-in-damage-Semiconductor-Business-News.pdf https://books.google.co.uk/books?id=km8A81WgIN4C&lpg=PA8&ots=scXLIOpQaL&dq=philips%20new%20mexico%20losses%20in%202000&pg=PA8#v=onepage&q&f=false https://www.sec.gov/Archives/edgar/data/313216/000115697305000224/u48379exv99w1.htm https://www.grips.ac.jp/r-center/wp-content/uploads/14-06.pdf https://www.cnet.com/tech/tech-industry/quake-will-cause-taiwan-chipmaker-to-lose-88-million/ https://investor.tsmc.com/static/annualReports/2016/english/pdf/e105_1.pdf https://uk.finance.yahoo.com/news/taiwan-earthquake-slow-apple-sales-152253658.html https://www.umc.com/upload/media/08_Investors/Annual_Reports/Form-20_pdf_eng/Form_20-F_December_31_2016.pdf https://pure.rug.nl/ws/portalfiles/portal/121518712/Using_virtual_laboratories_for_disaster_analysis_a_case_study_of_Taiwan.pdf
https://investor.tsmc.com/static/annualReports/2016/english/pdf/e105_1.pdf
https://www.umc.com/upload/media/08_Investors/Annual_Reports/Form-20_pdf_eng/Form_20-F_December_31_2016.pdf
https://uk.finance.yahoo.com/news/taiwan-earthquake-slow-apple-sales-152253658.html
36. https://www.independent.co.uk/news/uk/home-news/scheduled-blackouts-uk-1970s-life-b2245675.html
37. https://www.pwc.com/us/en/industries/tmt/library/semiconductor-supply-chain-disruptions.html
38. https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-makers-can-turn-a-talent-challenge-into-a-competitive-advantage
39. https://www.cnbc.com/2022/07/05/why-driving-big-rig-trucks-isnt-a-job-americans-want-to-do-anymore.html
40. https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-makers-can-turn-a-talent-challenge-into-a-competitive-advantage
41. https://matmatch.com/resources/blog/what-materials-are-necessary-for-computer-chip-fabrication/
42. https://www.wsj.com/articles/chip-makers-stockpiled-key-materials-ahead-of-russian-invasion-of-ukraine-11647167582
43. https://www.csis.org/blogs/perspectives-innovation/russias-invasion-ukraine-impacts-gas-markets-critical-chip-production
44. https://www.mckinsey.com/industries/semiconductors/our-insights/strategies-to-lead-in-the-semiconductor-world
45. https://newsroom.ibm.com/2021-05-06-IBM-Unveils-Worlds-First-2-Nanometer-Chip-Technology,-Opening-a-New-Frontier-for-Semiconductors
46. https://www.csis.org/blogs/strategic-technologies-blog/chip-shortages-light-geopolitics-and-climate-change
47. https://www.tandfonline.com/doi/full/10.1080/00131857.2022.2124914
48. https://www.reuters.com/article/us-usa-huawei-tech-tsmc-idUSKBN22U0EW
49. https://www.vice.com/en/article/qjkj7x/tsmc-us-china-semiconductors-tech-war-taiwan
50. https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_Nov-2022.pdf
51. https://www.brookings.edu/techstream/bringing-economics-back-into-the-politics-of-the-eu-and-u-s-chips-acts-china-semiconductor-competition/
52. https://www.cnbc.com/2022/12/06/tsmc-to-up-arizona-investment-to-40-billion-with-second-semiconductor-chip-plant.html
53. https://www.mckinsey.com/industries/semiconductors/our-insights/sustainability-in-semiconductor-operations-toward-net-zero-production
54. https://www.tmkiln.com/news-insights/news/tmk-and-carbonchain-partner-to-evaluate-customers-carbon-emissions/
55. https://www.kearney.com/technology/article/-/insights/why-a-resilient-semiconductor-supply-chain-is-imperative-and-how-to-create-one

56. https://www.kearney.com/technology/article/-/insights/why-a-resilient-semiconductor-supply-chain-is-imperative-and-how-to-create-one
57. https://www.businesswire.com/news/home/20210719005439/en/Luminar-Acquiring-Exclusive-Lidar-Chip-Partner-and-Specialized-Fab
58. https://www.semiconductor-digest.com/water-supply-challenges-for-the-semiconductor-industry/
59. https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/
60. https://blog.se.com/sustainability/2022/01/31/how-semiconductor-fabs-can-design-a-greener-future/
61. https://spectrum.ieee.org/new-metalair-transistor-replaces-semiconductors
62. https://www.semiconductors.org/wp-content/uploads/2022/05/SIA-2022-Factbook_May-2022.pdf
63. https://sciencebusiness.net/news/poor-ip-protection-china-causes-irreparable-harm-eu-companies
64. https://www.linkedin.com/posts/global-industry-analysts-inc._semiconductorintellectualproperty-activity-6819229589911556096-WNaf/?trk=public_profile_like_view&originalSubdomain=in
65. https://semiengineering.com/knowledge_centers/materials/rare-earth-elements-ree/
66. https://www.mordorintelligence.com/industry-reports/semiconductor-materials-market
67. https://www.precedenceresearch.com/semiconductor-materials-market
68. https://www.mordorintelligence.com/industry-reports/semiconductor-materials-market
69. https://espas.eu/files/Global-Semiconductor-Trends-and-the-Future-of-EU-Chip-Capabilities-2022.pdf
70. https://www.theregister.com/2022/02/10/record_wafer_year/
71. https://www.factmr.com/report/electronic-design-automation-eda-tools-market
72. https://www.synopsys.com/glossary/what-is-electronic-design-automation.html
73. https://www.factmr.com/report/electronic-design-automation-eda-tools-market
74. https://www.globenewswire.com/news-release/2022/10/04/2528254/0/en/The-Global-Semiconductor-Capital-Equipment-Market-is-expected-to-grow-by-17-05-bn-during-2022-2026-accelerating-at-a-CAGR-of-5-18-during-the-forecast-period.html
75. https://technode.com/2022/11/16/canon-exec-shares-progress-in-lithography-and-views-on-the-chinese-chip-market/
76. https://www.bbc.com/future/bespoke/made-on-earth/how-the-chip-changed-everything/
77. https://www.marketreportsworld.com/global-semiconductor-foundry-market-14638470
78. https://www.einnews.com/pr_news/615418663/semiconductor-foundry-market-2023-worth-us-112-9-billion-by-2028-growth-rate-cagr-of-6-2
79. https://www.trendforce.com/presscenter/news/20220324-11169.html
80. https://www.trendforce.com/presscenter/news/20220324-11169.html
81. https://www.electronicsweekly.com/news/business/fabless-2022-07/
82. https://www.semi.org/en/news-media-press-releases/semi-press-releases/global-silicon-wafer-shipments-projected-to-set-new-record-in-2022-semi-reports#:~:text=%E2%94%80%20November%207%2C%202022%20%E2%94%80,forecast%20for%20the%20semiconductor%20industry.
83. https://www.alliedmarketresearch.com/outsourced-semiconductor-assembly-and-test-market-A08874
84. https://www.statista.com/statistics/802632/world-semiconductor-shipments/
85. https://www.statista.com/statistics/553236/worldwide-fabless-system-company-idm-ic-sales-comparison/
86. https://semiconductor.samsung.com/support/tools-resources/dictionary/semiconductor-glossary-integrated-device-manufacturer-idm/

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