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Whitepaper

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Semiconductor Manufacturing Industry Analysis

REPORT PRODUCED BY THE INTEROS INC.
BUSINESS ANALYST TEAM

Semiconductor Manufacturing Industry Analysis

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About Interos

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Based in Washington, DC, Interos serves global clients with business-critical, interdependent relationships. The fast-growing private company is led by CEO Jennifer Bisceglie and supported by investors Venrock and Kleiner Perkins.

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1.0
Executive Summary

Purpose Statement

The growing trade friction between Western countries and China encompasses numerous products and industries, but few more critical than semiconductors. Essential to all electronics manufacturing, the semiconductor industry has been in upheaval since the start of the pandemic and, given the industry's concentration in Taiwan and downstream dependence on China, is likely to remain of subject of concern for the foreseeable future.

This report, from the Interos Business Analyst Team, provides context on the current shortage of semiconductor devices; outlines precipitating factors; identifies mitigation efforts; explains mitigation obstacles; and highlights vectors for disruptions.

The shortage is expected to continue through 2023, after which additional capacity is expected to shorten lead times. Meanwhile, organizations can identify supply blocks, diversify suppliers, communicate with foundries, balance inventory practices, adjust technological designs, and conduct scenario exercises to better adapt to this dynamic environment.

Key Points

- Lead times have experienced elevated levels since the pandemic's start and are expected to remain elevated through 2023. A range of disruption events have continued to exacerbate lead times. These lead times differ based on semiconductor device, reaching up to 55 weeks.
- Interos data reveals 38% of disruption events had a limited impact on operations, and 17% had no impact at all, indicating that only an estimated 45% of disruption events have ripple effects.
- Power outages often have negligible effects on operations, though they can be a factor of temporary shutdowns and disruption events. Earthquakes have limited effects unless they trigger power outages.
- Cyber-attacks are rare for the industry and have yet to cause a major impact disruption event. However, with demonstrated Western dependence, foundries can serve as high-profile targets.
- $52 billion USD will be available through FY26 for the U.S. semiconductor manufacturing industry pending Senate and House bills' reconciliation. However, a lack of high-skilled engineers required to operate specialized equipment in fabs can undermine U.S. efforts to bolster its semiconductor industry.
- The aerospace and defense (A&D) industry is notably absent from leading foundries' lists of core businesses, largest markets, expected areas of growth, and in some cases delivery priorities.
- The industry is experiencing consolidation as M&A activity reached its highest recorded levels in 2020.

2.0
Background and Current State of Affairs

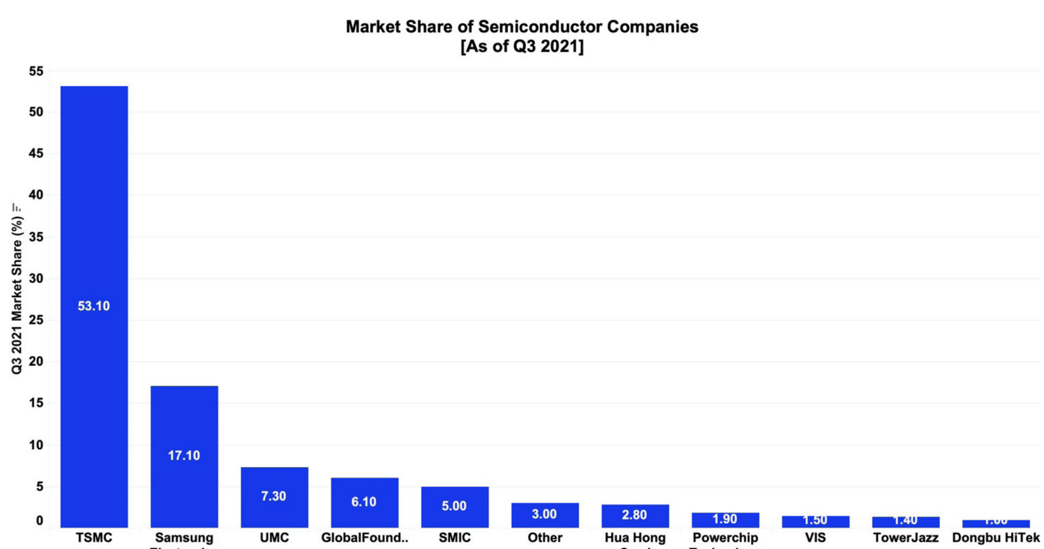
The semiconductor manufacturing industry is complex, though it can generally be categorized into five segments:

1. **Instruction Set Architecture**
2. **Design**
3. **Fabrication**
4. **Equipment & Software**
5. **Packaging**

Fabless companies such as Qualcomm, Broadcom, NVIDIA, Xilinx, MediaTek, and AMD are engaged in the design step, though they do not manufacture the chips themselves, opting to subcontract manufacturing to other companies.[1] The fabrication step is where semiconductors, often referred to as ‘integrated circuits’ (ICs), ‘microchips’ or simply ‘chips,’ are manufactured in fabrication facilities, known as ‘fabs’ during the front-end process. Companies like Amkor Technology, Inc. and ASE are involved in the fifth step, also known as the back-end, by testing and preparing cut dies for embedded integration into a device or system. An in-depth view of each main phase, along with main actors operating in each of those phases, can be found in Appendix A of this report, and an overview of the complexity of the semiconductor supply chain can be found in Appendix B.

2.1 Market Concentration

As of Q3 2021, more than 60% of the manufacturing market share was captured by companies in Taiwan, making the country the primary hub for semiconductor manufacturing globally. Additional concentration is found in the fact that just five companies comprise 88.60% of the total global market share of semiconductor manufacturing.



Source: Statista

The semiconductor industry is heavily concentrated in Taiwan, and in particular, Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC). TSMC alone holds a majority of market share (53%), followed by South Korea-based Samsung Electronics with 17.10%. Taiwan-based United Microelectronics Corp. comes in third with 7.30%, followed close behind by GlobalFoundries, Inc. (GF) with 6.10%. China-based Semiconductor Manufacturing International Corp. (SMIC) ranks fifth in the world with 5.00% of the global market share. These five companies comprise 88.60% of the global market. A more in-depth analysis of each of the top four above listed companies that also details respective top serviced customers can be found in Appendix C of this report.

Market concentration has occurred as the result of a trend over time of companies shifting towards a fabless model where chip design becomes the primary function of a company and the manufacturing of those designed chips is subcontracted out as a cost-effective measure.

Given the clear concentration in Taiwan, this state of affairs has alarmed analysts in multiple disciplines as China continues to declare sovereignty over Taiwan while U.S.-Sino tensions mount with ongoing trade wars, territorial and intellectual property disputes, and Chinese military developments,[2] and Russia's ongoing war in Ukraine. Although geopolitical speculation is outside the scope of this brief, it must be stated that any Chinese military action against Taiwan would have a significantly negative backlash effect on China's ability to acquire ICs since China's manufacturing industry currently heavily relies on imported ICs.[3]

2.2 COVID-19's Effect on Demand and Automotive Manufacturers

Truly global by nature, the semiconductor manufacturing industry experienced significant disruptions in lead times, labor capacity, and output as a result of the COVID-19 pandemic and the demand shock it caused to the market. COVID-19 also fundamentally shifted the pre-pandemic market dynamic as lockdowns led to a surge in the purchase of goods with imbedded ICs, cancelled automotive chip orders forced manufacturers to pivot their production lines, and fabs around the world shutdown, exacerbating an already constrained global supply.

Although actors within this industry have been acutely aware of the risks and supply shortcomings associated with manufacturing and the complex supply chain for years, the pandemic precipitated several fundamental shifts.

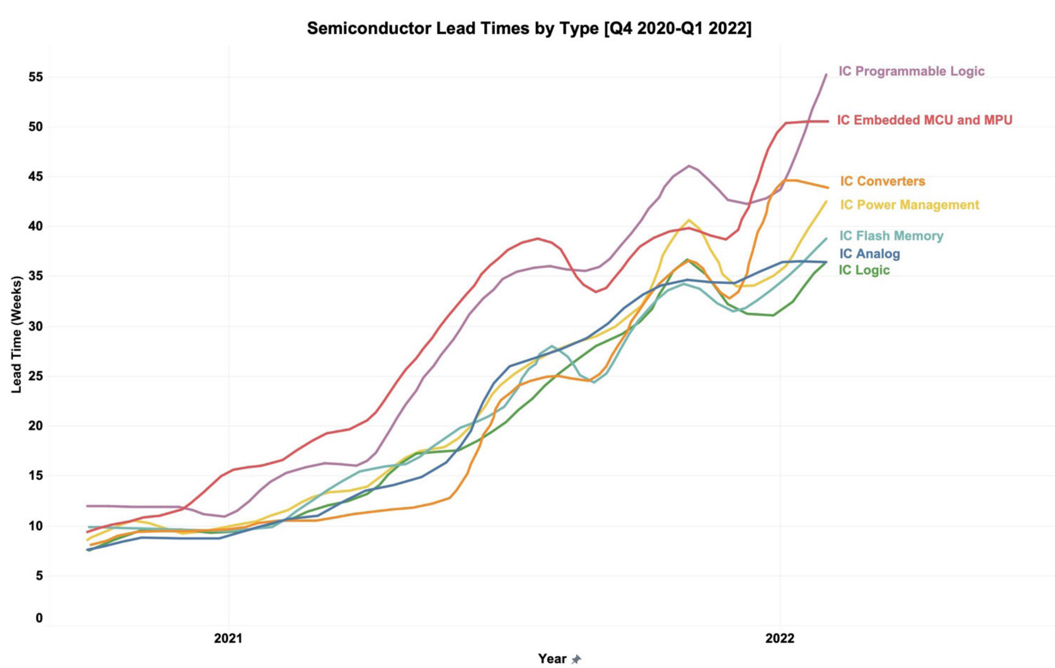
Market predictions within the automotive industry at the outset of the pandemic forecasted a significantly reduced demand for automobiles, driving automotive manufacturers to reduce or cancel orders for semiconductor chips that are integrated into their vehicles.[4] These cancellations shocked demand within the industry, forcing chip manufacturers to pivot to producing semiconductors suited for different purposes. When market demand did not behave as predicted, the automotive industry found itself trying to acquire chips with a renewed sense of urgency. However, given the semiconductor manufacturing industry's shift in response to the automotive industry's initial actions, automotive manufacturers experienced significant cuts in revenue[5] from reduced production and temporary facility closures given chip lead times.

Government restrictions and lockdowns around the world exacerbated supply shortages as companies abided by them. Temporary gaps in production highlight concentration risks like the one that exists in Malaysia for the semiconductor packaging, assembly, and testing industry. Malaysia accounts for approximately 13% of global capacity for back-end assembly, testing, and packaging.[6] Government-imposed shutdowns in the country, as well as voluntarily imposed shutdowns, have at times cut production, creating a roadblock for the supply chain and increasing lead times.[7]

Imposed restrictions and lockdowns intended to slow the spread of COVID-19 also forced personnel across numerous industries to shift from working in person to teleworking solutions. The necessity of teleworking drove demand for in-home office equipment, entertainment devices, and other household equipment that helped individuals cope with a reduced ability to socialize or travel.[8] Semiconductors are essential to enabling the functionality of those devices, and as the Internet of Things (IoT) is constantly expanding so too is the general manufacturing industry's reliance upon the integration of semiconductors into new products and emerging technologies.[9]

2.3 Lead Times

Lead times, defined as the elapsed time between the initiation of an order and its delivery, have been rising amidst the COVID-19 pandemic and industry disruptions. Though incentives for bolstered semiconductor manufacturing are planned have been employed globally, elevated lead times are expected to continue through 2023.



The trend of sum of Lead Time (Weeks) for Year. Color shows details about Type. The marks are labeled by Type. The view is filtered on Exclusions (Type,Year), which keeps 391 members.

The graph on the previous page illuminates observed trends in chip lead times for several individual semiconductor devices. Unsurprisingly, IC Programmable Logic chips have the highest lead time at above 55 weeks since they are general purpose devices that can be programmed after shipping, allowing for user-customization and design flexibility.

Next are IC Embedded Microcontroller Units (MCUs) and Microprocessor United (MPUs). MCU ICs contain a Central Processing Unit (CPU), memory, and input/output peripherals on a single IC chip and it functions as a standalone small computer. MPUs by contrast use external memory to provide program and data storage, and MPUs rely on external power management devices. IC Embedded MCU and MPUs have the second longest lead time at approximately 51 weeks.

Following that are IC Converters which include Analog to Digital Converter (ADCs) and Digital to Analog Converters (DACs) which have lead times of approximately 44 weeks. ADCs convert an analog signal, such as electric voltage, into a binary one allowing for input into computers, while DACs convert a binary signal into an analog value prior to input to an electronic or electrical device.

Next are Power Management ICs (PMICs), devices which have lead times of approximately 43 weeks. PMICs are used to manage power on an electronic device or in modules on devices that may have a range of voltages. PMICs typically contain DC-to-DC converters and linear voltage regulators.

Next are IC Memory and Flash Memory devices which have lead times of approximately 38 weeks. Memory devices provide memory storage capacity, primarily in the form of Dynamic Random Access Memory (DRAM) and Electronically Erasable Programmable Read Only Memory (EEPROM) of which NAND Flash is a subset. DRAM is the most common type of computer memory, and NAND Flash can be found in devices like USB memory drives.

Analog and Logic ICs have approximately the same lead time of 36 weeks. Analog ICs use continuous varying signals and are often used to construct electronic circuits such as amplifiers and voltage comparators, and they are best suited for audio and video transmission since memory is stored in wave form. Digital ICs by contrast use discontinuous or binary signals and are best suited for computing and digital electronics since memory is stored in the form of a binary bit.

Additional analysis on future lead times based on modelled assumptions can be found in Appendix D of this report.

3.0
Industry Disruptions

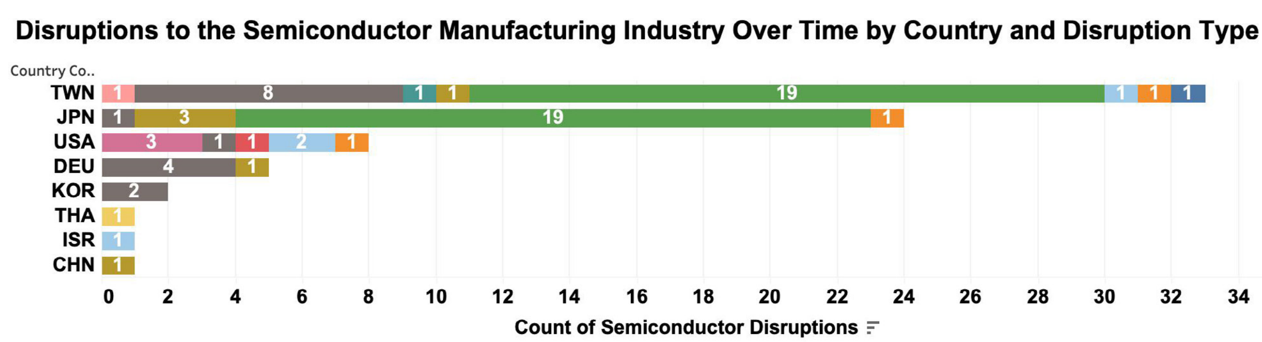
Although COVID-19 introduced significant disruptions to the semiconductor supply chain, this industry is already inundated with several disrupting variables such as natural disasters, accidents, and facility fires, with power outages posing the most significant threat to operations.

There are several notable events which have adversely affected the semiconductor industry since just the beginning of 2020. The ongoing trade war between the U.S. and China raises the cost of certain goods and limits access to certain products by blacklisted Chinese entities. In December 2020, the U.S. added Semiconductor Manufacturing International Corp. (SMIC) to a trade blacklist due to a relationship linking SMIC to China's military, limiting the already constrained pool of chipmakers from which companies can receive their chips.[10]

In February 2021, severe winter weather in the U.S. shutdown fabs in Texas owned by NXP Semiconductors N.V.,[11] Samsung Semiconductors, Inc.,[12] and Infineon Technologies AG,[13] in a major disruption to the supply chain as ensuing power outages halted operations. New fabs, like the one constructed by Robert Bosch GmbH in Dresden, are unfortunately not immune to the challenges that face the industry, even when they are constructed with some of the most up-to-date technologies and capabilities to counter expected disruptions. In September 2021, the German city of Dresden experienced a large-scale power outage which halted multiple fab operations after a foil balloon caused a short-circuit at an electricity substation.[14] Major impact events like this can significantly damage the fragile nature of semiconductor supply chains, and though measures can be taken to mitigate them there it is impossible to remove them from the equation. In light of that fact, this report takes a closer look at disruptions to identify trends and inform on the potential impact of future expected disruptions.

3.1 Country Disruption Trends

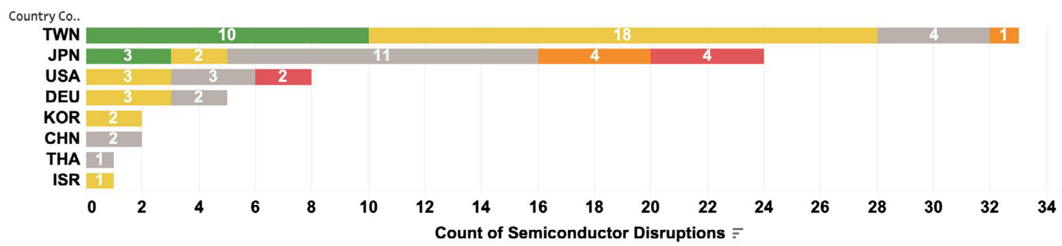
According to Interos data, Taiwan and Japan experience the most disruption events to their semiconductor manufacturing industry. Earthquakes account for a significant portion of disruptions in both countries. Moreover, captured Moderate and Major Impact events were concentrated in Japan.



Count of Semiconductor Disruptions for each Country Code (3-Letters) https://www.iban.com/country-codes. Color shows details about Disruption Type. The marks are labeled by count of Semiconductor Disruptions. The view is filtered on Disruption Type, which excludes COVID-19.

With 33 captured events, Taiwan has experienced the highest number of disruptions to its semiconductor manufacturing industry as well as the most diverse collection of event types. Japan has experienced the second most disruptions with 24 captured events. When all disruption events are combined from Taiwan with Japan earthquakes comprised 67% of all disruption events.

Disruptions to the Semiconductor Manufacturing Industry Over Time by Country and Severity



Count of Semiconductor Disruptions for each Country Code (3-Letters) https://www.iban.com/country-codes. Color shows details about Disruption Effect (No Impact, Limited Impact, Moderate Impact, Major Impact, Temporary Shutdown). The marks are labeled by count of Semiconductor Disruptions.

Although Taiwan appears to have sustained more disruptions than other countries, 55% of captured events had a limited impact, and 30% had no impact at all reflecting a degree of resilience to disruptions.

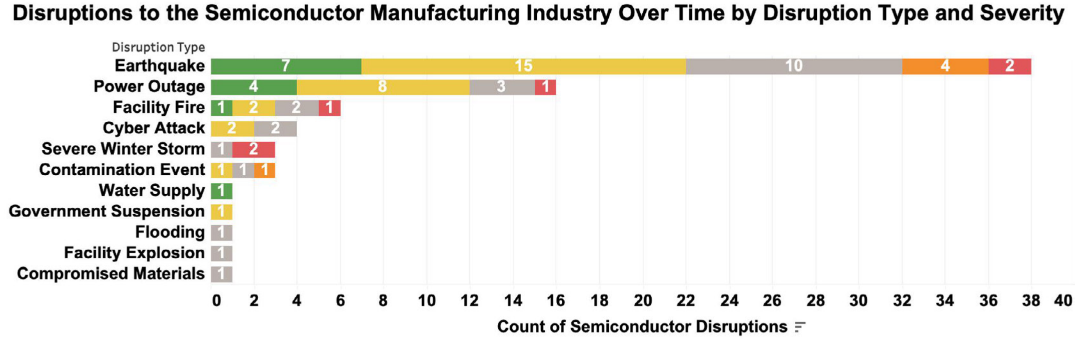
Meanwhile, Japan sustained the highest number of major impact events, moderate impact events, and temporary shutdowns, reflecting a degree of susceptibility to disruptions.

In terms of major impact disruption events, Japan and the U.S. appear to have sustained the most significant events. These events include the fire at Renesas Electronics Corporation's fab,[15] the fire at Asahi Kasei Microdevices (AKM) Corporation's fab, a 13-minute power outage in Yokkaichi province which caused a month-long shutdown, and power outages caused by severe winter storms in Texas. While a power outage in Dresden in 2021 was significant, fabs resumed operations shortly after the event and did not endure the same weeks' long delay to restart manufacturing as fabs had to do in Texas.

3.2 Disruption-Specific Trends

Interos data reveals that 38% of captured disrupting events had a limited impact on operations, and 17% had no impact at all, indicating that only an estimated 45% of disruption events have significant ripple effects on the supply of semiconductors to the global market.

Disruptions to the Semiconductor Manufacturing Industry Over Time by Disruption Type and Severity



Earthquakes

Although earthquakes account for 52% of limited impact events and 54% of events which have no impact at all, these natural disasters have the potential to cause extended shutdowns like the 8-day long shutdown experience by Renesas Electronics Corporation in February 2021[16] if they cause damage to fab structures, machines, utility infrastructure, or instigate a power outage.

Limited impact disruptions are often the result of earthquakes in the Pacific Rim. Owing to earthquake-conscience architectural design, fabs often shutdown operations for a just a short period of time, sometimes only a few hours, to assess equipment, wafers in-process, and any structural damages before resuming operations.[17] The further a fab is from earthquake epicenters the lower that earthquake registers on the Richter scale, thus causing less damage.

Power Outages

Although power outages can often have negligible effects on operations, Interos data reveals they are the primary factor driving temporary shutdowns and major impact events, accounting for disruptions like those in Texas, Dresden, and Yokkaichi Province.

Second to earthquakes, power outages account for 28% of events which have a limited impact, and 31% of events which have no impact at all to operations; this is a result of fabs' use of reliable generators which are designed to start immediately in the event of an emergency, as they did for GlobalFoundries (GF) during the power outages in Dresden in September 2021.[18]

Facility Fires

Fires, like the one Renesas Electronics Corp. suffered in March 2021, are more likely to have an adverse effect on fabs, though their frequency is less than earthquakes or power outages, and the extent of damage they cause is highly dependent upon emergency systems, rapid responses, and the fire's location.

In October 2020, a fire erupted for more than two days in a Japanese facility owned by AKM in Nobeoka City, causing significant damage and panic amongst buyers. Buyers who relied on AKM in their supply chain tried to stockpile supplies to avoid additional disruptions after AKM suggested buyers should switch to alternative products.[19] In contrast, Kioxia Holdings Corporation experienced a fire at its facility in the Japanese province of Yokkaichi in January 2020, but it expected no impact in its wake.[20]

3.3 Other Disrupting Variables

Cyber-Attacks

Cyber-attacks, like the malware virus that affected TSMC machines in 2018[21] or the ransomware attack X-Fab Silicon Foundries experienced in 2020,[22] are scarce in number for the industry, accounting for just 5% of all captured events. Consequently, cyber-attacks have not caused a major impact disruption event, but data indicates a significant upward trend in their frequency since the outset of the pandemic.[23]

The global semiconductor market faces a wide array of cyber-related challenges emanating from an increase in global cybercrime and state-sponsored hacking, particularly from state-sponsored groups in China seeking to steal intellectual property to bolster domestic chip manufacturing capabilities. Cyber-related challenges facing the semiconductor industry are expected to continually grow in cost and scale in the ensuing years, with some projections predicting cyber-crime to grow by 15% year-by-year through 2025.[24] Such attacks on the semiconductor industry could have massive repercussions across the supply chain, potentially crippling various industries and sensitive capabilities, including U.S. defense posturing in which semiconductors have played an increasingly greater importance in U.S. defense technologies.[25]

As the West imposes sanctions on Russia as its invasion of Ukraine continues, Russia is likely to respond against the West with targeted cyber-attacks. This industry could pose a potential target for Russian cyber-attacks, especially since export controls against shipments of semiconductors to Russia would significantly mitigate any negative effects directly felt by Russia as a result.

Contamination Events, Compromised Materials and Water Supply

In 2017, Micron Technology temporary halted operations for two weeks due to a contamination event from leaking gas.[26] In 2019, TSMC had to briefly halt production when it found subpar photoresist, a material used in the photolithography process, on its production line.[27] Moreover, droughts in Taiwan have also posed a threat to semiconductor production as fabs require vast quantities of water, though manufacturers have been able to secure alternative methods in times of increased scarcity.[28]

CONTINUED ...

4.0
U.S. Industry Overview

Alongside policies aimed at mitigating the spread of COVID-19, countries around the world have been moving to bolster domestic IC production to meet growing demand so that future global disruptions can be offset by expanded capacity. The pandemic has aided special interest groups such as the Semiconductor Industry Association to increase policymakers' awareness of the challenges facing the industry, such as lead times, natural disasters, shipping, and logistics. Legislation currently being reconciled in Congress can bolster U.S. manufacturing, provide R&D funding, and prepare a future high-skilled workforce to operate future fabs. This section aims to briefly highlight recent government activity in the U.S. to incentivize and develop the semiconductor manufacturing industry. A brief overview of what other countries around the world are doing in this area can be found in Appendix E.

United States

Although there has been clear movement to bolster the American semiconductor manufacturing industry with R&D funding and tax incentives, several of these measures have yet to materialize. If and when a reconciled Senate USICA and House America COMPETES Act is agreed upon, incentive funding up to $52 billion USD will be available through FY26 for the American semiconductor manufacturing industry. However, the lack of high-skilled engineers that are required to operate highly specialized equipment in semiconductor fabs can significantly undermine U.S. efforts to expand this industry.

4.1 Manufacturing Incentives

The America COMPETES Act is the House version of the Senate's United States Innovation and Competition Act (USICA). America COMPETES was passed in the House on 4 February 2022.

This bill allocates money for three funds in line with USICA:[29]

- **CHIPS for America Fund** - $50.2 billion USD appropriated from FY22-FY26 for the Department of Commerce to use as a semiconductor incentive program for investment in U.S. located fabs. The fund would allocate $24 billion USD in FY22, $7 billion USD in FY23, $6.3 billion USD in FY24, $6.1 billion USD in FY25, and $6.8 billion USD in FY26.
- **CHIPS for America Defense Fund** - $2 billion USD appropriated for the Department of Defense to carry out research, development, testing, evaluation, and workforce development and other requirements unique to the Intelligence Community. Increments of $400 million USD will be made available each year from FY22-FY26.
- **CHIPS for America International Technology Security and Innovation Fund** - $500 million USD for the State Department to provide for international information and communications technology security and semiconductor supply chains. Increments of $100 million USD will be made available each year from FY22-FY26.

Notable differences between the House-passed America COMPETES and the Senate-passed USICA:[30]

- America COMPETES Act expands eligible covered entities to include manufacturers of materials used to make semiconductors or semiconductor equipment whereas USICA does not.
- America COMPETES Act allocates up to $6 billion USD of the total $50.2 billion USD for the Department of Commerce to be used in direct loans or loan guarantees whereas this authorization is not granted in USICA.

These bills also call for the establishment of a National Semiconductor Technology Center (NSTC) to provide a public-private consortium for advanced research, prototyping, and innovation. Currently, reconciliation efforts are underway to move the legislation out of Congress and over to the White House. The Office of Management and Budget recently published its FY22 report which proposes $50 billion USD for semiconductor manufacturing and research incentives, demonstrating White House approval of current efforts. As recently as 23 March 2022, the CEO of Intel Corp., Pat Gelsinger, provided written testimony to the U.S. Senate Committee on Commerce, Science, and Transportation for a hearing on developing next generation technology for innovation in which he urged Congress to act swiftly in its reconciliation. [31]

4.2 Shortage of Skilled Workers in the U.S.

According to a study published in 2017, 82% of semiconductor industry executives reported a shortage of qualified job candidates.[32] This is because most of the skills required in the manufacturing process take years of specialized training for individuals to develop.[33] Due to this talent gap, the U.S. will likely need to rely on foreign infusions of talent to deal with the immediate skills deficit,[34] and it is estimated that 500,000 openings for engineers in the semiconductor field will open in the next decade. To make up for this shortage, the U.S. will likely rely upon foreign talent to fill in gaps as the shortage is expected to grow in the wake of new fab constructions in multiple states.

To address this, companies often seek strategic partnership with universities to establish talent pipelines so that a flow of qualified future entrants to the workforce can be maintained. That is why Intel recently announced a $50 million USD investment in higher education in Ohio,[35] a state where Intel will invest $20 billion USD for advanced fabs.[36] However, given the U.S.'s leading position in software design, especially for semiconductors, companies efforts on this front are undermined by general student interest in software design or internet services, as well as a number of other career paths that engineers might pursue.

4.3 Expanded Capacity in the U.S.

Intel, Samsung, and TSMC have all demonstrated their desire to expand their operations in the U.S. with capital investments for new fabs which will significantly bolster the future American semiconductor manufacturing industry.

The U.S. has recently seen multiple expansion announcements from several major foundry companies. These include announcements by Intel in March 2021,[37] TSMC in April 2021,[38] GF in July 2021,[39] and Samsung Electronics in November 2021.[40] Additionally, Intel Corp. announced plans in January 2022 for an initial investment of more than $20 billion USD in the construction of two new leading-edge chip factories in Ohio. As of March 2022, UMC is also reportedly eyeing Detroit as a potential investment site for a 12-inch (300mm) fab.[41] Additionally, Micron Technologies has been scouting potential new fab sites as part of a 10-year $150 billion USD investment plan in Texas, California, Arizona, and, until recently,[42] North Carolina.[43]

5.0
Additional Industry Information and Trends

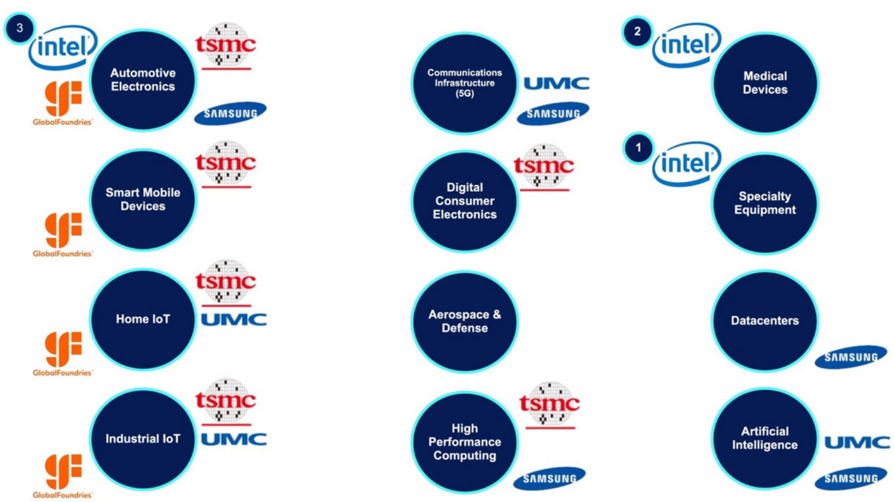
This section briefly highlights several industries that are reliant on semiconductors as well as an overview of merger and acquisition activity within the industry.

5.1 Industries Reliant on Semiconductors

The aerospace and defense (A&D) industry is notably absent from leading foundries' lists of core businesses, largest markets, expected areas of growth, and in some cases delivery priorities.

Semiconductor devices have become vital components of a range of manufactured products, ranging from computers to mobile phones, vehicles, communications infrastructure, A&D applications, medical devices, and artificial intelligence to name a few. Given the shortages exacerbated by the pandemic, foundries have had to modify operations in line with customer delivery prioritizations. For example, in 2021 TSMC reportedly prioritized chip orders for Apple, due in large part to Apple's order volume and the influence derived thereof. Simultaneously, chipmakers agreed to increase priority for automotive chips given the sever revenue loss experienced by that industry.

The following infographic is intended to highlight the range of industries which rely on semiconductors for end-user products. As the semiconductor shortage continues, foundries have taken steps to establish prioritization lists for received orders; however, detailed insight into those established priorities is not always available. A TSMC label has been placed next to industries that TSMC sees as its largest markets.[44] A Samsung label has been placed next to industries that Samsung sees as emerging growth business opportunities.[45] A UMC label has been placed next to industries from which UMC plans to gain more business.[46] A GF label has been placed next to industries that GF labels as its core markets.[47] And an Intel label with a number has been placed where Intel's CEO outlined where Intel will prioritize chip deliveries, where (1) is Intel's highest priority.[48]



5.2 Industry M&A Activity and Sales

Merger and acquisition deals in the semiconductor industry reached record levels of revenue in 2020 with total values reaching $118 billion USD in 2020 with continuing momentum into 2021.[49]

Most of the value came from five mergers with a combined value of $94 billion USD. Analog Devices announced it would buy Maxim Integrated Products for $21 billion USD in July. Later in September, Nvidia announced a $40 billion USD deal with processor-design supplier ARM in the UK, who licensed nearly all the central processor technology in variety of markets. Intel divested its NAND flash memory business and 300mm wafer fab site in China for a total of $9 billion USD. Also in October, Marvell Technology acquired mixed-signal supplier Inphi Corp. for a value of $10 billion USD. [50]

In 2021, 17 mega-suppliers listed more than $10 billion USD in sales with nine suppliers headquartered in the U.S., three in Europe, two in Taiwan, two in South Korea, and one in Japan.[51] This trend is expected to continue with sales increasing 26.8% in January of 2022 compared to January 2021.[52]

2022 Sales Percentage Growth by Region from 2021[53]	
REGION	**PERCENTAGE GROWTH**
Americas	40.2%
Europe	28.7%
Japan	18.9%
China	24.4%
Asia Pacific/All Other	21.0%

According to the Semiconductor Industry Association, global chip sales hit a record in 2021 with total value of $555.9 billion USD, which is a global increase of 26.2% on the year.[54] They also forecast an 8.8% growth in sales in 2022 as the industry continues to hit high levels of revenue, growth, and investments in 2022.[55] An early signal of rising expected demand includes Intel's plan to invest €80 billion euros in the European Union along the entire supply chain starting with R&D to manufacturing and packaging technologies.[56] Intel and Samsung currently lead the industry as of 2021 in Semiconductor sales, meaning this is a big move from a top player in the semiconductor industry.

This market is expected to grow by 10.4% in 2022, corresponding with sales of $613.5 billion USD.[57]

Expected 2022 Market Growth by Category	
CATEGORY	**PERCENTAGE GROWTH**
Sensors	17.2%
Logic	17.1%
Analog	14.1%
Memory	1.1%

6.0
Concluding Remarks

There does not appear to be a consensus of when shortages will ease in this industry. A recent report claimed that the market should expect the semiconductor shortage to extend through 2022 and into 2023 and that by the end of 2022 customers will still have lead times between 10-20 weeks.[58] This is in line with Intel's CEO who once stated there won't be a supply-demand balance until 2023,[59] and TSMC's stance that the chip shortage will last through 2022 as a result of high demand from high performance computing and 5G chips.[60] JPMorgan takes a more optimistic approach with estimates the chip shortage will drag on through 2022 with some improvement mid-year as more supplies become available,[61] whereas other investors believe the shortage could persist deep into 2023.[62] Intel's CEO now has a less optimistic view, stating in a Senate hearing that he expects the shortage to continue to at least 2024.[63]

In addition to the pandemic, several major impact events like the Renesas factory fire and the winter storm in Texas have constrained IC supply at a time when it was already experiencing severe shortages. Although manufacturers are investing capital and already are breaking ground on new fabs to ease pressure on supply chains, the bulk of those additions to the industry will likely have completion dates between 2023-2025. Moreover, those slated for completion in 2022 are not guaranteed to meet their deadlines as COVID restrictions and supply chain delays for construction materials and highly specialized equipment can be expected to continue. Although new fabs are expected to come online, an increasing number of manufacturers rely on those chips which increases demand, and disruptions are expected to continue which undermine global supply. As a result, the chip shortage should be expected to continue through 2023, after which the industry will see relief from expanded capacity from new or expanded fabs. Unfortunately, since fabs require highly specialized equipment, extensive automation, and uncompromising clean rooms, building a new fab is not a quick undertaking.

It is critical to note as well that although foundries have an incentive to increase production to meet elevated demand, these foundries are simultaneously calculating future expected markets. Foundries will be careful not to over-invest to avoid the potential problem for them of supply exceeding demand since the current situation of demand exceeding supply is profitable. However, since demand is expected to increase as the expansion of the use and integration of semiconductors in end-products increases, the current focus of foundries is likely still on meeting adequate levels of demand.

To adapt to this environment, several options are available to end-users that rely on semiconductors:

Identify specific supply inhibitors

Automotive manufacturers' operations have been held up by power management integrated circuits (PMICs). PMICs cost less than $1 USD but their short supply has cost automotive manufacturers billions of dollars as they have been forced to stall operations as they await PMIC deliveries. Since 'semiconductor' is an umbrella term for multiple specific-function devices, end-users should identify the exact products presenting problems within their supply chain.

Diversification of suppliers

This mitigates risk in the supply chain as concentrated reliance on one or two suppliers is offset by alternative sources in the event of operational disruptions. However, splitting up volume orders over a spread of suppliers can undermine the buying power and influence wielded with higher volume orders.

Direct communication with foundries

Establishing or expanding communication channels with foundries rather than, or in addition to, distributors will provide insights to foundry operations and present an opportunity for direct understanding of the situation at the fab level. Moreover, this presents an opportunity for establishing or promoting relations which could prove beneficial in future as additional supplier deals are made.

Balance selective 'just-in-time' practices with maintained inventories

'Just-in-time' manufacturing allows for flexibility in production but can pose a risk if requisite supplies become scarce, as has happened in the semiconductor industry. Identifying reliance on specific components and assessing the global situation can inform which components would benefit from having an expanded inventory to hedge against disruptions.

Leverage multiple technological designs or simplify designs

Complex systems often incorporate use-specific components which introduces additional nodes of vulnerability if the supply of any of those components experiences delays. Simplifying designs, or leveraging alternative designs, albeit with potentially considerable R&D input costs, can better place end-users to adapt to this dynamic environment.

Conduct scenario planning exercises

Scenario planning exercises are a supply chain risk management (SCRM) best practice tool which enable organizations to better prepare for disruptions in the supply chain. By identifying the criticality of supplies or suppliers, like how FIPS 199 does for federal information and information systems, SCRM tools can be used to proactively hedge against operational or logistical problems.

While foundries are expanding capacity and the U.S. seeks to incentivize reshoring of semiconductor manufacturing, those efforts are undermined by a lack in skilled workers, high input costs, vulnerabilities in the material supply chain, and preventable and unpreventable disruptions. World capacity will benefit from increased competition between the U.S. and China for an advantage in the semiconductor sector as well as European activity, but those investments will take time to materialize as fabs take anywhere from 2-5 years to bring online.

Unfortunately, front-end fabrication is just one piece of the puzzle in this complex industry and diverse supply chain. Bottlenecks elsewhere, from the supply of materials to the delivery of specialized equipment can have significant ripple effects on capacity, not to mention disruptions in shipping and logistics that can add delays to lead times. Therefore, any approach to expanding chip capacity must be multi-faceted and thorough, considering vulnerabilities at each step of the supply chain to mitigate associated risks and prevent further delays.

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Appendix A

Semiconductor Manufacturing Industry Analysis
(Main Phases)

Main Phases of the Semiconductor Manufacturing Process and Prominent Companies Operating within each Phase

Infographic created by the Interos Inc. Business Analyst Team

1

Instruction Set Architecture

In this phase companies are engaged in the creation of Instruction Set Architecture (ISA), which is part of the abstract model of a computer. ISA defines how software controls a central processing unit (CPU) since it describes the registers, instruction, and memory model of a CPU. An Instruction Set Architecture, or ISA, Notably, ISA does not describe the physical implementation of instructions. Two processors can be constructed in a fundamentally different way, but if both use the same ISA then they will be able to execute code identically.

Infographic created by the Interos Inc. Business Analyst Team

Company		Country	i-Score	Resilience ID
ARM Limited	arm	United Kingdom	83	a508e56f-9d24-4bc5-9fb7-b49aa3e58584
Intel Corporation	intel	United States	73	63af563a-6c76-444f-af7b-f5e897dfc0bf
RISC-V International (Previously RISC-V Foundation)	RISC-V	Open Source	69	034fdfd5-9902-45e8-bccb-33bda94d89c9
Member List Includes:				
Alibaba Cloud (Singapore) Pvt. Ltd.	Premier Member	Singapore	82	b86253c7-8ab7-436b-bbd8-c73236fb2542
Analog Devices, Inc.	Strategic Member	United States	71	db6fdf6c-00ca-44fa-a654-4fff69984340
Google, LLC	Premier Member & Founding Member	United States	73	eb15bae0-e753-4a33-8e7d-9360437451c4
* Huawei Technologies Co., Ltd.	Premier Member	China	36	23e3f724-ed7c-4efa-9735-c4866d895842
Intel	Premier Member	United States	73	63af563a-6c76-444f-af7b-f5e897dfc0bf
International Business Machines Corp.	Strategic Member & Founding Member	United States	71	e4da6ed1-029e-4423-904d-9cacc0d43e5c
MediaTek, Inc.	Strategic Member	Taiwan	81	1d2e8c78-c0f8-4732-87f5-cfbe50664da1
Microchip Technology, Inc.	Strategic Member & Founding Member	United States	69	617d730f-9775-44b0-a78d-73dfe9094e91
MIPS Technologies, Inc.	Strategic Member	United States	74	d042f3f8-207f-41b8-8d6a-22f6b8b8055a
Nvidia Corporation	Strategic Member	United States	72	d828691a-c691-4e30-b5a0-cc924a68faa2
Qualcomm, Inc.	Strategic Member & Founding Member	United States	72	da428027-797b-49e2-84ae-67552a4693bd
Renesas Electronics Corp.	Strategic Member	Japan	78	f28f1d86-7365-461b-8748-f183b353481f
Samsung Electronics Co., Ltd.	Strategic Member	South Korea	78	f9c62cc8-f6a1-4609-8a82-19664fed83f1
Siemens Aktiengesellschaft	Strategic Member	Germany	84	dc7937e7-7074-4527-8e5c-1691b4eefa90
Thales S.A.	Strategic Member	France	80	b1fd36d5-64b4-4449-90f7-6521e8c9d138
Xilinx, Inc.	Strategic Member	United States	72	800b0dc9-f4b3-4aa4-ae1f-bfc7efad621a
* ZTE Corporation	Premier Member	China	54	87482753-0c72-4d30-b3df-e0c28ae7347c

Source: RISC-V International Members

The above member list of companies supporting the RISC-V open-source project is not exhaustive. Chinese firms actively engage with open-source projects such as RISC-V to secure access to foreign software and hardware, promote domestic innovation, and adapt to US-imposed access restrictions to certain technologies.

(*) Huawei Technologies Co., Ltd. and ZTE Corporation are on multiple restrictions lists. Both companies are restricted in the U.S. as part of Section 889 of the 2019 National Defense Authorization Act, which prohibits executive agencies from entering into, or extending or renewing, a contract with an entity that uses any equipment, system, or service that uses covered telecommunications equipment or services as a substantial or essential component of any system, or as critical technology as part of any system, on or after August 13, 2020, unless an exception applies or a waiver is granted.

2 Design (Fabless)

In this phase companies design and market semiconductor chip hardware, after which they outsource the manufacturing of that hardware to a third-party partner. These companies are deemed "fabless" as they contract the manufacturing of their designed hardware to companies with fabrication facilities, or "fabs."

Infographic created by the Interos Inc. Business Analyst Team

Company	Q3 2021 Revenue (USD)	Country	i-Score	Resilience ID
Qualcomm, Inc.	$7.73 billion	United States	72	da428027-797b-49e2-84ae-67552a4693bd
Nvidia Corporation	$6.61 billion	United States	72	d828691a-c691-4e30-b5a0-cc924a68faa2
Broadcom, Inc.	$5.43 billion	United States	70	a5f48987-e69c-477c-9768-42a6f799fd23
MediaTek, Inc.	$4.70 billion	Taiwan	81	1d2e8c78-c0f8-4732-87f5-cfbe50664da1
Advanced Micro Devices, Inc.	$4.31 billion	United States	71	38a4984d-8d2a-44e6-9c0e-769fd5c76732
Novatek Microelectronics Corp.	$1.38 billion	Taiwan	83	aece8ff9-ba6b-47bb-b3b3-6bbc66d90229
Marvell Technology Group Ltd.	$1.17 billion	Bermuda	79	a3c89598-161d-4368-86ff-a36d12f85ef1
Realtek Semiconductor Corp.	$1.04 billion	Taiwan	82	4edacdc3-acec-4d51-a079-3a61521d7b77
Xilinx, Inc.	$936 million	United States	72	800b0dc9-f4b3-4aa4-ae1f-bfc7efad621a
Himax Technologies, Inc.	$421 million	Taiwan	79	488c61f0-31ab-4816-8d7b-9647b012a462

Source: TrendForce: 3Q21 Revenue of Global Top 10 IC Design (Fabless) Companies

"Fabless" companies appear to be concentrated in the United States where there the cost of labor is relatively high. This is the result of a trend over time where companies viewed fabricating their designed hardware in-house through a vertically integrated supply chain model to be less appealing since manufacturing can be carried out by third parties in countries where the cost of labor is relatively lower. As a result, companies like Taiwan Semiconductor Manufacturing Co., Ltd. have increased their business over time as more companies shifted towards a fabless model where manufacturing was subcontracted to companies positioned to meet their demands.

3 Fabrication (Fabs: Front-End)

In this phase companies are engaged in the physical manufacturing of semiconductor chips. Both additive and subtractive processes are employed. Processes include cutting silicon ingots into wafers, wafer doping, photolithography, ion implantation, etching, gate formation, metal deposition, layering, and sawing.

Infographic created by the Interos Inc. Business Analyst Team

Company	Global Market Share	Country	i-Score	Resilience ID
Taiwan Semiconductor Manufacturing Co., Ltd.	53.10%	Taiwan	86	694eb29e-ea4b-4f3c-af34-6c5c9f0b1da3
Samsung Electronics Co., Ltd.	17.10%	South Korea	80	f9c62cc8-f6a1-4609-8a82-19664fed83f1
United Microelectronics Corp.	7.30%	Taiwan	84	0cf1386e-834f-4224-a7f9-de9ff9950494
GlobalFoundries, Inc.	6.10%	United States	74	875b841d-e7af-482e-967b-90b634fd73a4
* Semiconductor Manufacturing International Corp.	5.00%	China	53	d7f34e16-3634-4d4d-8dc4-d3461e6c465b
Huahong Grace Semiconductor Manufacturing Corp.	2.80%	China	65	3b84b28b-843b-4707-9fec-08a9ddac6afa
Powerchip Semiconductor Manufacturing Corp.	1.90%	Taiwan	87	12469527-05ea-433c-83f0-47e9032a7850
Vanguard International Semiconductor Corp.	1.50%	Taiwan	83	f94a3032-18a7-44e6-add4-6ddff772d379
Tower Semiconductor Ltd.	1.40%	Israel	73	723ae45b-7d0f-41e8-aab8-d1183b978323
DB Hitek Co., Ltd.	1.00%	South Korea	81	c5912dd3-b9d3-48a6-affa-6ba655434052

Source: Statista; Leading Semiconductor Foundries Revenue Share Worldwide From 2019 to 2021, by Quarter

Semiconductor manufacturing is concentrated in Taiwan, and there is clear concentration in one company, Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC). TSMC makes chips for Apple, Intel, Nvidia, AMD, and Qualcomm. South Korea trails Taiwan with 18.10% of the global market share, followed by China with 7.8%. China seeks to quickly improve its semiconductor manufacturing industry after U.S. sanctions limited exports of advanced technologies to the country.

(*) Semiconductor Manufacturing International Corp. (SMIC) is on multiple restrictions lists after U.S. government policies dating back to 2020.

4 Equipment & Software

Rather than representing a linear progression from the previous phase to the following phase, this phase (Equipment & Software) is intended to highlight the companies which provide the means necessary to enable other companies to carry out the fabrication process as well as the Testing, Assembly, & Packaging (Back-End) phase of the semiconductor manufacturing process.

Infographic created by the Interos Inc. Business Analyst Team

Company		Process Supported	Country	i-Score	Resilience ID
Advanced Semiconductor Materials Lithography Holding N.V. (ASML)	ASML	Photolithography	Netherlands	84	ddb35ab8-cf20-4d25-919f-b41a3df035cf
Carl Zeiss SMT GmbH	ZEISS	Photolithography	Germany	92	101a657e-338f-41c6-b26b-2890d792b871
Tokyo Electron Ltd.	TEL TOKYO ELECTRON	Coating, Etching, Deposition, Testing	Japan	81	9f7cd503-8a9b-4040-b293-7394c09d737a
Lam Research Corporation	Lam RESEARCH	Etching, Deposition, Cleaning, Metrology	United States	73	7333170b-d611-40d4-bf36-bc206f456f28
Applied Materials, Inc.	APPLIED MATERIALS	Etching, Ion Implantation, Deposition, Metrology	United States	73	42159344-1e04-45f3-afdf-52337f05d9f2
Oxford Instruments plc	OXFORD INSTRUMENTS	Etching, Deposition, Microscopy, Optics	United Kingdom	84	c8133872-7314-4ff6-875f-96f4c4ab312b
ASM International N.V.	ASM INTERNATIONAL	Deposition, Epitaxy, Diffusion, Oxidation	Netherlands	86	869e0d25-3a14-4e73-95d9-a9a9faf0af31
Ayar Labs, Inc.	AyarLabs	Optics	United States	69	29fecb3c-8433-49cd-b2bf-9e65b501fb2b
SPTS Technologies Ltd.	SPTS A KLA Company	Etching, Deposition, Dicing	United Kingdom	86	ba152b22-8216-4327-a732-d3bca4a14d53
SEMES Co., Ltd.	SEMES	Cleaning, Etching, Testing, Line Automation	South Korea	79	26db8fca-c6ce-44a0-88cc-fa6611b683c9

The U.S. lobbied the Dutch government since at least 2018 to prevent the export of advanced photolithography machines with extreme ultraviolet (EUV) capabilities to Chinese companies like SMIC. This came as part of a concerted U.S. effort to undermine the development of an advanced semiconductor manufacturing industry in China on national security grounds. Currently, ASML is the sole producer of EUV lithography machines in the world.

Note: This list is not exhaustive, nor do companies appear in any specific order.

5 Testing, Assembly, & Packaging (Back-End)

In this phase companies are engaged in ensuring the quality of produced chips as well as packaging them for incorporation as subcomponents into electronic systems. Processes include wafer inspection, wafer probing, wafer dicing, die bonding, wire bonding, solder bumping, and encapsulation.

Infographic created by the Interos Inc. Business Analyst Team

Company	Q3 2021 Revenue (USD)	Country	i-Score	Resilience ID
Advanced Semiconductor Engineering Technology Holding Co., Ltd.	$2.15 billion	Taiwan	83	998b979f-4c98-44a4-bb32-e82d4a834c93
* Amkor Technology, Inc.	$1.68 billion	United States	71	b1c3e231-cdae-4ffc-afed-7816027d7ed8
JCET Group Co., Ltd.	$1.25 billion	China	64	5a8dd658-e8b0-4aba-b132-aa08ae278c1d
Siliconware Precision Industries Co., Ltd.	$1.04 billion	Taiwan	84	76b9cf3c-7825-4c22-a465-1c56d374a877
Powertech Technology, Inc.	$802 million	Taiwan	84	1c38500f-2f0b-4a38-8b14-b1a4e01039b3
TongFu Microelectronics Co., Ltd.	$636 million	China	66	48f139ec-4fd3-4146-99ea-d1846a5efcb1
Tianshui Huatian Technology Co., Ltd.	$502 million	China	64	04da99b4-e880-4724-9e94-1185813d88a7
King Yuan Electronics Co., Ltd.	$323 million	Taiwan	85	611473e8-298f-4265-b0c5-f0de8bb596ea
ChipMOS Technologies, Inc.	$257 million	Taiwan	82	20d4511f-6ea5-4c25-8e62-19bc31776112
Chipbond Technology Corporation	$255 million	Taiwan	84	5b26bc19-a45a-4279-9fc6-a6ebfacb322f

Source: *[evertiq; Revenue Ranking of the Top 10 OSAT Companies for 3Q21]*

(*) Though headquartered in the United States, factory production for Amkor Technology, Inc. is concentrated in Asia, specifically in: China, Japan, Malaysia, South Korea, Taiwan, and The Philippines.

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Appendix B

Semiconductor Manufacturing Industry Analysis
(Main Fab Companies)

3 Fabrication (Fabs: Front-End)

In this phase companies are engaged in the physical manufacturing of semiconductor chips. Both additive and subtractive processes are employed. Processes include cutting silicon ingots into wafers, wafer doping, photolithography, ion implantation, etching, gate formation, metal deposition, layering, and sawing. Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC) is the clear leader in this industry. Notably, there is considerable crossover of customers served amongst the top four companies. This includes Apple, Inc. (client of TSMC & Samsung), MediaTek, Inc., AMD , Qualcomm, and Broadcomm (all four are clients of TSMC, UMC, & GF), Intel (client of TSMC & UMC), and NXP (client of UMC & GF).

Infographic created by the Interos Inc. Business Analyst Team

Company	Global Market Share	Country	i-Score	Resilience ID

Main Phases of the Semiconductor Manufacturing Process

Primary Semiconductor Manufacturers

Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC) accounts for a majority (53.10%) of global market share. The company's production includes 150mm, 200mm, and 300mm wafers using processes up to 5nm, with plans to include 3nm processes in the near future. TSMC has fabs predominantly in Taiwan, with additional fabs in China and the United States.

Samsung Electronics Co., Ltd. (Samsung) is the leading semiconductor manufacturer in South Korea, accounting for 17.10% of the global market share. Samsung's production includes 200mm and 300mm wafers with fabs in South Korea, China, and the United States. Although Huawei Technologies Co., Ltd. used to be a top 5 customer of Samsung, that has changed in the wake of U.S. sanctions against Huawei on national security grounds.

United Microelectronics Corp. (UMC) is the second largest Taiwan-based semiconductor manufacturer and the third largest in the world with 7.3% of the global market share. The company's production includes 150mm, 200mm, and 300mm wafers using processes ranging from [0.11µm - 90nm] with operations are primarily in Taiwan. UMC has additional fabs in China, Japan, and Singapore.

GlobalFoundries, Inc. (GF) is the fourth largest semiconductor manufacturer with 6.10% of the global market share. Headquartered in the United States, GF produces 200mm and 300mm sized wafers with fabs in the United States, Singapore, and Germany. In 2018, GF pivoted away from plans to invest in leading-edge technologies.

Semiconductor Manufacturing International Corp. (SMIC) is the fifth largest semiconductor manufacturer with 5.00% of the global market share. Headquartered in China, SMIC has been blacklisted by the United States to stymie the growth of China's domestic semiconductor manufacturing industry. As a result, SMIC has been forced to rely on open-source projects like RISC-V to gain access advanced technologies. SMIC's operations are primarily in China.
Note: a more in depth look at SMIC's operations is not included in this report.

3

Taiwan Semiconductor Manufacturing Co., Ltd. (TSMC) [Resilience ID: 694eb29e-ea4b-4f3c-af34-6c5c9f0b1da3] is a critical semiconductor manufacturer, accounting for a majority of global market share. The company's production includes 150mm, 200mm, and 300mm wafers using processes up to 5nm, with plans to include 3nm processes in the near future. TSMC has fabs predominantly in Taiwan, with additional fabs in China and the United States. Amid the global semiconductor shortage, TSMC has earmarked $44 billion USD for manufacturing expansion in 2022, up from its previous record of $30 billion USD in 2021. The following are TSMC major clients.

Infographic created by the Interos Inc. Business Analyst Team

Company	TSMC Derived Annual Revenue as of Dec. 21' (%)	Country	i-Score	Resilience ID
Apple, Inc.	25.93%	United States	72	52c341ab-b6c4-40e7-a5da-3ee393341553
MediaTek, Inc.	5.80%	Taiwan	81	1d2e8c78-c0f8-4732-87f5-cfbe50664da1
Advanced Micro Devices, Inc.	4.36%	United States	71	38a4984d-8d2a-44e6-9c0e-769fd5c76732
Qualcomm, Inc.	3.90%	United States	72	da428027-797b-49e2-84ae-67552a4693bd
Broadcom, Inc.	3.77%	United States	70	a5f48987-e69c-477c-9768-42a6f799fd23
Nvidia Corporation	2.83%	United States	72	d828691a-c691-4e30-b5a0-cc924a68faa2
Sony Corporation	2.54%	Japan	78	bebefdf9-8d6b-4700-bf95-60c86967e74f
STMicroelectronics N.V.	1.39%	The Netherlands	89	9e455139-748b-49e3-84b7-c5c0edf5b785
Analog Devices, Inc.	1.06%	United States	71	db6fdf6c-00ca-44fa-a654-4fff69984340
Intel Corp.	0.84%	United States	73	63af563a-6c76-444f-af7b-f5e897dfc0bf

Source: AMD Becomes TSMC's Third Largest Customer

3

SAMSUNG

Samsung Electronics Co., Ltd. (Samsung) [ResilienceID: f9c62cc8-f6a1-4609-8a82-19664fed83f1] is the leading semiconductor manufacturer in South Korea, accounting for 17.10% of the global market share. Samsung's production includes 200mm and 300mm wafers with fabs in South Korea, China, and the United States. In 2020, Samsung's major customers included Apple, Best Buy, Deutsche Telekom, Hong Kong Techtronics, and Verizon (listed alphabetically). Sales to those five major customers accounted for approximately 14% of total sales. In the first half of 2021, AVP Electronics Ltd. replaced Hong Kong Techtronics in the top five, the group then accounted for 13% of total sales. In 2019, that list of major companies included Huawei Technologies Co., Ltd. though that is no longer the case after U.S. sanctions against Huawei on national security grounds.

Infographic created by the Interos Inc. Business Analyst Team

Company		TSMC Derived Annual Revenue as of Dec. 21' (%)	Country	i-Score	Resilience ID
Apple, Inc.		Specified Client in 2020 Annual Report	United States	72	52c341ab-b6c4-40e7-a5da-3ee393341553
Best Buy Co., Inc.	BEST BUY	Specified Client in 2020 Annual Report	United States	72	2ca30cb5-d11a-41fc-8bbb-c1914a21ad9f
Deutsche Telekom AG	T Deutsche Telekom	Specified Client in 2020 Annual Report	Germany	83	1d1a8574-6d7d-448e-b295-70a0c46b4189
Hong Kong Techtronics Industrial Ltd.	Techtronics 泰科源	Specified Client in 2020 Annual Report	Hong Kong	77	5908a9c9-0840-44be-b234-e335c9f487d5
Verizon Communications, Inc.	verizon	Specified Client in 2020 Annual Report	United States	71	19ac6dbc-9ce2-45ed-b44e-c9af2c6ecf3a
AVP Electronics		Specified Client in 2021 Half Year Report	Hong Kong	77	c11df3bf-f809-42bf-afa7-b6a6ff6821fb
Huawei Technologies Co., Ltd.	HUAWEI	Specified Client in 2019 Annual Report	China	36	23e3f724-ed7c-4efa-9735-c4866d895842

Source: *Samsung Electronics Co., Ltd. 2020 Business Report*, *Samsung Electronics Co., Ltd. 2021 Half Year Report*

3

United Microelectronics Corp. (UMC) [Resilience ID: 0cf1386e-834f-4224-a7f9-de9ff9950494] is a major semiconductor manufacturer based in Taiwan. The company's production includes 150mm, 200mm, and 300mm wafers using processes ranging from [0.11µm - 90nm] with operations are primarily in Taiwan. UMC has additional fabs in China, Japan, and Singapore. According to UMC financial documents, its top ten customers accounted for 53.7% of its operating revenue in 2020. Seven companies specified in financial documents are included below, as well as three other companies with whom UMC has notable relationships.

Infographic created by the Interos Inc. Business Analyst Team

Company	Relationship Source	Country	i-Score	Resilience ID
Broadcom, Inc.	Specified Client in Annual Report	United States	70	a5f48987-e69c-477c-9768-42a6f799fd23
Intel Mobile Communications GmbH	Specified Client in Annual Report	Germany	91	01a36288-4090-4ab1-9077-b5a501dae433
MediaTek, Inc.	Specified Client in Annual Report	Taiwan	81	1d2e8c78-c0f8-4732-87f5-cfbe50664da1
Novatek Microelectronics Corp.	Specified Client in Annual Report	Taiwan	83	aece8ff9-ba6b-47bb-b3b3-6bbc66d90229
* Qualcomm, Inc.	Specified Client in Annual Report	United States	72	da428027-797b-49e2-84ae-67552a4693bd
Realtek Semiconductor Corp.	Specified Client in Annual Report	Taiwan	82	4edacdc3-acec-4d51-a079-3a61521d7b77
Texas Instruments, Inc.	Specified Client in Annual Report	United States	72	3140e1c7-14f1-4e98-8f79-8317fee1ea41
Advanced Micro Devices, Inc.	Client Not Specified in Annual Report	United States	71	38a4984d-8d2a-44e6-9c0e-769fd5c76732
Micron Technology, Inc.	Client Not Specified in Annual Report	United States	72	52a219d1-db4f-4639-aa50-c68700047529
NXP Semiconductors N.V.	Client Not Specified in Annual Report	The Netherlands	83	753edb85-447d-4af6-90c4-9ed302d00779

Source: [United Microelectronics Corp. Form 20-F United States Securities and Exchange Commission Filing]

Additional major clients identified through open-source research.

3

GlobalFoundries, Inc. (GF) [Resilience ID: 875b841d-e7af-482e-967b-90b634fd73a4] is the most prominent United States-based semiconductor manufacturer in terms of global market share. The company produces 200mm and 300mm sized wafers with fabs in the United States, Singapore, and Germany. In 2018, GF pivoted away from plans to invest in leading-edge technologies. According to GF financial documents, the following are the top 10 customers based on wafer shipment volume for the first half of 2021. As a group, GF's top ten customers account for close to 75% of GF's revenues. In 2020, AMD and Qualcomm were GF's only customers exceeding 10% of the company's net revenues. AMD accounted for 21% of net revenues, whereas Qualcomm accounted for 11% of net revenues.

Infographic created by the Interos Inc. Business Analyst Team

Company	Relationship Source	Country	i-Score	Resilience ID
Advanced Micro Devices, Inc. (AMD)	Specified Client in Annual Report	United States	71	38a4984d-8d2a-44e6-9c0e-769fd5c76732
Qualcomm, Inc.	Specified Client in Annual Report	United States	72	da428027-797b-49e2-84ae-67552a4693bd
Broadcom, Inc.	Specified Client in Annual Report	United States	70	a5f48987-e69c-477c-9768-42a6f799fd23
Cirrus Logic, Inc.	Specified Client in Annual Report	United States	72	a4d4a43e-a366-43b2-9fd8-03594ff31f44
MediaTek, Inc.	Specified Client in Annual Report	Taiwan	81	1d2e8c78-c0f8-4732-87f5-cfbe50664da1
Murata Manufacturing Co., Ltd.	Specified Client in Annual Report	United States	79	48c8de1f-92f2-461e-bf00-4448807d92b4
NXP Semiconductors N.V.	Specified Client in Annual Report	The Netherlands	83	753edb85-447d-4af6-90c4-9ed302d00779
Qorvo, Inc.	Specified Client in Annual Report	United States	70	b146d4e7-eafb-4e63-83c6-d89eb0558412
Samsung Electronics Co., Ltd.	Specified Client in Annual Report	South Korea	80	f9c62cc8-f6a1-4609-8a82-19664fed83f1
Skyworks Solutions, Inc.	Specified Client in Annual Report	United States	80	866a176e-9a08-46bb-9104-3c66419ee3b6

Source: GlobalFoundries, Inc. Form F-1 United States Securities and Exchange Commission Filing

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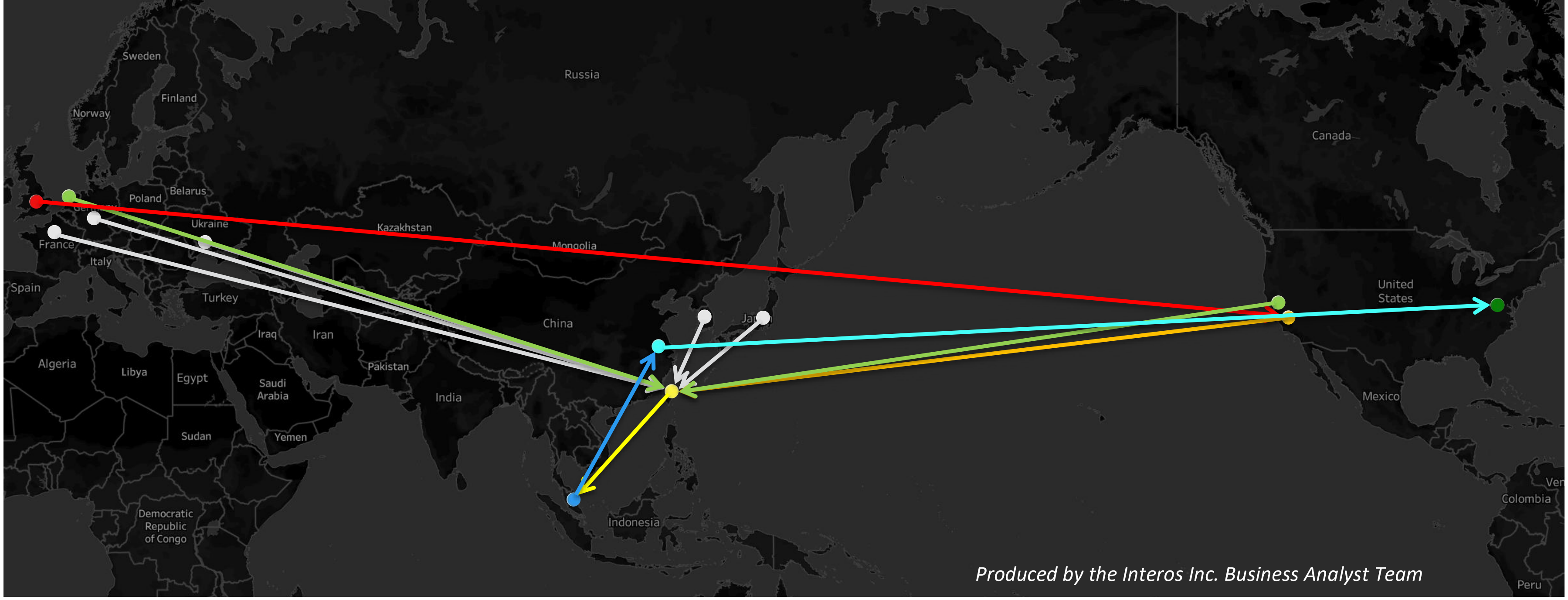
Appendix C

Semiconductor Manufacturing Industry Analysis
(Global Supply Chain Infographic)

Simplified Example of the Global Nature of the Semiconductor Manufacturing Supply Chain



Produced by the Interos Inc. Business Analyst Team

Below is the order in which the supply chain flows, transforming raw materials through advanced processes into semiconductors for use in final products.

- Materials: Helium from L'Air Liquide S.A. (France), Neon gas from Cryoin Engineering Ltd. (Ukraine), Silicon Wafers from Siltronic AG (Germany), Hydroflouric acid from SK Materials Co., Ltd. (South Korea), Silicon Wafers from Sumco Corp. (Japan), etc.
- Instruction Set Architecture: Arm Ltd. (United Kingdom)
- Semiconductor Design: Qualcomm, Inc. (United States)
- Semiconductor Fabrication (Front End): Taiwan Semiconductor Manufacturing Co., Ltd. (Taiwan)
- Equipment and Software: ASML Holding N.V. (The Netherlands), Lam Research Corp. (United States)
- Semiconductor Fabrication (Back End): Amkor Technology, Inc. (Malaysia)
- Electronics Manufacturing: Hon Hai Precision Industry Co., Ltd. (dba Foxconn) (China)
- Sale of End Product

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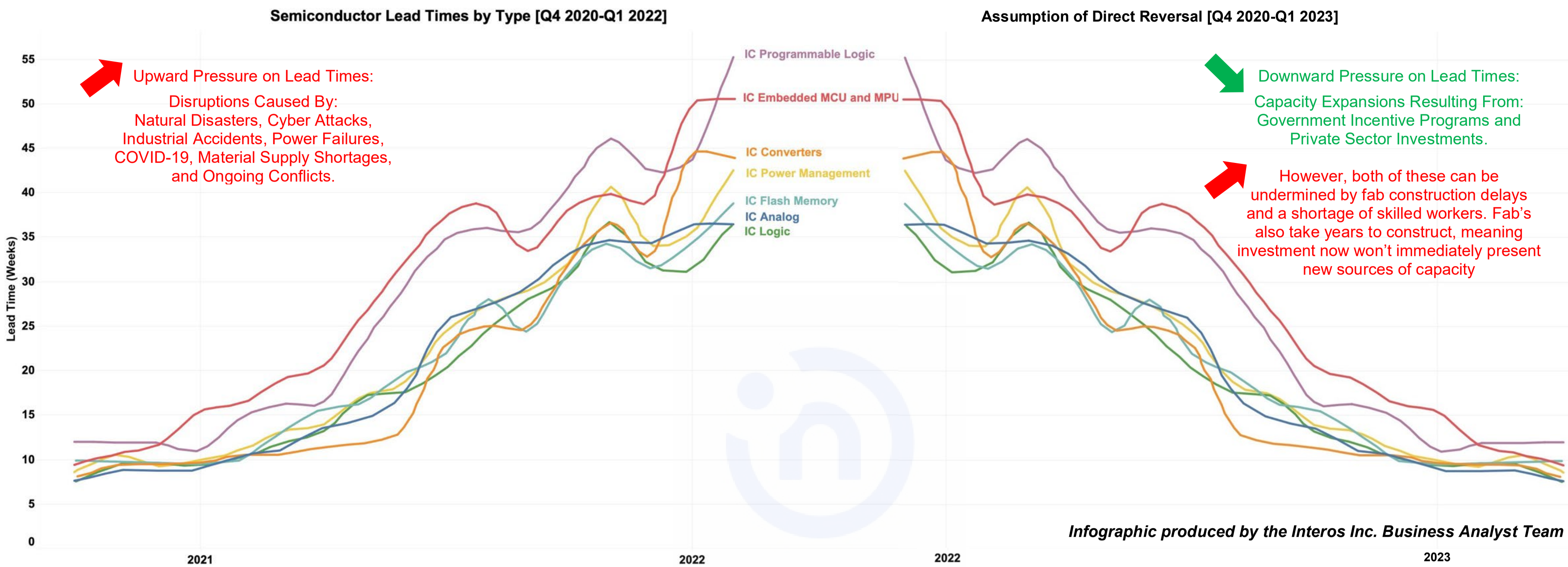
Appendix D

Semiconductor Manufacturing Industry Analysis
(Lead Times)



Expected Future Lead Time Analysis

In mirroring current lead time trends for a selected group of semiconductor devices, it can be concluded that a return to previously normal levels of lead times should not be expected before 2023. Notably, this mirrored graph assumes that lead times will be mitigated at the same rate that they increased, an assumption which must be challenged. Upward pressure on lead times will persist as the COVID-19 pandemic continues to cause congestion at ports around the world. Likewise, Russia's invasion of Ukraine adds additional upward pressure on lead times as air freight faces logistical delays from airspace restrictions. Moreover, disruption events resulting from earthquakes, cyberattacks, power outages, severe weather, factory fires, contamination, and compromised materials are expected to continue even as companies take steps to mitigate their negative effects and frequency. These events have varying degrees of potential to cause major disruptions in the supply chain. Downward pressure on lead times can be expected from new fabs coming online which will add to global capacity. However, construction delays, skilled labor shortages, and prolonged legislative processes to provide funding invectives undermine those efforts. Consequently, lead times should not be expected to return to previously normal levels through 2023, if indeed they return to previously normal levels and don't remain at a new elevated level.

Lead Times by Semiconductor Device

The above graph illuminates observed trends in chip lead times for several individual semiconductor devices. Unsurprisingly, IC Programmable Logic chips have the highest lead time at above 55 weeks since they are general purpose devices that can be programmed after shipping, allowing for user-customization and design flexibility. Next are IC Embedded Microcontroller Units (MCUs) and Microprocessor United (MPUs). MCU ICs contain a Central Processing Unit (CPU), memory, and input/output peripherals on a single IC chip and it functions as a standalone small computer. MPUs by contrast use external memory to provide program and data storage, and MPUs rely on external power management devices. IC Embedded MCU and MPUs have the second longest lead time at approximately 51 weeks. Following that are IC Converters which include Analog to Digital Converter (ADCs) and Digital to Analog Converters (DACs) which have lead times of approximately 44 weeks. ADCs convert an analog signal, such as electric voltage, into a binary one allowing for input into computers, while DACs convert a binary signal into an analog value prior to input to an electronic or electrical device. Next are Power Management ICs (PMICs), devices which have lead times of approximately 43 weeks. PMICs are used to manage power on an electronic device or in modules on devices that may have a range of voltages. PMICs typically contain DC-to-DC converters and linear voltage regulators. Next are IC Flash Memory devices which have lead times of approximately 38 weeks. IC Flash Memory devices provide memory storage capacity, primarily in the form of Dynamic Random Access Memory (DRAM) and Electronically Erasable Programmable Read Only Memory (EEPROM) of which NAND Flash is a subset. DRAM is the most common type of computer memory, and NAND Flash can be found in devices like USB memory drives. Analog and Logic ICs have approximately the same lead time of 36 weeks. Analog ICs use continuous varying signals and are often used to construct electronic circuits such as amplifiers and voltage comparators, and they are best suited for audio and video transmission since memory is stored in wave form. Digital ICs by contrast use discontinuous or binary signals and are best suited for computing and digital electronics since memory is stored in the form of a binary bit.

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Appendix E

Semiconductor Manufacturing Industry Analysis
(Government Incentives Comparison)

Comparison of Government Efforts to Bolster Semiconductor Manufacturing Around the World

$ Denotes the top five governmental entities promoting semiconductor manufacturing

Information collected and assembled by the Interos Inc. Business Analyst Team

North America

United States $

-$52 billion USD allocated as incentives for semiconductor manufacturers
-Establishment of a National Semiconductor Technology Center (NSTC)
-Investment Tax Credits

Canada

-$192 million USD ($240 million Canadian dollars) investment in semiconductor manufacturers
-Renewed investment in the National Research Council of Canada's Canadian Photonics Fabrication Center

Europe

European Union $

-$47.5 billion USD (€43 billion euros) in public and private investments
-Aiming to double EU's global market share to 20%
-Establishment of Digital Compass Outline, creating industry alliance across Europe
-Increased international cooperation with global allies

Germany

-$3.3 billion USD (€3 billion euros) investment in production sites
-$50 million USD investment in two funding programs intended to bolster chip production
-$30 million USD investment to support three processor development projects
-$24 million USD to develop trusted ecosystem

The Netherlands

-Major contributor to EU's investment plan policies
-Home to key private sector players such as NXP Semiconductors and Advanced Semiconductor Materials Lithography

France

-$33.3 billion USD (€30 billion euros) investment in microelectronic production capacity
-$6.6 billion USD (€6 billion euros) investment specifically in semiconductor production capabilities

Asia

Taiwan (ROC)

-$334 million USD in subsidies for manufacturers
-Continued government dedication towards development of local expertise in 2022
-Coordinating with India and US to account for water shortages need for fabs

South Korea $

-$450 billion USD investment in R&D and new fabs by 2030
-50% tax credits for R&D investments
-20% tax credits on facilities investments
-Training of 26,000 semiconductor experts

Japan

-$6.8 billion USD investment in production capabilities
-50/50 joint venture with TSMC on $171 million USD R&D center
-Agreement with U.S. to cooperate on semiconductor supply chain

China (PRC) $

-$100 billion USD in subsidies for manufacturers
-Two national chip funds of $50 billion USD
-$4 billion USD subsidized loans for state-backed companies
-Local government investment incentives

India $

-$10 billion USD investment incentives over next 6 years
-Creating 20 semiconductor design, components manufacturing, and fab units over a period of 6 years
-Negotiations with Taiwan to collaborate on production capabilities

Malaysia

-Accounts for roughly 12% of the global semiconductor assembly and testing services market
-Infineon Technologies to invest $2.6 billion USD in a frontend fab
-Intel to invest $7 billion USD in new chip packaging facility

The Philippines

-Total export of electronic parts in the Philippines declined to $37 billion USD in 2020, from $40 billion USD in 2019
-Corporate Recovery and Tax Incentives for Enterprises (CREATE) Act requiring exporters to surrender all fiscal incentives within 10 years

Vietnam

-$3.2 billion USD in funding towards an integrated circuit development program
-Tax incentives for up to 15 years
-Funding for training costs

About Interos

Interos is the operational resilience company. We are reinventing how companies manage their supply chains and business relationships through a breakthrough SaaS platform that uses artificial intelligence to model and transform the ecosystems of complex businesses into a living global map, down to any single supplier, anywhere. Reducing months of backward-looking manual spreadsheet inputs to instant visualizations and continuous monitoring, the Interos Operational Resilience Cloud helps the world's companies reduce risk, avoid disruptions, and achieve superior enterprise adaptability. Businesses can also uncover game-changing opportunities to radically change the way they see, learn and profit from their relationships.

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