

RESILIENCE OF THE SEMICONDUCTOR SUPPLY CHAIN

DISCUSSION PAPER



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Technology is all around us. From the visible to the invisible.

And never has the power of technology been greater, not just to make things easier, but to make things better. It is the tool that enables us to shape our world and enriches our lives.

Technology brings us together. It connects us.

And these connections power innovation, foster creativity, and drive discovery.

We know our partners operate in a dynamic and fast-changing market and need to deliver the latest advancements around the world - safely, reliably and quickly. This requires resilient and flexible supply chains to ensure that goods reach their destinations intact and on time.

We also offer multi-modal, specialized solutions to transport invaluable machinery and precious parts, leveraging our own network that connects more than 220 countries and territories globally. Technology connects people.

Logistics connects the world. Connecting you.

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CHAPTER 1 INTRODUCTION

We are living in a fast-paced digital world in which chips enable much of the technological development. A new version of an electronic device, such as a smartphone, is often defined by the performance of the chip that powers it. As the world digitizes, devices incorporate more and more sophisticated chips. Advanced passenger cars, for example, may contain 1,000 to 3,500 chips¹. Future developments, such as the growth of artificial intelligence, autonomous driving, and industrial automation, are expected to drive this demand for chips even further. As a result, the semiconductor industry is predicted to achieve annual sales of US\$1 trillion by 2030, up from around \$600 billion today².

As we explore in Chapter 2, this development depends upon highly complex supply chains. A small number of highly specialized companies are involved in each phase of the chip manufacturing process. To keep up with the latest technological developments, increasing investment in R&D and capital expenditure are needed. A new fabrication plant ('fab') for manufacturing the latest chip generation (sub-3 nanometers) is expected to cost up to \$20 billion, for example³. As a result, chip manufacturers have an economic incentive to run these factories close to full capacity.

While periods of over- and under-capacity are not unusual for the semiconductor industry, pandemic-fueled demand for devices exceeded the available manufacturing capacity. That led to chip shortages which have impacted many industries since the second half of 2020. Consultancy Deloitte estimates that semiconductor shortages drove revenue misses of more than \$500 billion worldwide in 2020 and 2021, with lost auto sales of more than \$210 billion in 2021 alone ⁴.

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To satisfy the growing demand for chips, semiconductor manufacturers are expanding and upgrading their production capacity, investing \$99 billion in fab equipment in 2022, almost double the pre-pandemic rate ⁵. As we explore in Chapter 3, this unprecedented expansion presents significant logistics challenges for all companies involved. Not least because it requires parallel construction of fabs in different regions, some of which have little existing semiconductor production infrastructure. We explore the logistics implications of this extraordinary growth and the role logistics companies can play in supporting the construction process.

The chip shortages of the last three years have also exposed vulnerabilities in the supply chains of different industries. Beyond the chip shortage, pandemic-related disruptions to the transportation market, trade tensions, and the war in Ukraine have impacted supply chains across the world. As a result, supply chain resilience is high on the agenda everywhere. In a series of interviews with supply chain leaders from different industries, we explore how these companies are increasing their supply chain resilience and identify common themes that are applicable across different sectors. In Chapter 4, we show how leading companies are using supply chain visibility, strong partnerships, smart increases in inventory levels, and sustainability to improve their supply chain resilience. Additionally, we discuss the role logistics companies can play in this process. In Chapter 5, we summarize key takeaways and recommendations from this document.

> Alexander Gunde, President Technology Sector at DHL Customer Solutions and Innovation

Peter Rolfes, **Director Sector Development** at DHL Customer Solutions and Innovation

CHAPTER 2 THE DRIVING FORCE BEHIND DIGITALIZATION

Semiconductors have now become so pervasive that it is difficult to imagine life without them. The average American adult spends more than 12 hours a day interacting directly with electronic devices⁶. In 2022, Gartner expects sales of PCs, tablets and mobiles phones to reach 1.9 billion units⁷.

Each of those products is likely to contain multiple semiconductor components, including processors, memory chips, wireless communication devices, sensors, and a collection of simpler parts. Altogether, the global semiconductor industry sold a record 1.15 trillion units in 2021⁸. The sector's recent performance has been boosted by the coronavirus crisis, which increased demand for digital services, e-commerce infrastructure, and tools for remote working.

The growth of the semiconductor industry is expected to continue in the coming years, although progress may be bumpy. By the middle of 2022, for example, semiconductor demand had begun to slow in the face of lower consumer demand and as companies sought to cut their pandemic-era inventories.



1,000 to 3,500 chips in every car

GLOBAL SEMICONDUCTOR REVENUE, IN \$ BN



Source: Word Semiconductor Trade Statistics (WSTS), McKinsey, Gartner

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Analysts at consultancy McKinsey & Company predict average annual demand growth of 6 to 8% for the rest of the current decade, with the semiconductor sector becoming a trillion-dollar industry by 2030². Most of that growth will be driven by three sectors, McKinsey says: investments in processing and data storage capacity needed to run emerging Al-powered services; new generations of connected devices and the infrastructure needed to support them; and the radical changes underway in the automotive sector².

Of those, it is the automotive industry that is expected to be the biggest single source of \$1 growth for the semiconductor industry. trillion Today's cars are already packed with electronics, with between 1,000 and global semiconductor 3,500 chips used to control multiple revenue in 2030 functions¹. The shift to electric powertrains and the addition of advanced self-driving features could result in an eight-fold increase in the semiconductor content of some vehicles. And the automotive sector's share of total semiconductor demand could rise from 8% today to as much as 15% in 2030².

1.9 billion PCs, tablets and mobile phones to be sold in 2022

To assemble

a singe chip requires

40

1,000+

process steps

A COMPLEX, CAPITAL-INTENSIVE, AND GLOBAL SUPPLY CHAIN

The semiconductor industry is one of the most globalized industries in the world. The manufacture of a modern integrated circuit (IC) involves more than 1,000 separate processing steps, and 70 or more border crossings between suppliers and service providers in a dozen or more countries.

The journey of a chip might begin in the US, where silicon dioxide is mined and refined before it is shipped to Japan to be melted down and grown into a giant single crystal called an ingot. That ingot might then be sliced into wafers in South Korea, before being shipped to a foundry (fab) in Taiwan. At the fab, equipment from Europe is used to etch the circuits for multiple chips onto each wafer, based on designs created by multiple US and European technology suppliers. The completed wafers might then go to Malaysia where the individual chips are separated and packaged. Then they are shipped to China to be assembled into finished products destined for customers anywhere in the world.

Each major step along the semiconductor value chain is completed by highly specialized organizations, taking advantage of know-how built up over decades. Different generations of semiconductor technology are often described by the approximate size of their smallest features, a dimension known as the 'technology node'. This size has shrunk dramatically from around 50 micrometers (μ m) in the 1960s to just a few nanometers (nm) today. The race to stay at the leading edge of chip technology has driven extensive consolidation in the sector. In the 1990s, around a dozen companies operated foundries capable of producing the most advanced chips of the day. Today only three have that capability. These companies tend to concentrate their production in a few key geographical locations in

the world. For example, 92% of global fabrication capacity for the most advanced sub-10-nm chips is in Taiwan³. The rest is in South Korea. These advanced factories are getting more expensive too. For example, TSMC's most advanced fab dedicated to 3-nm chips is expected to cost as much as \$20 billion⁹.

GLOBAL SEMICONDUCTOR VALUE CHAIN



- 1. A UK firm licenses the IP on application process architecture
- 2. A US-based fabless firm designs the chip
- **3.** Highly advanced manufacturing equipment is developed by companies in the US, Europe, or Japan
- Silicon dioxide is mined and refined in the US and sent to Japan to be melted down and grown into a giant single crystal called an ingot
- 5. That ingot might then be sliced into wafers in South Korea

- The wafers may be shipped to fabs in Taiwan and turned into integrated circuits
- 7. Individual chips are separated and packaged by an Assembly & Testing in Malaysia
- 8. The chip is shipped to the smartphone OEM's assembly partner in China, to be incorporated into a circuit board inside the phone
- 9. The smartphone is sold to a customer in the US

ECO-SYSTEM OF SEMICONDUCTOR MANUFACTURING



Source: Semiconductor Industry Industry Association (SIA), Boston Consulting Group (BCG): Strengthening the Global Semiconductor Supply Chain in an Uncertain Era



PANDEMIC-FUELED DEMAND FOR CHIPS

COVID-19 boosted demand for many electronic devices. For example, demand for PCs and laptops saw its highest growth rate in ten years, fueled by working from home and home schooling $^{\rm 10}$. In 2020, demand for semiconductors exceeded pre-COVID forecasts in almost every major sector except automotive and industrial applications.

While demand was booming, delivering finished products to end customers was difficult. The collapse of passenger air travel removed significant air cargo capacity from the global market since much air freight travels as belly cargo on scheduled passenger flights. Additionally, congestion at major seaports especially in the US - compounded ongoing air freight shortages.

But the semiconductor sector's challenges did not end when pandemic restrictions eased. Companies in the automotive sector, for example, had been quick to cut their orders for semiconductor products as demand fell. Semiconductor manufacturers then allocated production capacity to other customers, such as consumer electronics manufacturers. When vehicle sales recovered rapidly after the crisis, semiconductor manufacturers lacked spare capacity to fulfil the resulting surge in new orders. And even where they did, extra time was needed to switch factories back to the production of automotive products.

The capital-intensity of the semiconductor industry means that chipmakers try to run their plants as close to full capacity as they can, with little headroom for unexpected spikes in demand. Utilization has been consistently high (at or above 80%) in the past decade. In 2020, it was close to 90%, effectively full utilization given the need to maintain equipment and switch production lines between different product types¹¹. Additionally, as it takes at least 24 months to set up a new fabrication facility, supply and demand in the semiconductor sector can get out of sync. In the past, this has resulted in periods of under capacity followed by periods of increased investment to satisfy the growing demand.

Growing demand and limited supply of chips led to shortages in 2021 and 2022. Problems appeared first in the automotive industry but soon spread to other sectors. Multiple automotive companies were forced to close plants and adjust production plans because they couldn't get the semiconductors they needed. Analysts at Deloitte estimate that the chip shortage of the past two years resulted in revenue misses of more than \$500 billion worldwide between the semiconductor industry and its customer industries, with lost auto sales of more than \$210 billion in 2021 alone⁴.

embarking on significant changes to its value chain. Upstream, chipmakers are making unprecedented worldwide investments in new manufacturing plants designed to boost overall capacity and reduce the risks associated with the geographical concentration of critical facilities. Downstream, semiconductor users are adapting their supply chains to boost resilience by securing the long-term availability of critical products and buffering smaller cyclical changes in demand and supply patterns.

reached a

SEMICONDUCTOR SALES IN 2019 BY APPLICATION



'Products include memory, microcomponents, logic, analog, discrete, optoelectronic, and sensors/ actuators. ²Includes Chinese inventory effect; growth rate without inventory expected to be -4 to -8%. ³Graphics processing unit. ⁴As of December 2019. The estimates for 2020 were calculated using a 2019 baseline, and percentages have been rounded. Source MckKinsey, IHS, Strategy Analytics

FORECASTED VS. ACTUAL SALES GROWTH IN % (2020)







CHAPTER 3 UNPRECEDENTED EXPANSION OF MANUFACTURING CAPACITY

With much of its existing manufacturing infrastructure running at close to full capacity, the semiconductor industry is embarking on a significant wave of capital investments to satisfy growing demand for chips. Constructing a new foundry capable of etching the smallest transistors on the largest wafers can cost more than \$20 billion³ and take two years or longer. The big chipmakers must also invest billions of dollars every year to update and replace manufacturing equipment in their existing plants. Total capital investment by the sector is expected to be more than \$99 billion in 2022, almost twice the \$55 billion investment made in 2019⁵.

This latest investment surge is a worldwide phenomenon. As ongoing shortages highlight the strategic importance of semiconductors, governments in many regions are enacting policies designed to support the development of local production capacity. The US CHIPS for America Act, for example, includes a \$52 billion provision for investment in semiconductor research, design, and manufacturing. The EU's European Chips Act offers a bundle of incentives designed to encourage the construction of new manufacturing facilities in the region.

These incentive programs are already beginning to reverse some of the recent geographic concentration in the sector. Intel, Samsung, and TSMC have all announced plans for advanced semiconductor plants in Europe and the US, for example. These new fabs are likely to encourage players from other parts of the semiconductor value chain to set up nearby, including suppliers of raw materials and capital equipment, R&D, and assembly and test organizations.

In recent months, the pace of capacity expansion has slowed a little. Some manufacturers have reduced their planned investments for 2022 and target completion dates for some new fabs have been pushed back. These delays are being driven by a combination of factors, including a slowdown in consumer demand, delays in the approval and distribution of subsidies, and shortages of critical capital equipment. Nevertheless, growth in the industry remains robust and is expected to continue.

> "In the past we were building in a timely sequence – one after finishing the previous – but now we are building multiple superfabs at the same time."

> > Rory P. O'Connor, Vice President Global Logistics, Intel

CONSTRUCTION CHALLENGES

Large capital projects are notoriously difficult to complete on time and on budget. For the semiconductor industry, the current surge in activity will be especially challenging. The construction of multiple facilities in parallel will place additional loads on project planning, project management, and project delivery resources, and some of this activity will take place in geographical areas where there is no established ecosystem for advanced manufacturing for sub-5-nm chips (e.g., in the US state of Ohio, and in France and Germany).

Efficient and well-coordinated logistics is a critical element of any major construction project. For semiconductor plants, the products and materials that must be delivered to the site fall into three broad categories. First, there are commodity items such as concrete or

steel beams. Second, there are general industrial products such as chillers, storage tanks, and gas handling equipment. These may be sourced from local, regional, or global suppliers and may be large, out-of-gauge items that need specialist transport assets and handling equipment. Finally, there is the highly specialized equipment used to make the chips. This consists of delicate, high-value items that require extremely careful handling.

At greenfield sites, semiconductor companies and their suppliers need to establish significant new logistics capacity to support construction activities. That means new multimodal transportation capabilities, including air, sea, and road freight, as well as warehouse space for the staging and preparation of equipment prior to installation. Demand for

> warehousing near semiconductor facilities is particularly acute, competing for the same space.

24+ Months duration of new fab construction

\$20

Cost of the most

advanced fabrication

plants (fabs)

billion:

The volume and variety of logistics activities required during the construction of a major semiconductor facility can be formidable. One recent mega-fab project, for example, involved almost 28,000 square meters of dedicated

warehouse space and an additional 60,000 square meters of yard space. These facilities can handle almost 13,000 separate shipments, ranging in size from 2-kg parcels to 50-ton items of capital equipment delivered on chartered ships. On average, 20 heavy or oversized items, outside the sizes of items transportable by standard equipment, can be delivered every week. Each of those movements requires detailed planning and the use of cranes and other specialist handling equipment.

DELIVERY OF CAPITAL EQUIPMENT AND SPARE PARTS

At the heart of every semiconductor fab are the expensive and highly specialized machines used to etch the transistors and other components onto silicon wafers. These machines are produced by only a handful of companies worldwide. At the moment, just one company - ASML of the Netherlands - manufactures the most advanced extreme ultraviolet (EUV) equipment needed to produce today's most advanced chips.

The limited availability of capital equipment is a significant challenge to today's wave of fab construction. The equipment for each chip production line takes several years to manufacture and requires thousands of components from highly specialized suppliers. ASML reports that it shipped only 42 EUV systems in 202112.

Transporting the machines from factory to fab is also a challenge. The most advanced system requires 40 shipping containers, 20 trucks, and three Boeing 747 cargo aircraft¹³ to move all its components. And once all that equipment is in place at a new site, the process of assembly, test, and setup can take several months. This is followed by a further ramp up period as the line is equipped with tooling for specific products and the fab operator optimizes its production and quality control processes. During these critical early phases of production, equipment and tooling suppliers will work closely with the fab, and they must have access to a comprehensive local supply of spare parts and equipment to support their customers.

INITIAL TOOLING AND SERVICE LOGISTICS

During the operating life of a fab, equipment providers will remain on hand to support, maintain, and repair their equipment. The service level agreements between suppliers and customers are stringent, with response times measured in minutes or hours rather than days. To deliver that level of support, equipment makers will hold spare parts inventories at forward stocking locations or warehouse facilities close to the customer. Suppliers face significant competition for the critical warehousing locations close to newly constructed fabs, which tend to be in short supply. They also require rapid and efficient transport links back to their home operations.

"FIT-FOR-PURPOSE" COMMERCIAL AND OPERATIONAL LOGISTICS MODELS

LOGISTICS SERVICES

- International and domestic transportation
- Special equipment
- Staging or FG / SL warehousing
- Project management, CT / LLP and VAS

Air Freight CarriersOcean Freight Carriers

- Road Special Equipment Providers
- Warehouse Providers

- 01
- Ability to provide labor / HR
- Training, safety and permitting management
- IT systems

COMMERCIAL

- Menu of Services
- Owner or Contractor Furnished and Contractor Installed Equipment
- Stakeholder / Contact Matrix

- Engineering and transport design
 Site requirements
 - Vendor management
 - STAKEHOLDER MANAGEMENT
 - Transport Management
 - Warehousing
 - LLP / Control Tower
 - Trade Compliance

Another area of increasing relevance at many new

semiconductor facilities is the provision of warehouse space

HOW LOGISTICS CAN CONTRIBUTE

project management roles during construction. They may work

with the plant's owner and main contractor to coordinate and

and materials, for example. Or they may operate warehouse

using their technology skills to provide supply chain and

execute purchase orders and inbound shipments of equipment

and yard facilities on their behalf. Logistics companies are also

inventory management capabilities, for example by operating supply chain control towers or acting as the lead logistics

Logistics service providers play multiple critical roles in the construction and operation of new semiconductor plants. As well as providing transportation capabilities, logistics companies are increasingly taking on coordination and

provider (LLP) for these projects.

and related warehouse operations. With land close to large plants in such high demand, industry suppliers are looking for flexible ways to manage their warehousing needs through the project lifecycle. That might involve using the same facility as a staging location during construction and for the storage of tooling and service parts during ramp up and operation, for example. Logistics service providers are well placed to assist in the construction and management of this warehouse space, and the provision of shared warehouse space can enable the efficient and cost-effective allocation of space between different value chain participants.

THREE QUESTIONS FOR BORIS FINSELBERG, GLOBAL LEAD DHL SEMICONDUCTOR LOGISTICS

What are the key challenges in fab construction from the logistics perspective?

In any big construction project, being on time and on budget is always the big challenge. Fab construction is especially complex, with many construction phases, numerous moving parts, and the need to

coordinate many different logistics processes within tight time windows. And right now, the industry faces the added complication of running multiple major projects simultaneously around the world. That's putting additional pressure on suppliers, and on the logistics resources and expertise needed to execute these projects.

Where can logistics improve the efficiency of project delivery and add value?

First, a specialist logistics provider will typically offer the most cost-efficient solution. Logistics is their core competence, and they will offer a range of different engagement models to suit the requirements of each project. Second, an experienced provider can assist with logistics planning and coordination, and they can offer project owners the transparency they need to keep things 2 3 4 5

on track during project execution. Finally, a big part of the challenge in global projects like these is the need to manage multiple vendors of logistics services. That's something that specialist logistics service providers do every day.

For semiconductor construction projects, what are the key requirements you should look for in a logistics service provider?

An experienced provider should be able to offer access to the right assets, including a global transport and warehouse network and sufficient infrastructure for direct site support. They should also be able to demonstrate that they have experienced people, from the frontline project team to the wider global organization and its management. Finally, there's the question of culture; a good provider must be willing to engage early and take a collaborative approach that focuses on finding the best solutions to complex logistics problems.

CHAPTER 4 **FUTUREPROOFING** THE SUPPLY CHAIN

"We are moving away from a world of availability (of materials) to a world where we need to manage the scarcity of materials" Jean-Francois Salles, Vice President Global Supply Chain, Renault-Nissan-Mitsubishi (RNM) Alliance

"At the end of this decade, our supply chain will look different compared to what we are doing today."

Peter Dressler, Vice President Logistics, Infineon

In time, newly constructed fabs will ease today's chip shortages and the transport market will recover. Only a few in the industry believe that the latest wave of disruptions will be the last, however. Having learned some difficult lessons during the pandemic, supply chain managers are now making wide-ranging changes to increase flexibility and resilience.

Accelerated

digitalization

Resilient product and inventory strategies **Build stronger** partnerships

Reduce environmental impact

To better understand how companies are adapting their supply chains, we conducted interviews with supply chain leaders from different sectors, including the automotive, consumer electronics and semiconductor industries. During these interviews, we identified multiple approaches that these companies are using to futureproof their supply chains.

While each industry is different and each company has its own supply chain resilience strategy, our interviews highlighted a few key themes, which we believe are applicable across industries: accelerated digitalization, a focus on stronger partnerships, the development of resilient product and inventory strategies, and targeted efforts to reduce the environmental impact of the supply chain.

These four themes are each significant in their own right; furthermore, we observed interlinkages between them. Digitalization is not only a key focus area for many companies but also an enabler for other areas: enabling a more resilient supply chain through improved visibility and insights, for example, and aiding reduction of the overall environmental footprint by revealing the sources of emissions and identifying network inefficiencies. Additionally, having strong partners is a key element of a resilient product or inventory strategy as companies that can rely on their supply chain partners don't need to maintain such high inventory levels. Last, every supply chain design decision and every logistics activity has an environmental impact and companies need to consider these choices in the context of their wider sustainability goals.

ACCELERATION OF DIGITALIZATION INITIATIVES

Knowledge is power in the supply chain. When participants know exactly what is happening, or about to happen, in their supply chains they can make faster, more effective operational and strategic decisions. Even before the pandemic, many organizations were working to improve the flow of information across their supply chains using digital tools. Those efforts have now gone into overdrive.

For most organizations, transparency begins at home. Supply chain managers told us that accelerated digitalization was a top priority during the pandemic, second only to the operational challenge of keeping supply chains flowing amid large-scale disruptions. Companies have increased their investment in digital tools to track orders, production processes, and inventories. A big focus for many interviewed companies was the integration of data from multiple systems across different geographies, legacy systems and external partners. One key lesson of the recent disruptions is that knowing the status of your direct (Tier 1) suppliers is no longer enough. Companies also need to understand the situation far upstream in the supply chain, allowing them to spot potential problems much earlier, especially for the key Tier 2, 3, and 4 suppliers. Many companies are trying to improve visibility of the inventory levels of their suppliers to better assess the overall robustness of their supply chains. And as supply chain decision-making becomes ever-more reliant on rich digital data, organizations are striving to improve the accuracy and speedy availability of that data. For one of the interviewed companies, a big focus has been achieving a consolidated overview of the supply chain ready at the touch of a button. Many of the supply chain managers we interviewed consider digitalization to have been a key enabler of agility and resilience during the pandemic and an area which has been accelerated in the past two years.

Some companies are now establishing dedicated control towers to monitor and manage their integrated, digitalized supply chains. With a clear view of the end-to-end supply chain, these control towers provide a range of levers at the user's fingertips to help companies overcome shortages and delays. They can facilitate expedited transport of critical parts, for example, and pull inventory from alternative warehouses or production locations, shipping from anywhere to anywhere to ensure orders are fulfilled. The data companies collect from their suppliers, customers, and logistics providers is becoming increasingly granular too. One of the interviewed companies is investing in telematics systems with GPS trackers so it can see the precise, real-time location of critical inbound components while they are in transit.

That sort of rich data enables the creation of much more detailed, dynamic models of the supply chain. Leading companies are now applying advanced analytical tools, using simulation systems such as 'supply chain digital twins', for example, to derive valuable operational and strategic insights. They use these systems in scenario planning to identify potential sources of disruption and evaluate different mitigation and response strategies. They are also analyzing data in real time to spot problems early and trigger appropriate responses. Additionally, these digital tools can help companies to better predict product demand, define suitable inventory levels, and optimize transportation networks to reduce emissions and costs.

Finally, digitalization and automation can also increase the efficiency of logistics operations, for example through implementation of warehouse robots. While very few expect or aim for dark warehouses without any workers in the foreseeable future, usage of robots and increased warehouse automation can support with labor shortages and support warehouse workers with repetitive tasks.

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

Jean-Francois Salles, Vice President Global Supply Chain, Renault-Nissan-Mitsubishi (RNM) Alliance

HOW LOGISTICS CAN CONTRIBUTE

Logistics players can assist the supply chain data revolution in several ways. First, they can provide timely, detailed data on the status of shipments, inventories, and transport assets. Additionally, they can provide

information for critical shipments such as GPS location, temperature, and shock measurements and more detailed visibility into warehouse operations. Leading providers already run their own operations on advanced digital platforms, allowing them to make customerspecific data available via appropriate interfaces. Those providers can also offer platforms that help their customers achieve greater visibility and derive new insights from logistics data. Additionally, logistics providers can combine visibility of multiple transport modes into one overview, making it easier for companies to switch between different transport modes.

Moreover, the logistics sector has been investing in advanced analytical capabilities, for example to optimize its own operations. Leading logistics players are now extending these offerings into the broader supply chain, helping customers find smart solutions for operational challenges, improve the design of their logistics networks, and optimize inventory levels for their warehouse operations.

Logistics providers can also provide direct operational support to their customers, for example by running supply chain control towers on their behalf. These control towers can provide the customer with a consolidated overview of all their transport operations, integrating data from different suppliers.

Finally, logistics providers can offer automation solutions, for example through implementation of warehouse robots.

"In 2019, supply chain visibility was a nice-to-have. In 2022, supply chain visibility has become a must-have."

Peter Dressler, Vice President Logistics, Infineon

BUILD STRONGER PARTNERSHIPS

When products, materials, and services are readily available, companies may pursue transactional relationships with their suppliers, driven primarily by cost considerations. In a world of scarcity, uncertainty, and disruption, however, many organizations are recognizing the benefits of closer, more collaborative relationships and strategic partnerships. At the same time, it is important to recognize the risks of being overly dependent on a single provider or supplier.

Companies are looking to diversify their supplier networks where possible, while keeping strong relationships with key suppliers.

In some sectors, for example consumer electronics or semiconductor manufacturing, strong relationships with key suppliers and partners have always played an important role. Production campaigns for short-lifecycle products, such as mobile handsets, require precise synchronization across the end-to-end supply chain. Participants may have just a few months to establish new supply chains and manufacturing lines, and they need

to reach a full production rate in weeks. That can only happen if semiconductor suppliers, consumer electronics manufacturers, and logistics service providers are collaborating effectively.

One consumer electronics manufacturer we interviewed highlighted the importance of strong relationships with its own suppliers, such as chip manufacturers to be able to secure critical delivery of chips in times of supply chain scarcity. This sometimes goes beyond firm order commitments to include prepayment to secure necessary production capacity when there is high demand. Another company mentioned the importance of understanding how customers are going to use their products (standard 'off-the-shelf' or customized products) to set up their own production and operations efficiently.

In the automotive industry, for example, original equipment manufacturers (OEMs) and their suppliers used to plan their production independently, based on each OEM's forecast, which was then adjusted a few times a year. During the pandemic, this approach proved problematic. At the beginning of the crisis, OEMs cut their sales forecasts and their suppliers reduced their semiconductor order volumes in response. When sales bounced back from pandemic-era lows, the semiconductor supply chain was unable to meet industry demand. Across the sector, manufacturers were forced to temporarily remove features from their vehicles and to even close production lines. To avoid a recurrence of these problems, automotive OEMs are now shifting to a more collaborative model, developing a joint forecast with suppliers and placing firm chip orders for the upcoming year.

Collaboration within organizations is becoming more critical too. During the pandemic, many organizations relied upon close collaboration between different functions, for example cross-functional sales and operations planning (S&OP) teams to coordinate their response to the crisis. That approach is set to become the norm. When supplies are limited, for example, manufacturing and supply chain teams need to work closely with their sales and marketing colleagues to manage customer expectations, maintain service levels, and protect margins.

"Collaboration between industry players will drive a competitive edge." Rory P. O'Connor, Vice President Global Logistics, Intel

"Strong relationships with our key suppliers play an important role in our resilience strategy and increase the flexibility of our operations." Russell Shimp, Executive Director, Lenovo

HOW LOGISTICS CAN CONTRIBUTE

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Logistics service providers have become important strategic partners in today's semiconductor value chains. As elsewhere, companies are moving away from the traditional transactional approach to the procurement of logistics services and towards long-term relationships with their chosen providers.

By engaging logistics providers early and sharing forecast data regularly, companies can ensure that the transport capacity they need is available when they need it. That is especially important for lanes where capacity is currently constrained, such as major air and sea routes during seasonal peaks, or the provision of specialist equipment for the handling of capital equipment.

Some companies in the sector are pursuing higher levels of integration with their logistics providers, giving those providers responsibility for activities that were once handled in house. Under this logistics support service model, the provider may run supply chain control towers on behalf of its customer, for example. Or the provider may operate warehouses for inbound materials and finished products.

The scope of logistics partnerships is becoming broader too. While many semiconductor players manage their logistics activities around specific sites or value chains, some are now creating globally integrated networks with centralized management and a small number of strategic provider relationships. This approach can boost resilience, for example when companies supply the same products from multiple production locations, run several simultaneous construction projects, or seek to replicate best practice supply chain management across facilities in different regions.

DEVELOP RESILIENT PRODUCT AND INVENTORY STRATEGIES

For decades, companies have pursued a 'less-is-more' approach to inventory. Stock on the shelves ties up working capital and incurs storage costs. In fast-moving markets, large inventories risk becoming obsolete before they sell. A policy of low stocks and high inventory addresses these problems, and just-in-time models have become accepted best practice in some sectors. Automotive assembly plants, for example, store only the components they need for a few days or even just a few hours of production.

However, lean inventory strategies are vulnerable to volatile demand and disruptions in supply. And the COVID-19 crisis and subsequent bumpy recovery have exposed many industries to both. Now organizations are reassessing their inventory policies, aiming to improve their resilience to unexpected events. Larger 'just-in-case' safety stocks are becoming common across industries.

While inventory targets for both components and finished goods have risen across supply chains, companies we spoke to are using different inventory management approaches. Some have taken a blanket approach, increasing the target inventory levels to three, six, or even nine months. Other companies are improving their applied analytics models to help determine the right inventory levels for different components, based on historical and forecast demand, ease of resupply, the costs of the component and its storage, and the riskiness of the upstream supply chain. That means that inventory targets for the same component can vary between different warehouses in different locations due to differences in ease of resupply. One company we interviewed has shifted its whole approach to inventory optimization. Rather than setting targets to keep inventory costs to a minimum, it now links its inventory goals to its orders and demand forecasts, with the aim of maximizing manufacturing output.

Product and portfolio simplification is another way to improve resilience without increasing overall inventory levels by reducing the diversity of components purchased. During the coronavirus crisis, for example, some automotive companies rationalized their offerings so that limited resources could be focused on a smaller range of products. While the features removed from vehicles were primarily sound-system and infotainment components, some companies temporarily stopped offering certain advanced safety features too.

"As result of past supply chain disruptions, we decided to increase our inventory levels from 90 to 120 days"

Senior supply chain director, consumer electronics manufacturer

Some companies are pursuing a similar strategy by increasing the use of common – often more advanced – chips that are shared by multiple end products rather than using a different chip for each device across the product portfolio. Automotive subsystems for different classes of vehicle may share identical hardware with different software features, for example. Additionally, some of the interviewed companies are looking at reducing the overall number of chips used in a single device, again by using more advanced chips. At a higher cost per chip, this allows them to simplify the supply chain.

It improves long-term availability as well. A typical car manufacturer plans its models numerous years into the future. For safety reasons, all components and chips need to be properly tested and substituting a different chip is not easy. Reducing the number of different chips, and favoring more advanced models, helps companies to ensure that their preferred products will remain in production for the life of the vehicle program.

As companies seek to improve resilience while keeping inventory costs down, there is growing interest in the use of collaborative approaches. Customers and suppliers may agree to share information on their inventory levels, allowing the optimization of stock levels in their respective supply networks. One consumer electronics manufacturer we interviewed decided to keep a stock of finished products to guarantee delivery to its key customers, for example. Vendor-managed Inventory (VMI) strategies allow customers to benefit from guaranteed service levels at their production sites without the cost and complexity of owning and managing inventory before it is required.

Horizontal collaboration between industry players also offers potential benefits. Flexible, shared warehouse space close to a large customer provides a cost-effective way for multiple suppliers to ensure availability of components and spare parts, for example. Some semiconductor industry groups are also exploring the potential of 'strategic reserves' of critical inputs, such as wafers and gasses, which could be accessed by multiple fabrication plants in the event of supply disruption.

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HOW LOGISTICS CAN CONTRIBUTE

Logistics service providers can support the semiconductor sector's changing approach to inventories and product design. They can offer organizations the extra warehouse capacity they need for additional safety stocks, for example.

Additionally, logistics providers can offer more flexible fulfillment setups such as using one forward-stocking location to support multiple manufacturing points, and offering networks of smaller warehousing locations strategically placed across different countries to give customers more flexibility.

Logistics organizations can use their analytical expertise to help customers fine-tune inventory targets, and help them decide how to best allocate inventory across different warehouses. Logistics partners can also run VMI programs, high-speed service logistics operations, and similar activities on behalf of their customers.

NAVIGATE TO ZERO ENVIRONMENTAL IMPACT

Most major companies are now committed to the target of net-zero greenhouse gas emissions by the middle of the century, and some want their supply chains to become carbon neutral by as early as 2030. Additionally, a key focus of many interview participants was not only reducing the carbon emissions but also the environmental impact of manufacturing processes, including reducing the use of water, chemicals, and virgin materials.

Some companies are looking at refurbishing used products, reusing parts of products which cannot be refurbished, for example for product repair, recycling materials recovered from end-of-life products, and safely disposing of any remaining materials. These steps have both environmental and economic advantages, as companies can reuse existing parts and materials instead of producing them new.

While transport- and warehousing-related emissions often represent only a small part of the overall emissions of the interviewed companies and their suppliers, many companies mentioned that their sustainability targets became additional KPIs for their supply chain operations.

To reduce emissions, companies first need to understand the source of the emissions. That is no trivial task, especially for such complex, global supply chains often spanning different continents and multiple transport modes.

The first step towards reduction of the overall demand for transportation is optimizing the transport network. One of the companies we interviewed aims to reduce road transport-related emissions in its supply chain by as much as 30% by better optimizing its transportation network and sourcing. Many companies are aiming to source materials and components (whenever possible) more locally.

Where products, components, and materials do need to travel, they will need low or zero carbon way of doing so. Several companies we interviewed are already exploring changes in their logistics practices designed to minimize emissions, for example by using electric vehicles for last-mile deliveries and alternative fuels, such as sustainable aviation and maritime fuels (SAF and SMF), LNG and hydrogen.

"We need to make our supply chains more efficient and less emissive at the same time."

Jean-Francois Salles, Vice President Global Supply Chain, Renault-Nissan-Mitsubishi (RNM) Alliance

HOW LOGISTICS CAN CONTRIBUTE

Logistics players can support their customers' sustainability initiatives in several important ways. First, they can fill the information gap by providing data on emissions related to transportation

and warehousing. Second, they can help those customers minimize the impact of both new and existing supply chains by optimizing routes, loads, and transport modes. Third, they can help to identify quick-win areas where emissions can be reduced without significant additional cost.

Logistics and transport companies are also investing in sustainable technologies from electric trucks and zeroemissions warehouses to low-emission fuels for ships and aircraft. Logistics companies can collaborate with their customers to develop new closed-loop logistics chains for reusable packaging and end-of-life product recovery. Additionally, logistics companies can support customers' circular economy initiatives, for example by providing product repair and refurbishment services.

Switching from carbon-intensive air freight to rail or ocean freight is one option, if the supply chain is set up to handle the longer transport times required. That approach works well for less time-sensitive, build-to-stock products and lower-value commodity items. One company we interviewed uses ocean freight for recovering transport packaging and customer-returned products to its own facilities, even at the cost of slightly longer lead times. Another area of focus is the optimization of packaging. Much of the packaging used across the semiconductor supply chain is single use, incurring significant financial and environmental costs. In the case of large capital equipment used in semiconductor foundries, for example, the cost of the single-use crates required to protect machines in transit can equal the cost of shipping them. Switching to reusable containers for this application could cut logistics costs dramatically, and the right designs would also improve protection and simplify handling.

"At Google, our goal is to achieve net zero emissions across all of our operations and value chain by 2030."

Carolin Seward, Vice President of Custom Silicon Sourcing and Operations, Google

CHAPTER 5 KEY TAKEAWAYS

INSIGHTS FOR CHIP MANUFACTURERS

The last three years have highlighted the importance of the semiconductor industry. First the coronavirus crisis drove a spike in demand for many product categories. Then the rapid post-crisis economic recovery created additional demand pressure in a value chain that was already operating at full capacity. The resulting component shortages, price increases, and long lead times have adversely affected semiconductor customers in multiple sectors. Now the industry – and its customers – are striving to increase manufacturing capacity and improve the resilience of supply chains, applying lessons learned during the pandemic to build systems that can mitigate shocks and support sustained long-term growth.

Chip manufacturers are making significant investments in new production facilities, aiming to increase overall capacity and reduce the geographic concentration of critical production capabilities. All major chip manufacturers are currently in the process of constructing multiple fabs in different geographies across the world. Construction of a single fab has always been a challenging, expensive, and time-sensitive process with multiple moving parts, and a single delay can have a cascading effect on the whole project. The simultaneous construction of so many fabs in so many places significantly compounds this complexity.

Logistics companies can add value by playing a more active role across the multiple stages of the process, including the construction phase, the end-to-end manufacturing process, and final distribution of semiconductors. A logistics provider can support and add value at every different stage of the process.

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HOW LOGISTICS CAN CONTRIBUTE TO FAB CONSTRUCTION

- Define the scope of work during the construction phase and initiate the development of an operational business model for logistics processes with the project owner and the assigned construction company
- Offer network and bespoke solutions for transportation of capital equipment, out-of-gauge products, wafers, and finished goods
- Support inventory concepts and warehousing / laydown solutions for efficient supply chains and resilience
- Foster transparency across the entire ecosystem through digitalization of the logistics process and tier-n supplier engagement
- Offer commercial models which support the different parties in the ecosystem, for example aligned incoterms, payment terms, and rate management
- Facilitate collaboration between different parties and contribute to the achievement of customers' sustainability targets

INSIGHTS ABOUT INCREASING SUPPLY CHAIN RESILIENCE

Companies that use semiconductors in their products, meanwhile, are rethinking their supply chains to make them more resilient. Our conversations with leading players from across the end-to-end semiconductor value chain have

helped us identify several critical areas of focus. While each industry and the approach of each company is different, we believe that these themes are universally applicable.

INVITATION TO ACTION

We look forward to collaborating with our customers and partners from across the semiconductor value chain as they strive to build a new generation of robust, resilient, flexible, and truly sustainable supply chains. If your organization is embarking on that journey, please reach out to us. You don't need to strive alone.

FOOTNOTES

¹ Accenture, 2021: Harnessing the power of the semiconductor value chain

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- ³ Semiconductor Industry Association (SIA), Boston Consulting Group (BCG), April 2021:
- Strengthening the Global Semiconductor Supply Chain in an Uncertain Era ⁴ Deloitte 2022 semiconductor industry outlook
- ⁵ SEMI press release, Sept 27, 2022: Global fab equipment spending forecast to reach all-time high of nearly \$100 billion in 2022 ⁶ The Nielsen Total Audience Report, April, 2020
- ⁷ Gartner press release, June 30, 2022: Gartner Forecasts Worldwide PC Shipments to Decline 9.5% in 2022
- ⁸ Semiconductor Industry Association (SIA) press release, Feb 14, 2022: Global Semiconductor Sales, Units Shipped Reach All-Time Highs in 2021 as Industry Ramps Up Production Amid Shortage
- ⁹ Reuters article, December 7, 2017, TSMC sasy lastest chip plant will cost around \$20 bln
- ¹⁰ Gartner press release, Jan 11, 2021: Gartner Says Worldwide PC Shipments Grew 10.7% in Fourth Quarter of 2020 and 4.8% for the Year
- ¹¹ Semiconductor Industry Association (SIA): 2021 State of the U.S. Semiconductor Industry
- ¹² ASML Annual Report 2021
- ¹³ ASML, Feb 23, 2022: Busting ASML myths

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