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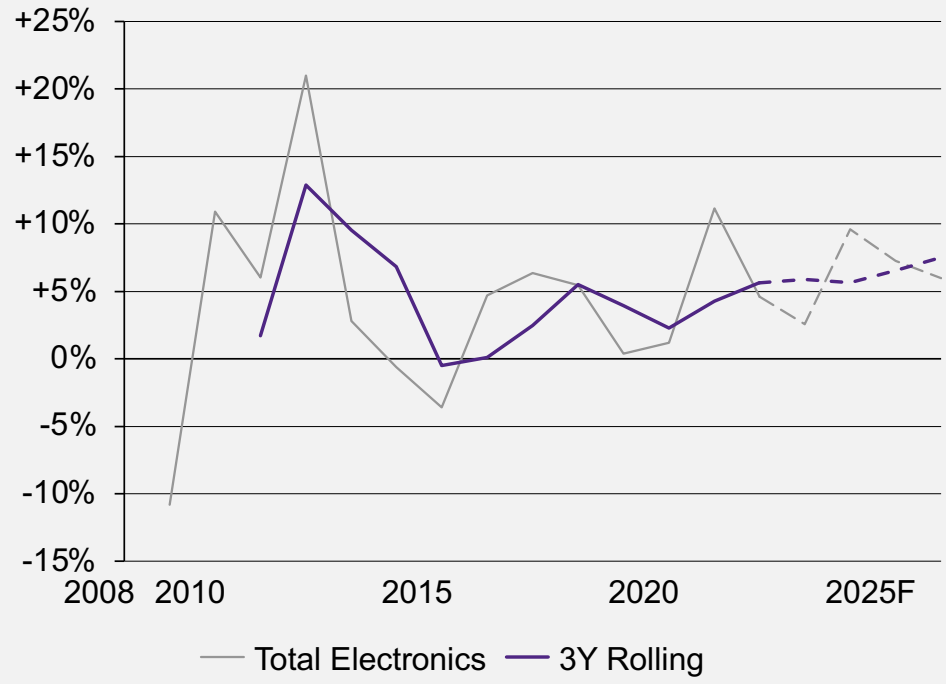
Silicon to Software™

The Changing Semiconductor Industry Landscape

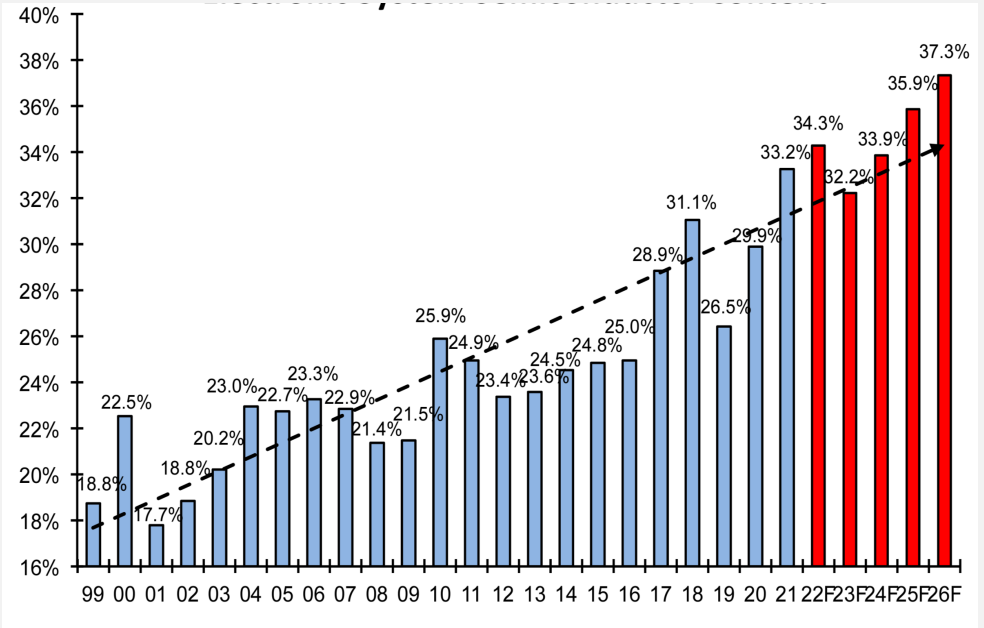
Joachim Kunkel
Synopsys, Inc.
April 20, 2023

Rising Semiconductor Content In Electronic Systems Compounding Growth

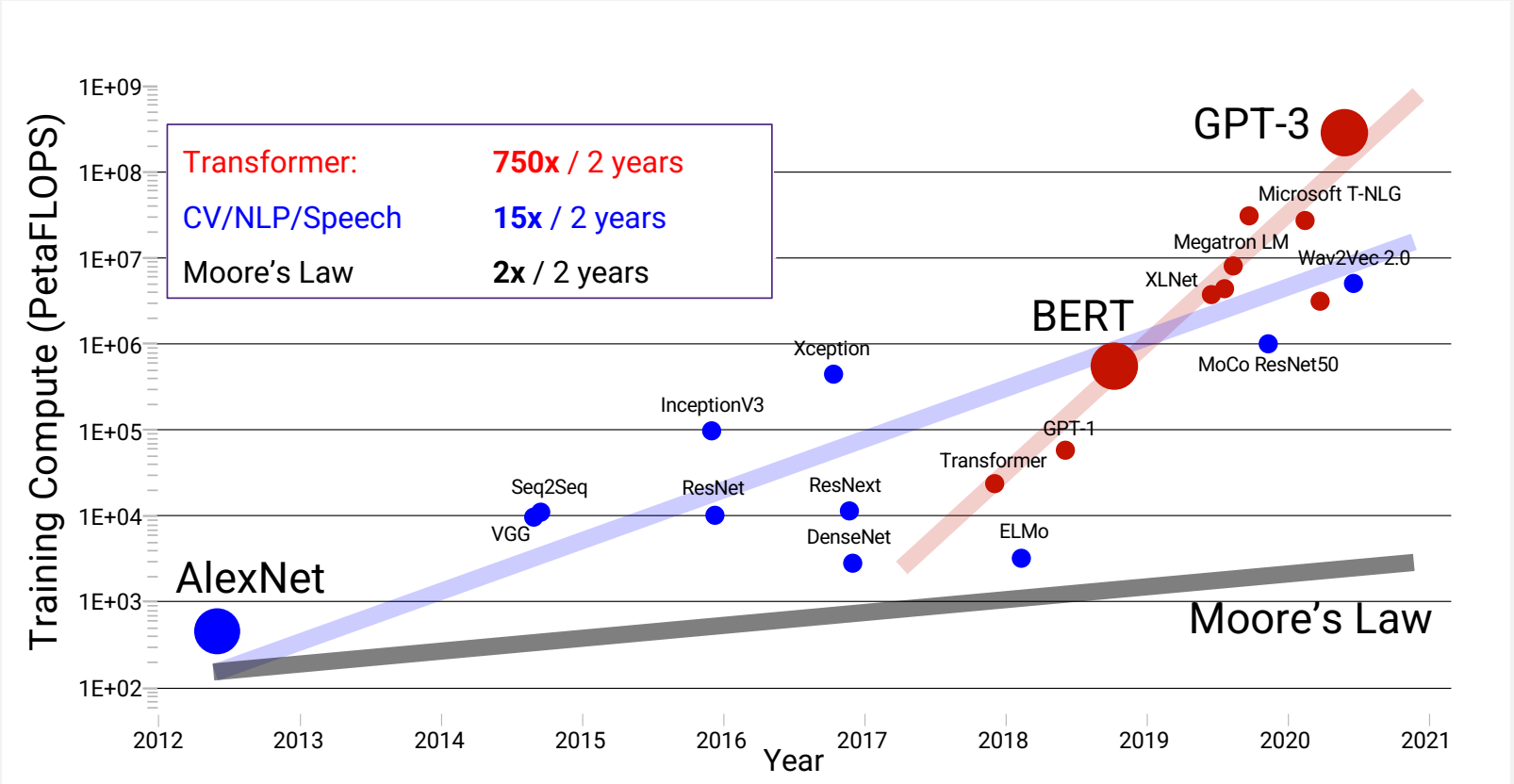
YoY % growth in electronics ex-factory production revenue



% Semiconductor content in electronic systems



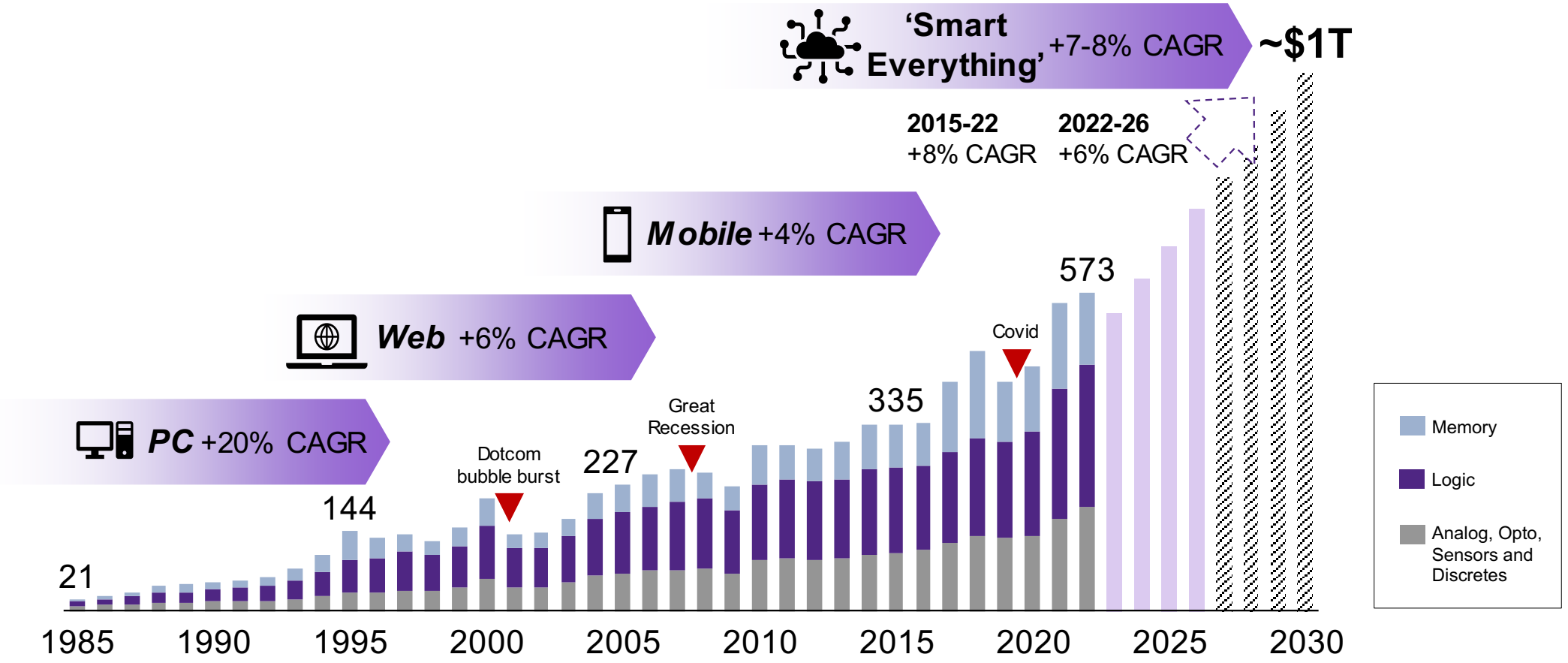
Compute Demands Are Growing At An Unprecedented Pace



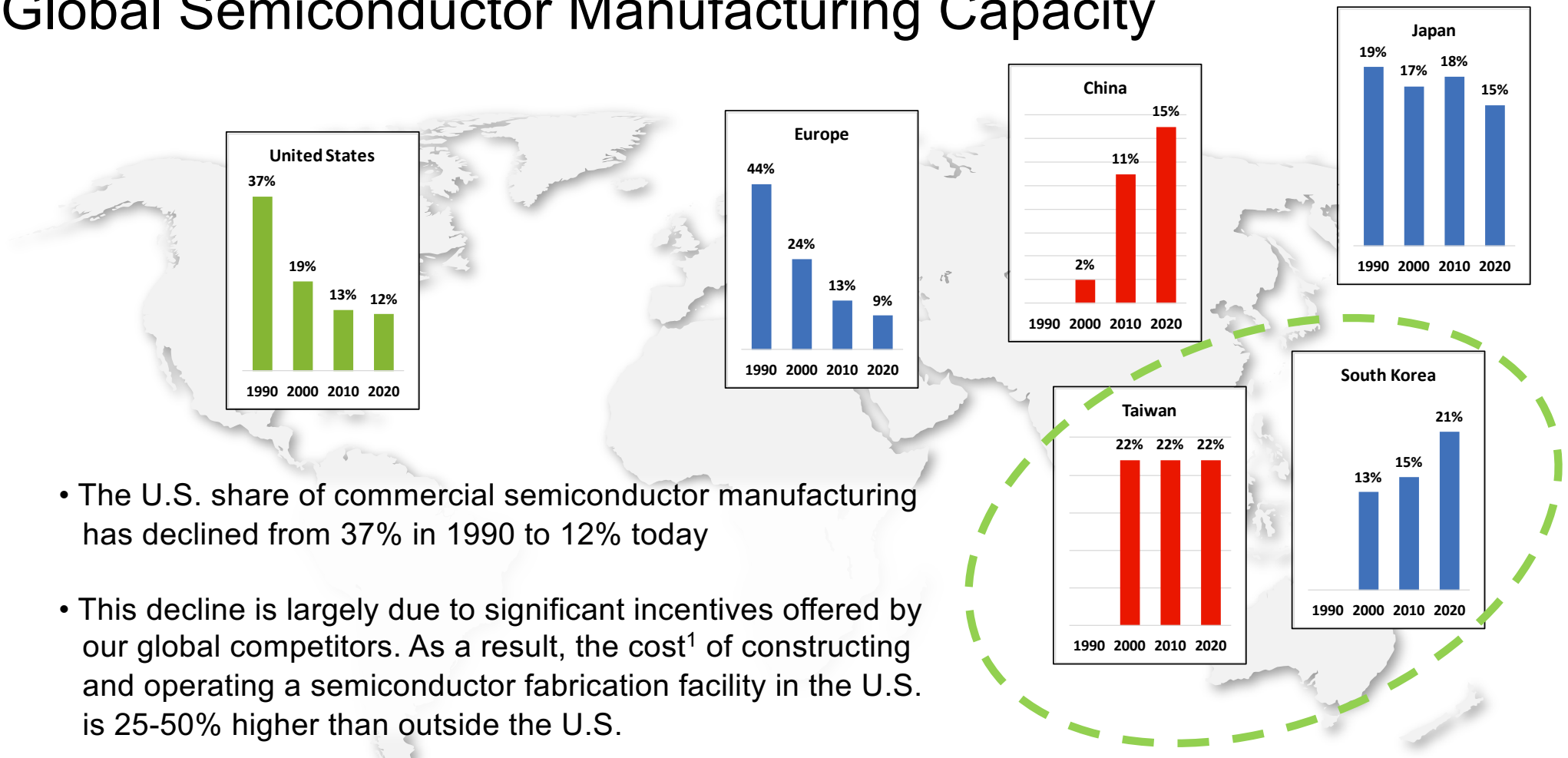
Exa- to Zetta- scale: 1,000x in compute

A New Era Of Accelerated Growth In Semiconductors

Global semiconductor sales over time [$B]



Global Semiconductor Manufacturing Capacity



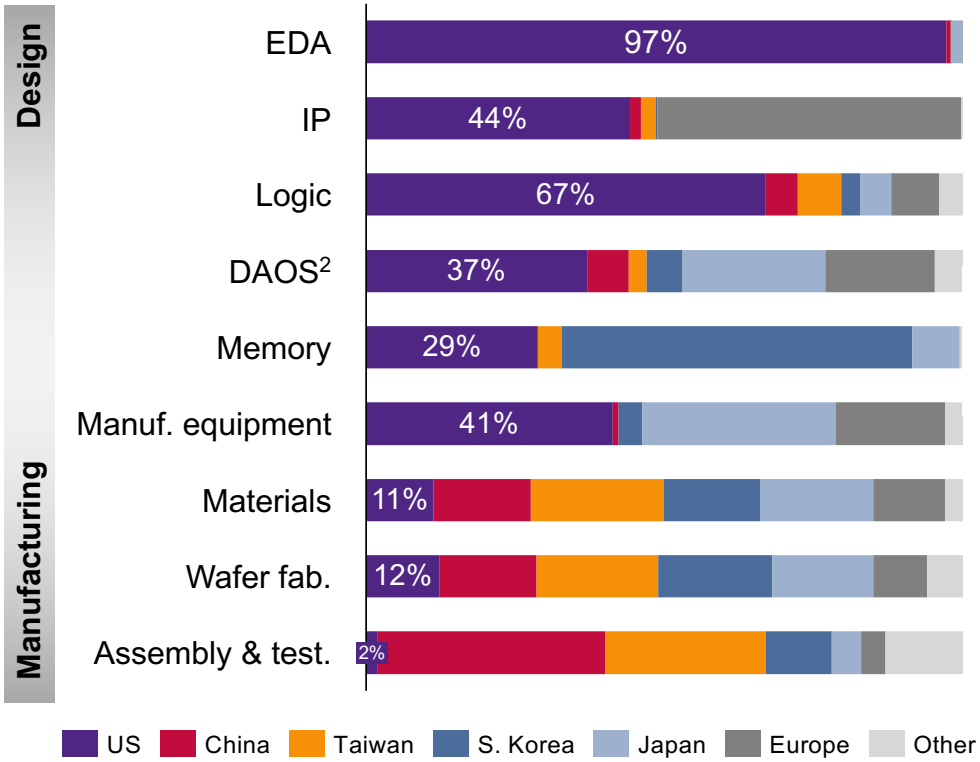
- The U.S. share of commercial semiconductor manufacturing has declined from 37% in 1990 to 12% today
- This decline is largely due to significant incentives offered by our global competitors. As a result, the cost[1] of constructing and operating a semiconductor fabrication facility in the U.S. is 25-50% higher than outside the U.S.

1. based on 10 year total cost of ownership of a new fab

source: SIA

Global Semiconductor Supply Chain

Market shares by country, 2020[1]



Highly globalized supply chain

US-China Frictions

- US export controls
- China indigenization policy

- WFE based on specific technology nodes and end use
- EDA Tools based on specific technology nodes
- Chips based on their performance
- Unverified List and Entity List
- U.S. extraterritorial export controls

1. Based on 2020 revenues grouped by firms' country, except for wafer fabrication and assembly, packaging and testing – which are based on capacity location. Siemens EDA (former Mentor) classified as US firm.
2. Discretes, Analog, Optoelectronics and Sensors Sources: ESDA, IPNest, BCG/SIA, CapitalIQ

The Thinking Behind The U.S. CHIPS Act

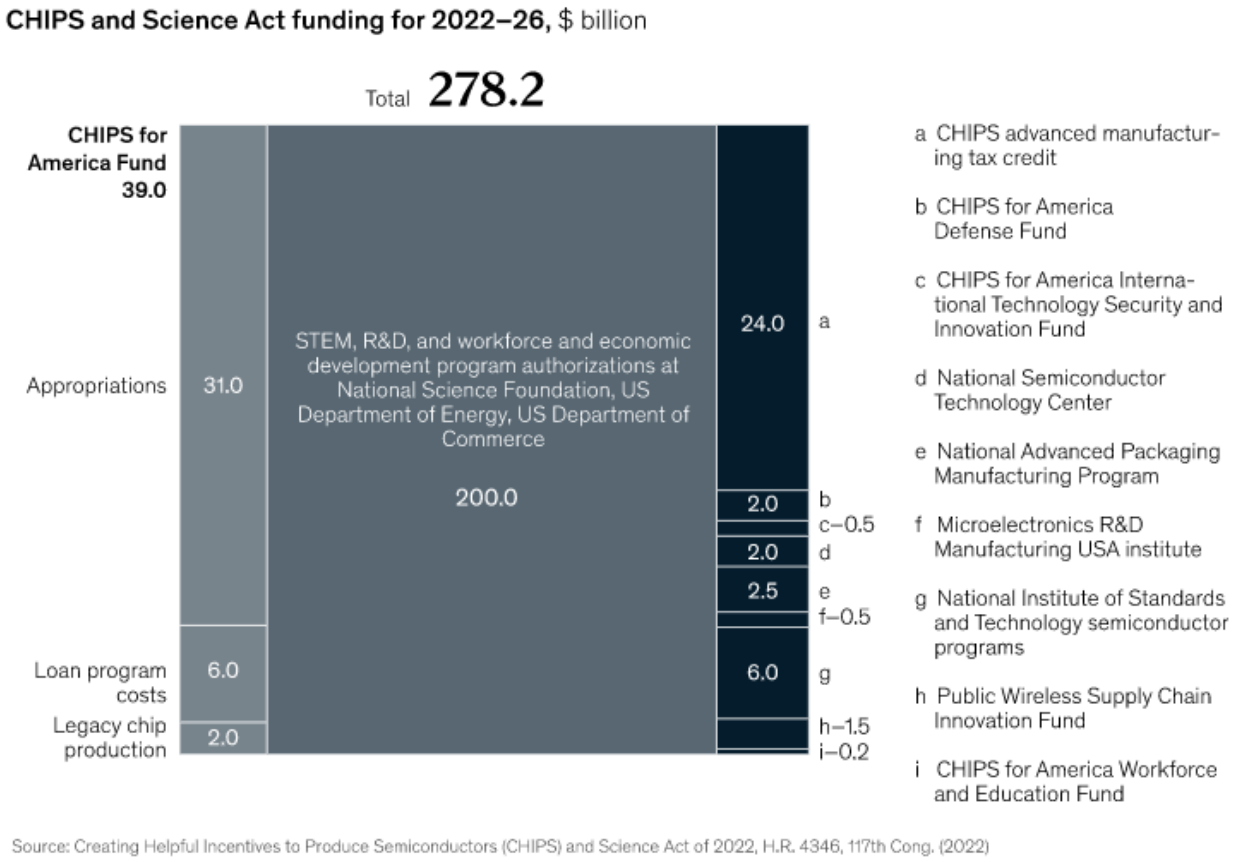
"... a holistic policy approach to maintain U.S. semiconductor leadership"[1]

According to analysis by the Boston Consulting Group, a $50 billion incentive program could make U.S. incentives competitive enough to attract 19 new fabs, or 24% share of the addressable new capacity entering the market in the next decade. This would increase U.S. share of global installed capacity from 12% in 2020 to 13-14% in 2030 and capacity located in the United States by 57%, effectively reversing the prevailing trend over the past 30 years.

1. source: SIA

U.S. CHIPS And Science Funding Act

Enacted August 2022



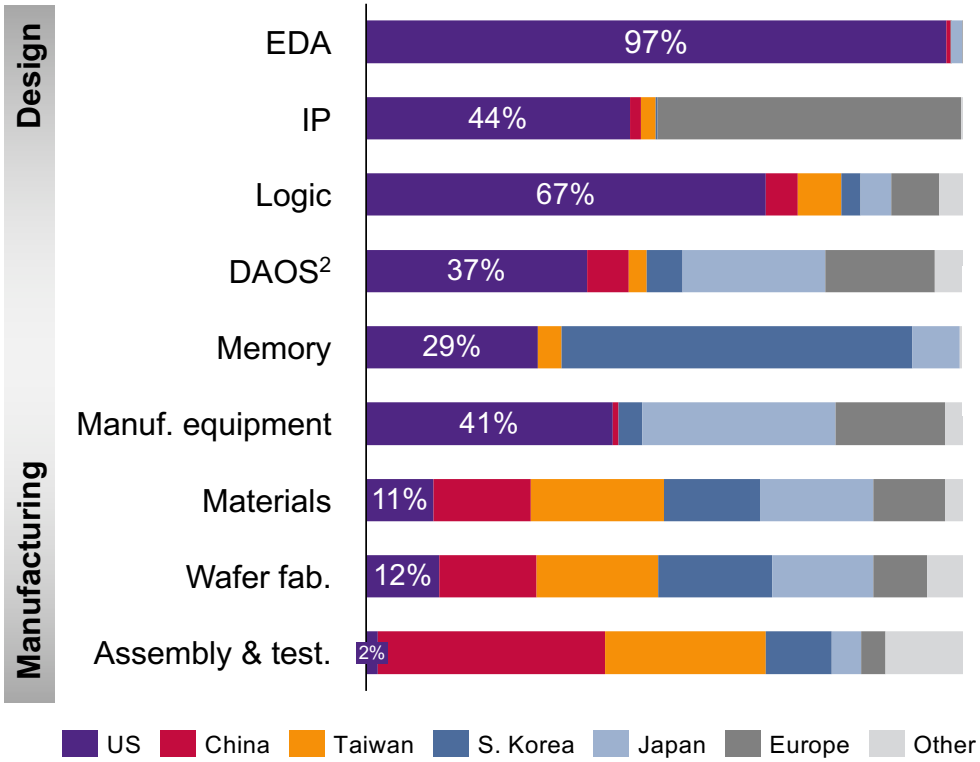
Source: Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022, H.R. 4346, 117th Cong. (2022)

Company	Investment
TSMC	$40,000,000,000
Texas Instruments	$30,000,000,000
Intel	$20,000,000,000
Micron	$20,000,000,000
Intel	$20,000,000,000
Samsung Electronics	$17,300,000,000
Micron	$15,000,000,000
Texas Instruments	$11,000,000,000
Texas Instruments	$6,000,000,000
Wolfspeed	$5,000,000,000
Intel	$3,500,000,000
NXP	$2,600,000,000
EMP Shield	$1,900,000,000
SkyWater	$1,800,000,000
Integra Technologies	$1,800,000,000
Global Foundries	$1,000,000,000
Analog Devices	$1,000,000,000
Microchip	$880,000,000
Microchip	$800,000,000
Pallidus	$443,000,000
Western Digital	$350,000,000
Nhanced Semiconductors	$236,000,000
Rogue Valley Microdevices	$44,000,000
SkyWater	$37,000,000
Trusted Semiconductor Solutions	$34,000,000
Radiation Detection Technologies	$4,000,000
Everspin Technologies	NA

source: SIA, December 2022

Global Semiconductor Supply Chain

Market shares by country, 2020[1]



Highly globalized supply chain

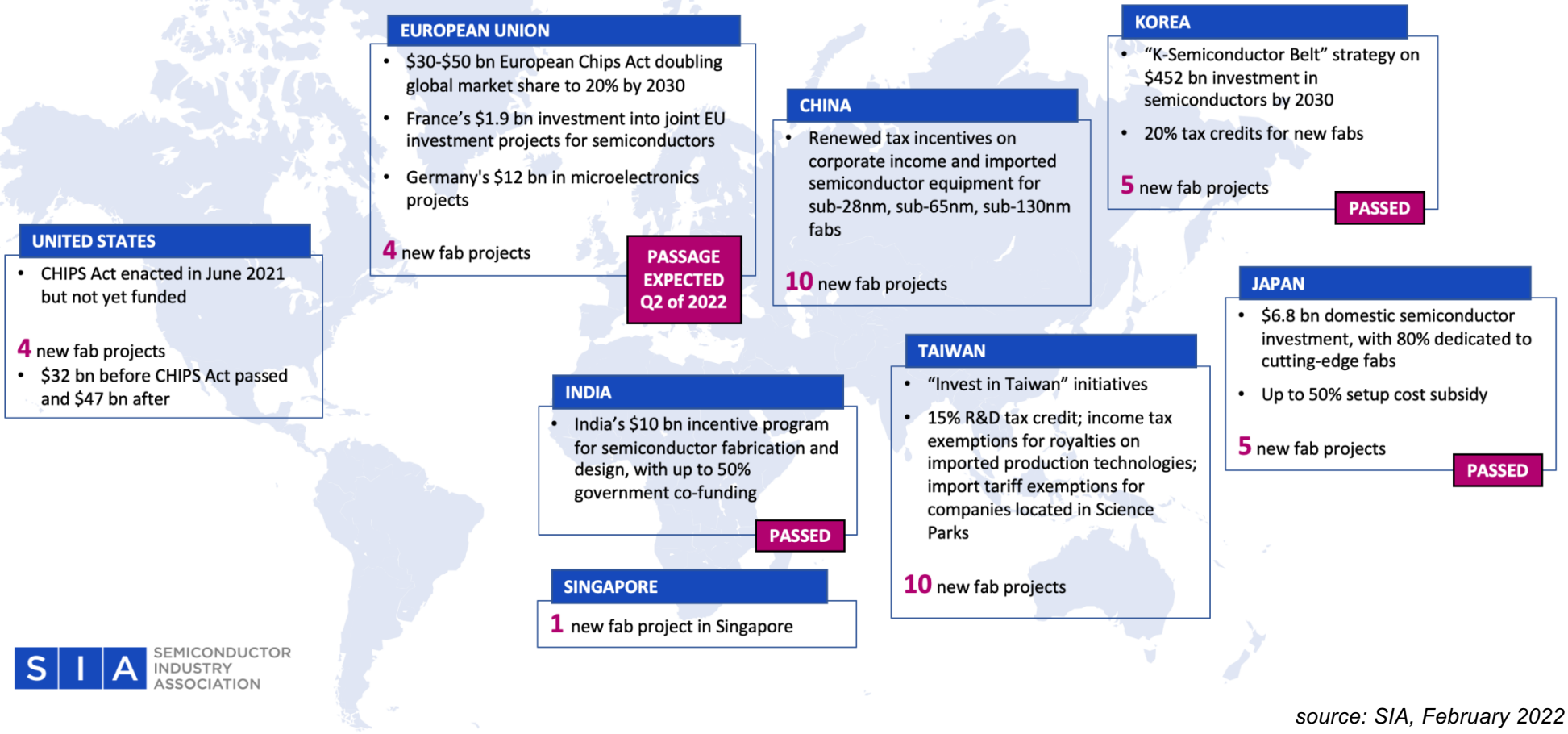
US-China Frictions
- US export controls
- China indigenization policy

CHIPS Acts Around The World
- Global supply resiliency concerns
- National industrial policies

1. Based on 2020 revenues grouped by firms' country, except for wafer fabrication and assembly, packaging and testing – which are based on capacity location. Siemens EDA (former Mentor) classified as US firm.
2. Discretes, Analog, Optoelectronics and Sensors Sources: ESDA, IPNest, BCG/SIA, CapitalIQ

GLOBAL SEMICONDUCTOR FAB INVESTMENT ACTIVITIES

Of the 39 new fab projects announced globally in 2021, only 4 are in the U.S.



UNITED STATES
- CHIPS Act enacted in June 2021 but not yet funded

4 new fab projects
- $32 bn before CHIPS Act passed and $47 bn after

EUROPEAN UNION
- $30-$50 bn European Chips Act doubling global market share to 20% by 2030
- France's $1.9 bn investment into joint EU investment projects for semiconductors
- Germany's $12 bn in microelectronics projects

4 new fab projects

PASSAGE EXPECTED Q2 of 2022

CHINA
- Renewed tax incentives on corporate income and imported semiconductor equipment for sub-28nm, sub-65nm, sub-130nm fabs

10 new fab projects

KOREA
- "K-Semiconductor Belt" strategy on $452 bn investment in semiconductors by 2030
- 20% tax credits for new fabs

5 new fab projects

PASSED

JAPAN
- $6.8 bn domestic semiconductor investment, with 80% dedicated to cutting-edge fabs
- Up to 50% setup cost subsidy

5 new fab projects

PASSED

TAIWAN
- "Invest in Taiwan" initiatives
- 15% R&D tax credit; income tax exemptions for royalties on imported production technologies; import tariff exemptions for companies located in Science Parks

10 new fab projects

INDIA
- India's $10 bn incentive program for semiconductor fabrication and design, with up to 50% government co-funding

PASSED

SINGAPORE
1 new fab project in Singapore

SIA SEMICONDUCTOR INDUSTRY ASSOCIATION

source: SIA, February 2022

CHIPS Act(s) Reshaping The Geographic Footprint

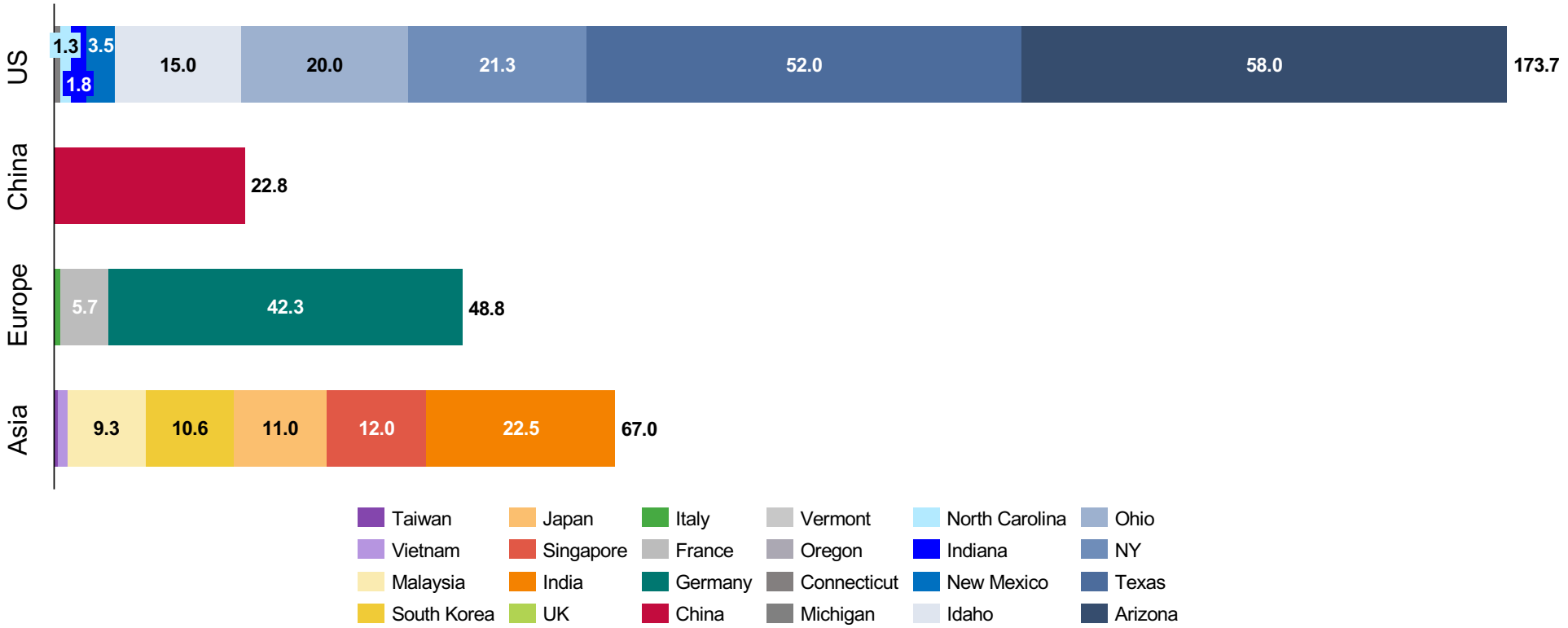
New fabs starting construction in 2021 through 2023

Location	#fabs
United States	18
China	20
Europe/Middle East	17
Taiwan	14
Japan/Southeast Asia	6
South Korea	3

source: SEMI World Fab Forecast Report, 4Q22 update

CHIPS Act(s) Reshaping The Geographic Footprint

New manufacturing, design facilities and fabs announced[1] in 2021 and 2022 [$B]



1. Includes prominent announcement of new manufacturing and design facilities and fabs announced in 2021 and 2022, not exclusive as some companies do not disclose investment details. Additional TSMC investment in Arizona included ($28bn) as announced in Dec 2022, additional Samsung investment in Texas (beyond $17bn in Taylor) not included as not formally announced. Source: Where All The Semiconductor Investments Are Going (semiengineering.com) (Nov 2022); announcement on TSMC's additional investment in Arizona

U.S. CHIPS Act(s) Reshaping The Geographic Footprint

Imposing investment restrictions in China, among other countries

South China Morning Post | Source: https://scmp.com/tech/tech-war/article/3214733/tech-war-proposed-us-guardrails-new-semiconductor-investment-china-block-tsmc-samsung-expansion

Tech/ Tech War

Tech war: proposed US 'guardrails' on new chip investment in China to block TSMC, Samsung expansion plans on mainland

The proposed guidelines bar companies receiving US Chips and Science Act subsidies from using the funds for projects in China, Russia, Iran and North Korea

The new rules threaten to block major chip makers such as TSMC, Samsung and SK Hynix from expanding their existing production facilities in China

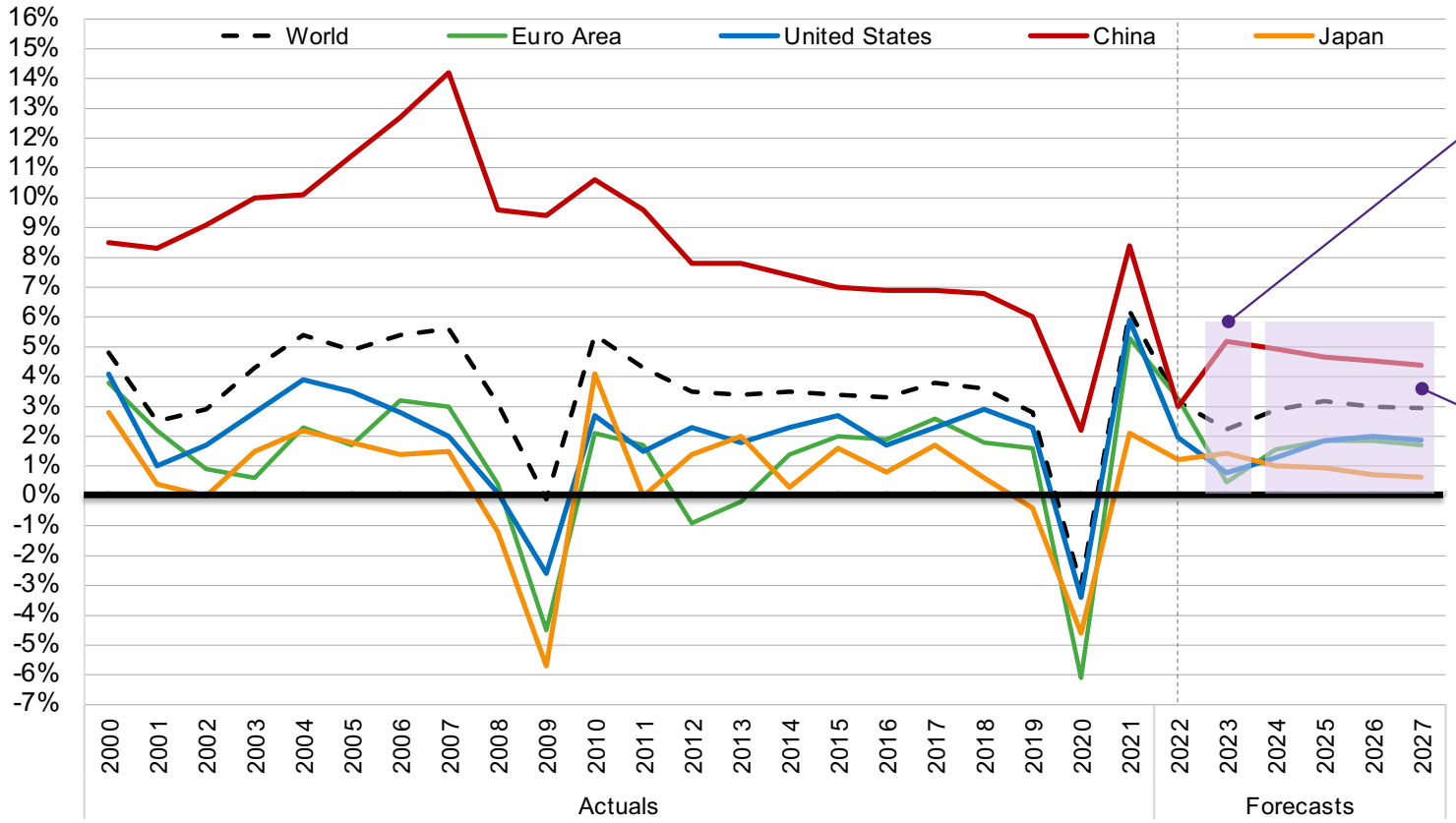
Lilian Zhang + FOLLOW

Published: 10:30pm, 24 Mar, 2023

Why you can trust SCMP

Global Economy Entering New Period Of Slower Growth

Real GDP annual percent change



2023 Outlook

- Further slow down expected in US and Europe – but not a lasting recession…
- … partially compensated by rebound in China

Medium-term forecasts

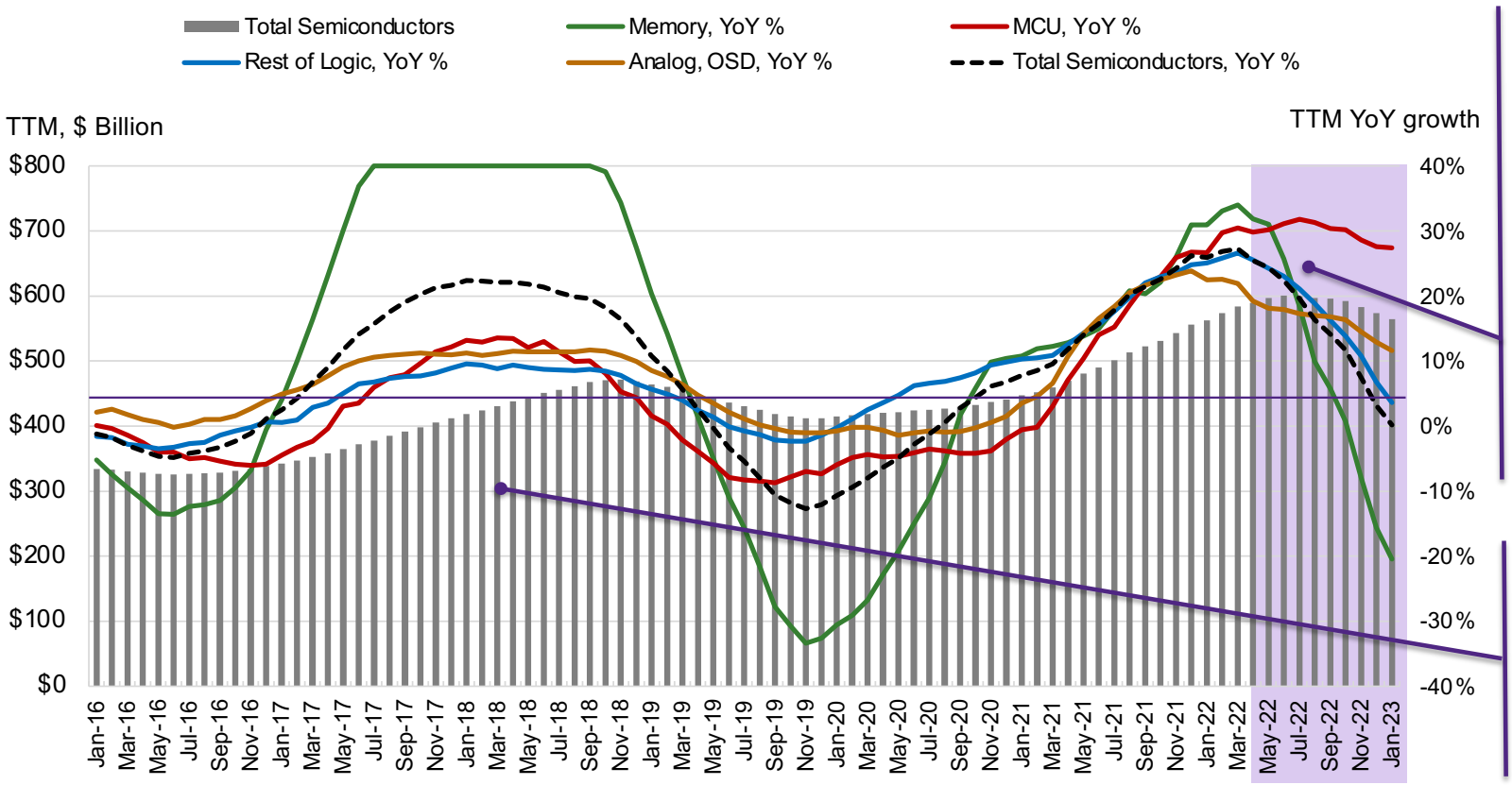
Global GDP growth in 2024-27 ~0.5 pp below pre-COVID years

- Interest rates at ~4%
- China sliding down towards 4.5% GDP growth
- Deglobalization
- Demographic constraints
- Green energy transition

sources: Historical: IMF. Forecasts: consensus of IMF/Jan'23, World Bank/Jan'23, EIU/Feb'23, KPMG/Jan'23, S&P Global/Mar'23, OECD/Mar'23, Bloomberg/Mar'23.

Semiconductors In Downward Phase Since CY22 Q2

Global semiconductor sales (TTM)



CY22 ended with +3% growth … but that hides underlying dynamics

- Entered CY22at +20%, peaked in Q1, and then fast correction to exit year at -18%
- Memory and advanced logic experiencing more rapid drops
- MCUs (driven by Auto and Industrial) holding better, but small portion of demand

We have seen this before!

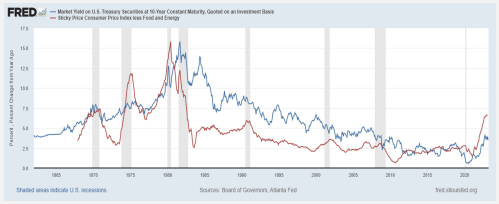
- As recently as 2018-19
- In last 20 years, annual decline every 2-3 years on average

Source: SIA, Mar 2023

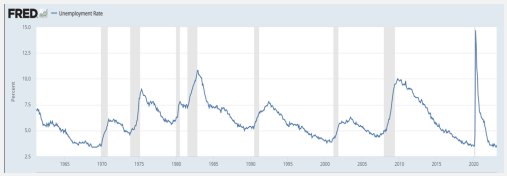
Note: For visualization purposes, YoY variation rates are displayed in a range from -40% to +40% Source: SIA/WSTS

Uncertain Macro Environment – As Illustrated By U.S. Data

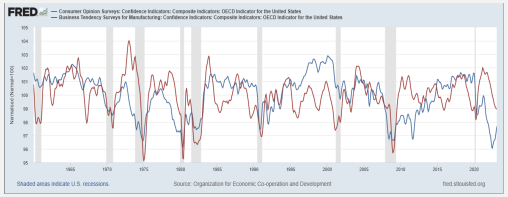
Inflation peaked, but remains high despite fast-paced Fed rate hikes



Despite layoffs in the news, unemployment at historical low



Consumer, business confidence moving in opposite directions



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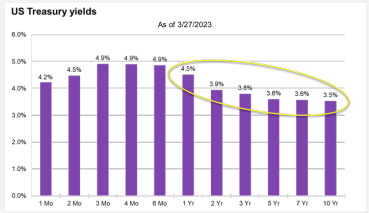
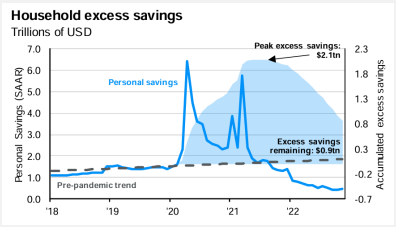
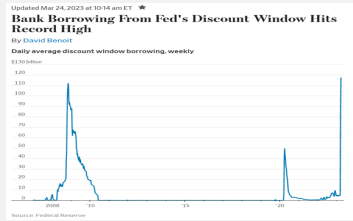
Treasury yield curve inverted, implying Fed may reverse in 2 Qs



Consumers still with ~40% of pandemic excess savings to burn



Potential risk of banking crisis adds new source of uncertainty

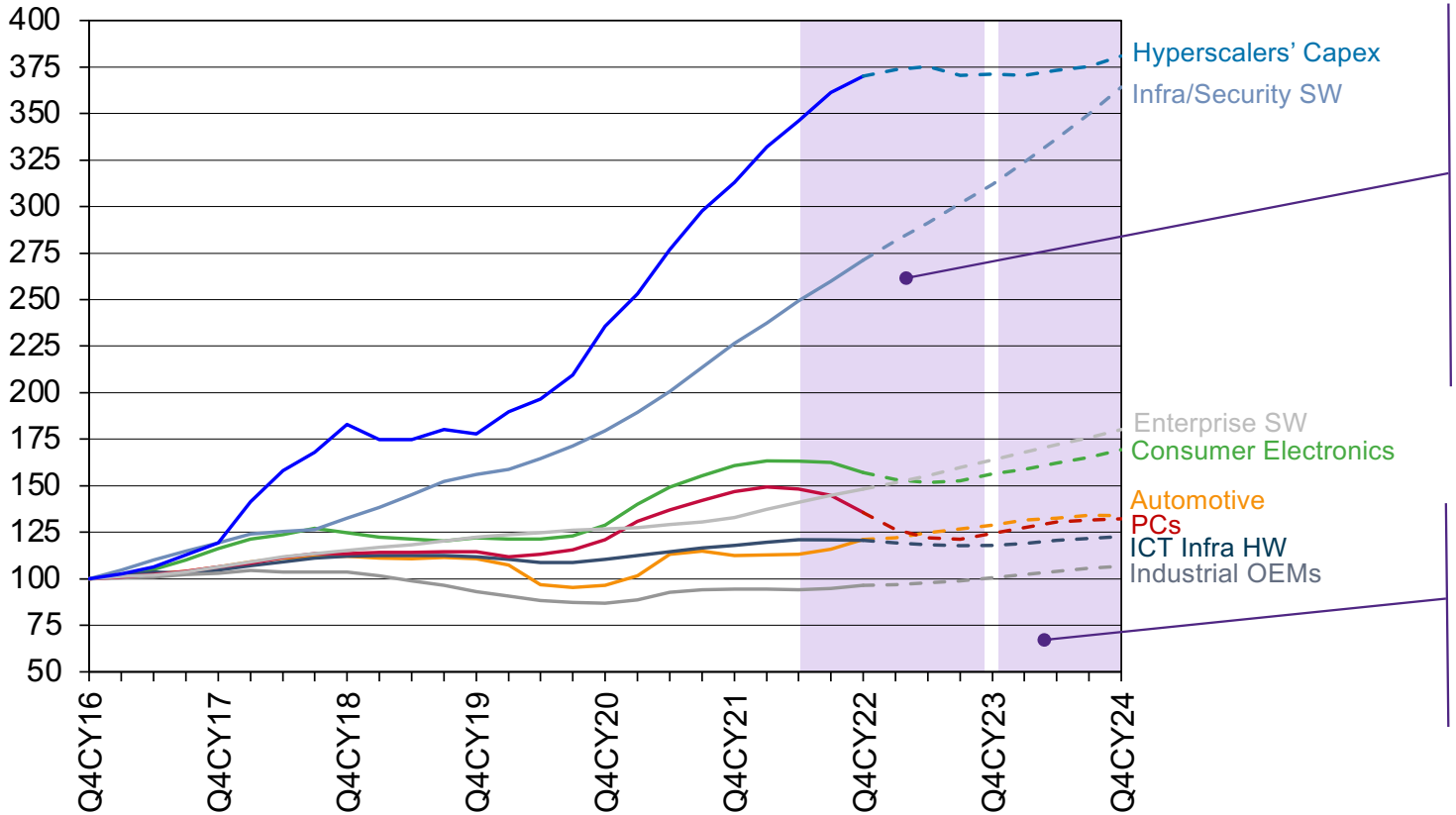


Probability of recession in the US currently assessed at 35-65%[1]

Sources: Bloomberg, Goldman Sachs, New York Federal Reserve, Bankrate

Despite Macro Uncertainty, Tech Outlook Remains Strong

TTM revenues of sample of leading Tech companies (indexed 2016=100)



source: Capital IQ consensus forecasts, company reports, Mar 2023

2023 Outlook

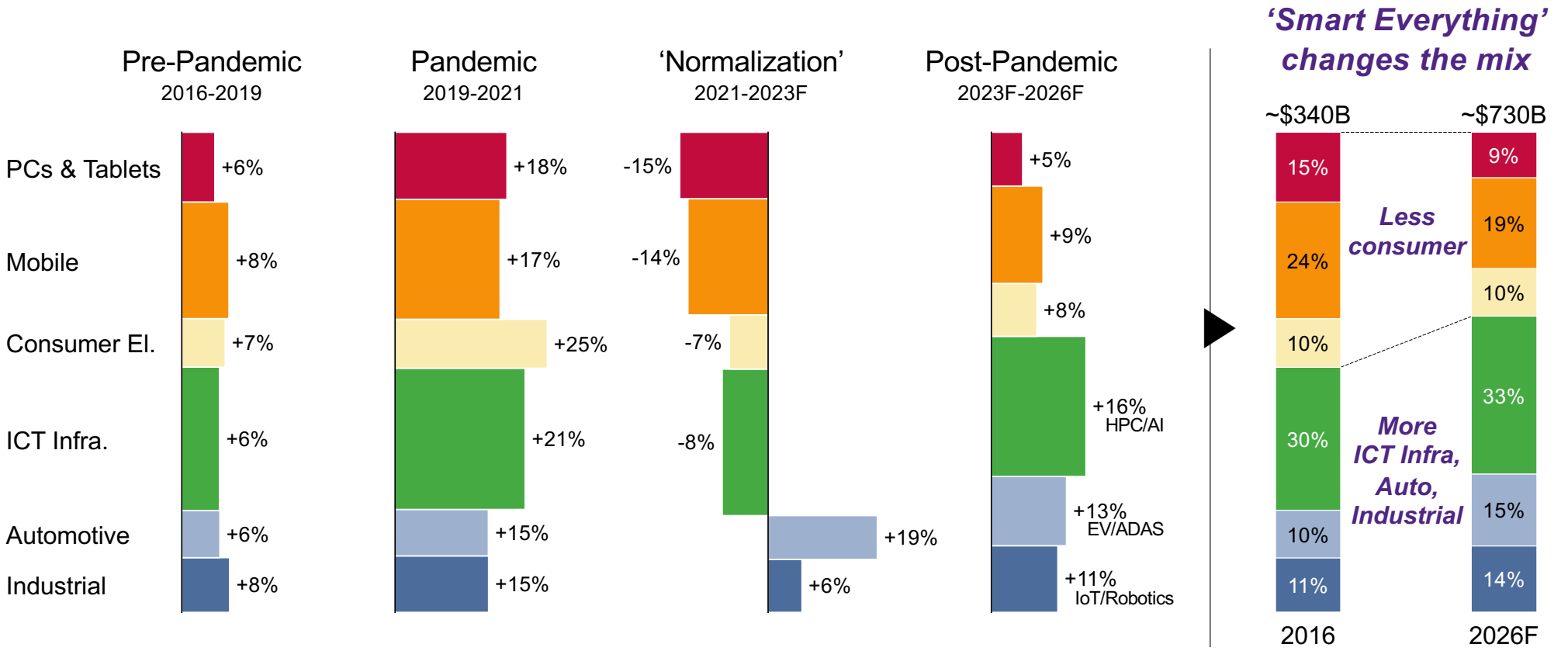
- Post-COVID normalization…
  - Fading of one-off drivers of strong demand in 2020-21 (particularly for Consumer Electronics and PCs)
  - Auto and Industrial rebounding after chip supply shortage
- … and some softness linked to macroeconomic concerns

Medium-term trend

- Structural trends drive growth in line/above 2017-19 levels…
- … except PCs: do not get back to 2022 peak

Drivers of Semiconductor Demand Growth Are Shifting

Growth in total global semiconductor sales by end application market[1]

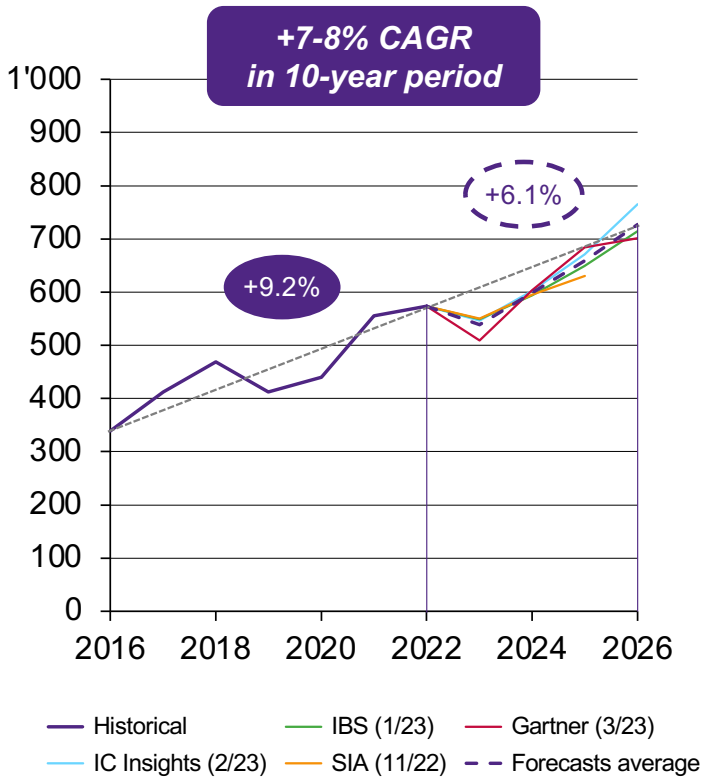


[1]Bar height = CAGR in period; bar width = % of total semi sales in first year of period

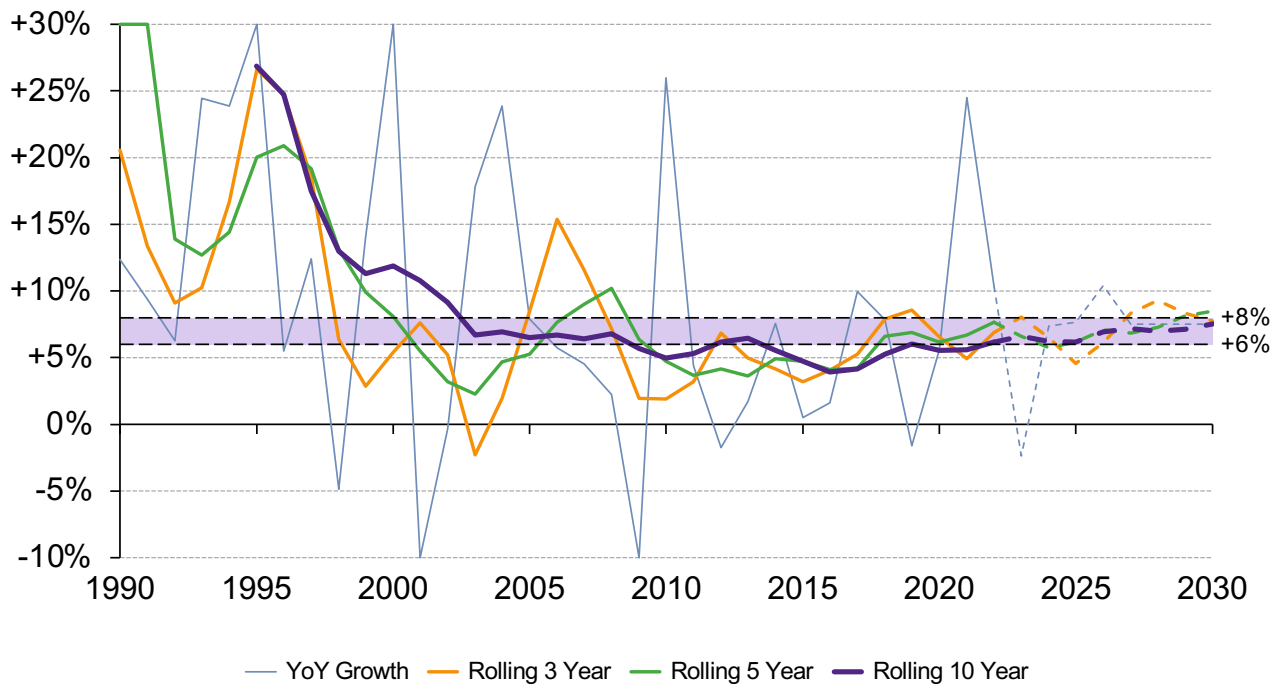
sources: Gartner (3/23)

Medium-Term Forecasts Show Continued Growth Acceleration

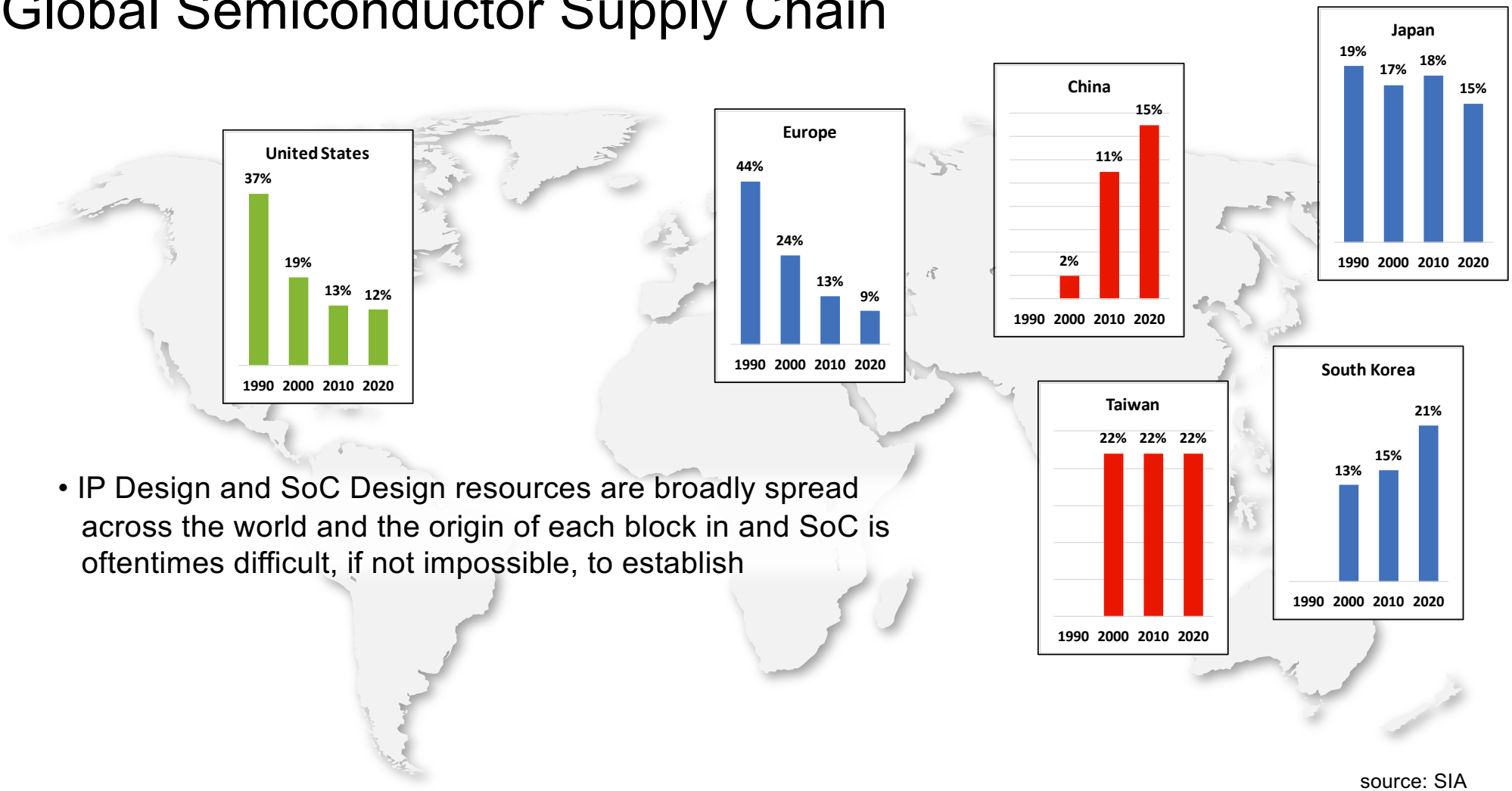
Semiconductor sales forecasts
$ Billion



YoY growth of multi-year rolling global semiconductor sales (excluding memory)



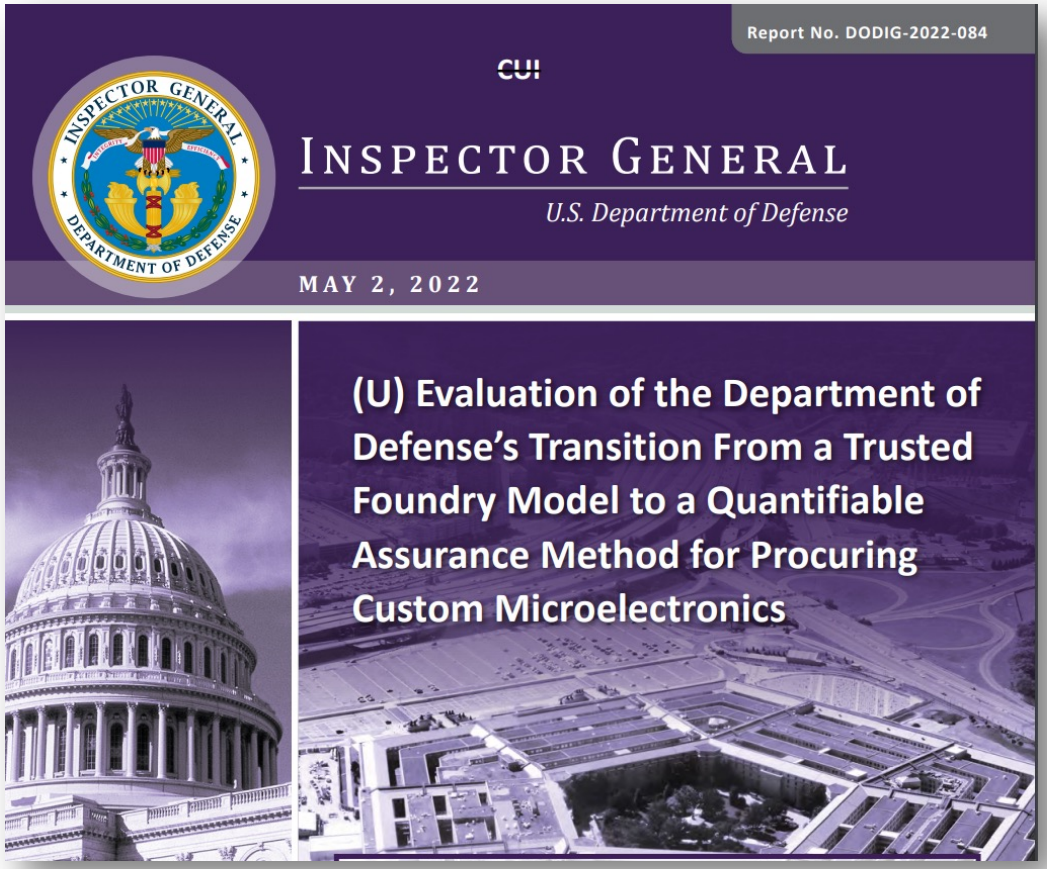
Global Semiconductor Supply Chain



- IP Design and SoC Design resources are broadly spread across the world and the origin of each block in and SoC is oftentimes difficult, if not impossible, to establish

source: SIA

Transitioning From a Trusted Foundry Model To a Quantifiable Assurance Method for Procuring Custom Microelectronics



(U) The Trusted Foundry Is No Longer Viable for Custom State-of-the-Art Microelectronics Procurement

(U) The current DoDI 5200.44 relies on domestic and accredited facilities to protect custom microelectronic components with specific military end-use by manufacturing microelectronics in a trusted foundry. However, OUSD(R&E) personnel told us and provided documentation and background briefings that identified that this policy is no longer viable for adoption by microelectronics foundries for two reasons.

1. (U) Modern state-of-the-art fabrication facilities cannot succeed in the commercial marketplace if they meet DoDI 5200.44 trusted foundry requirements for the following reasons.
   a. (U) Engineering skillsets required for a successful fabrication facility are so specialized that they can only be obtained through a global workforce. As a result, there are no state-of-the-art facilities that are DMEA-accredited trusted foundries.

"DMEA" - Defense Microelectronics Activity

Semiconductor Supply Chain Thread Model

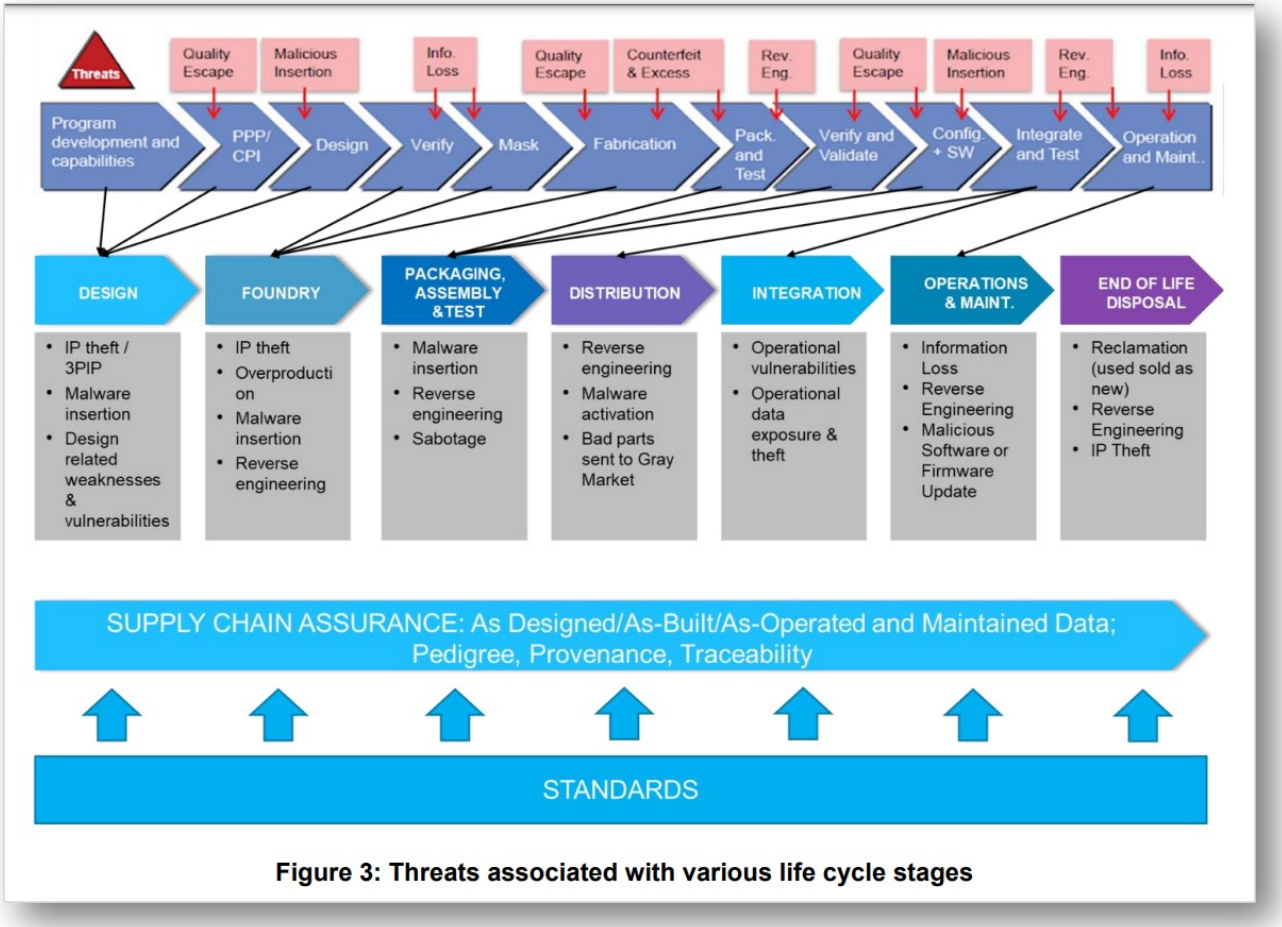


Figure 3: Threats associated with various life cycle stages

NDIA

Zero Trust for Hardware Supply Chains: Challenges in Application of Zero Trust Principles to Hardware

White Paper

Electronics Division
October 2021

A discussion of the Zero Trust and Quantifiable Assurance concepts as related to microelectronics to promote broader dialog on the complexities facing the Defense Industrial Base regarding these controversial topics.

President's Council of Advisors on Science and Technology

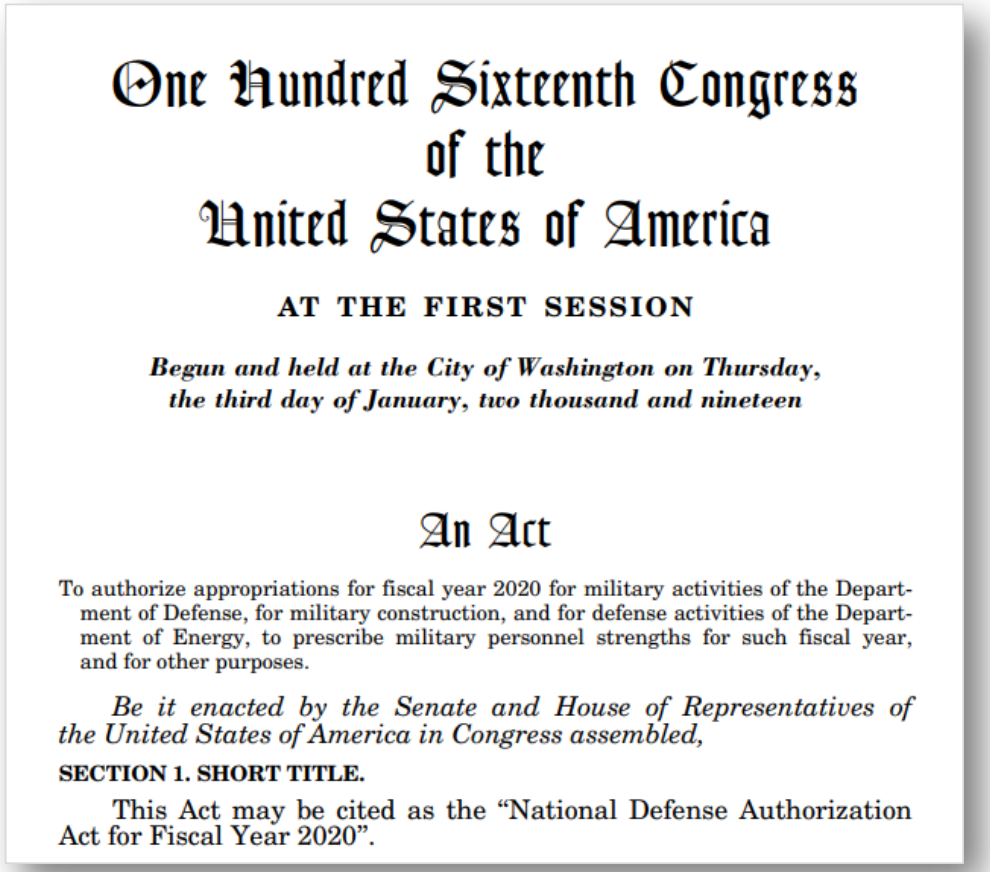
(e) Semiconductors and System Security

Criminal and state-sponsored cyber-attacks pose increasing threats to the United States. To enable the implementation of secure systems, every aspect of the system must be considered including sensors, data converters, computing, memory, storage, and communications, while providing robustness against side-channel attacks and ensuring security of supply chains. There is a tremendous opportunity for the design of secure semiconductor chips. To maximize effectiveness, security must be pursued as an integral part of design, not as an add-on after the chip is designed.

Academia, industry and government stakeholders have an opportunity to standardize a trusted approach for systems implementation. The specific opportunity is to bring together algorithm and software/systems designers with chip designers in a center of excellence, to develop the next generation of secure systems. Although open-source security approaches are the best for innovation and transparency, they remain unpalatable for the industry. We must address this reluctance in a way that enables the United States to continue to be the global leader in standardized security approaches.

We envision a research agenda in this area that should include, but is not limited to, the following: (1) design for fully secure end-to-end hardware and software solutions that are secure against various forms of attacks on operation, data, and communications; (2) security in the chip design tool chain that would enable end-to-end security solutions to be verified by design; (3) secure hardware supply chain covering chip fabrication, packaging, and system integration; (4) implementation of post-quantum cryptography; (5) implementation of low-power cryptography for secure communications and transactions; and (6) other privacy preserving hardware implementations for processing encrypted data.

National Defense Authorization Act, 2020 - Section 224



One Hundred Sixteenth Congress
of the
United States of America

AT THE FIRST SESSION

Begun and held at the City of Washington on Thursday, the third day of January, two thousand and nineteen

An Act

To authorize appropriations for fiscal year 2020 for military activities of the Department of Defense, for military construction, and for defense activities of the Department of Energy, to prescribe military personnel strengths for such fiscal year, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "National Defense Authorization Act for Fiscal Year 2020".

SEC. 224. REQUIRING DEFENSE MICROELECTRONICS PRODUCTS AND SERVICES MEET TRUSTED SUPPLY CHAIN AND OPERATIONAL SECURITY STANDARDS.

(a) PURCHASES.—To protect the United States from intellectual property theft and to ensure national security and public safety in the application of new generations of wireless network technology and microelectronics, beginning no later than January 1, 2023, the Secretary of Defense shall ensure that each microelectronics product or service that the Department of Defense purchases on or after such date meets the applicable trusted supply chain and operational security standards established pursuant to subsection (b), except in a case in which the Department seeks to purchase a microelectronics product or service but—

(1) no such product or service is available for purchase that meets such standards; or

(2) no such product or service is available for purchase that—

(A) meets such standards; and

(B) is available at a price that the Secretary does not consider prohibitively expensive.

(b) TRUSTED SUPPLY CHAIN AND OPERATIONAL SECURITY STANDARDS.—

(1) STANDARDS REQUIRED.—(A) Not later than January 1, 2021, the Secretary shall establish trusted supply chain and operational security standards for the purchase of microelectronics products and services by the Department.

(B) For purposes of this section, a trusted supply chain and operational security standard—

(i) is a standard that systematizes best practices relevant to—

(I) manufacturing location;

(II) company ownership;

(III) workforce composition;

(IV) access during manufacturing, suppliers' design, sourcing, manufacturing, packaging, and distribution processes;

(V) reliability of the supply chain; and

(VI) other matters germane to supply chain and operational security; and

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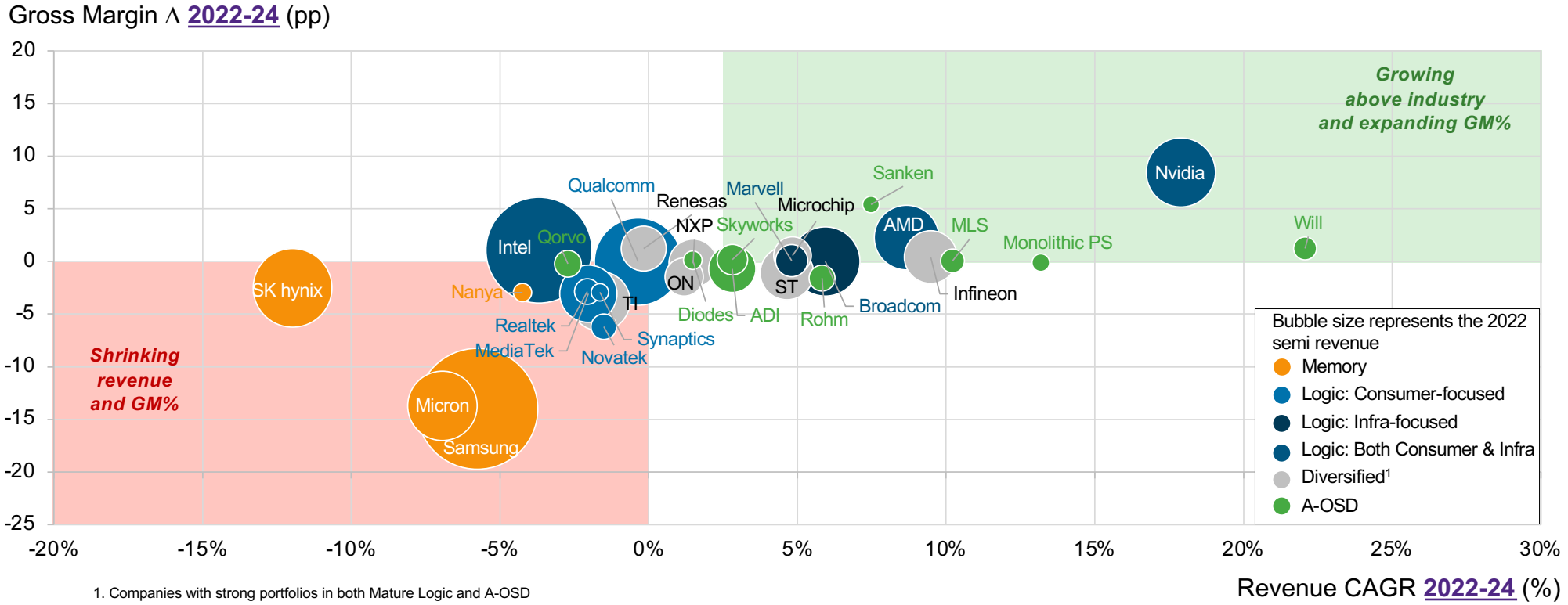
Latest export controls and restrictions imposed by the U.S. government will have a major impact on capex. 1, 2 These restrictions impose controls on WFE that can be exported to China from the U.S. based on specific technology nodes and end use. There are also controls on the sale of certain chips based on their performance to China. The U.S. government has updated the unverified list and continues to do that on a regular basis, while also adding domestic Chinese companies on the entity list.

source: Gartner

Memory And Consumer-Focused Players Under Most Pressure

Consensus forecasts for largest public semiconductor companies

Top 30 companies accounting for ~70% of industry revenue



1. Companies with strong portfolios in both Mature Logic and A-OSD

… But Full 5-Year Cycle Is Positive For Most Companies

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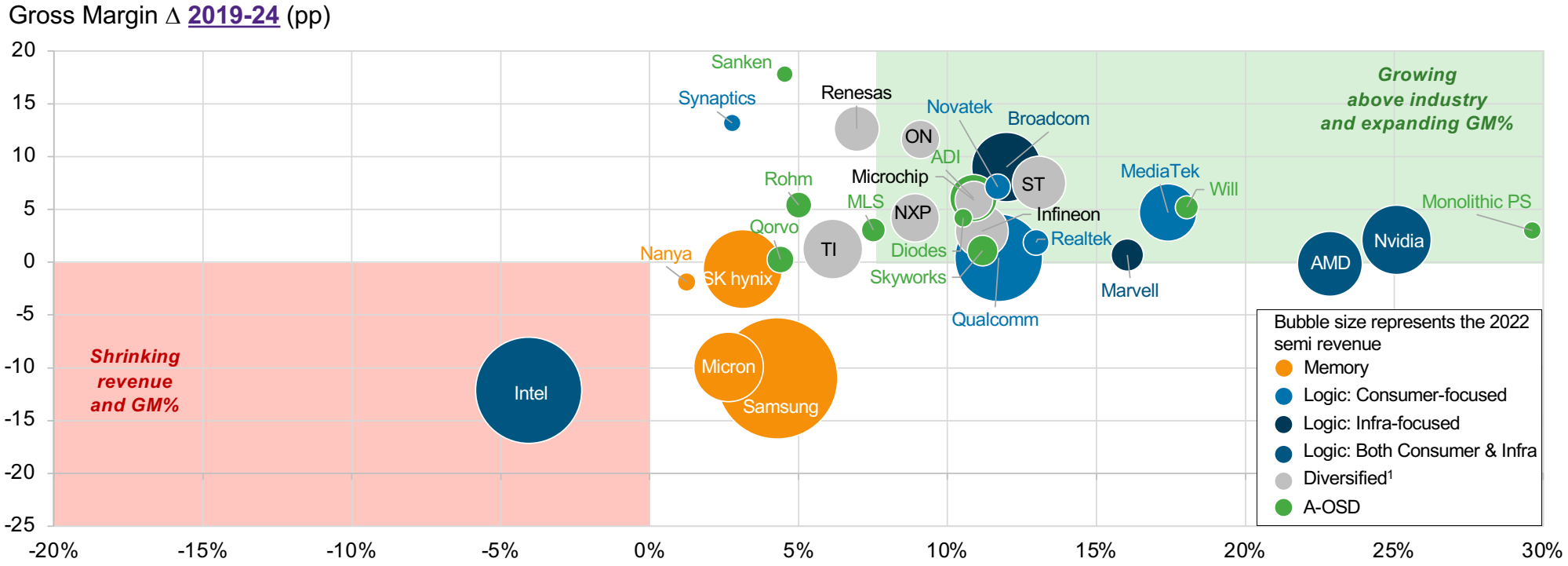

1. Companies with strong portfolios in both Mature Logic and A-OSD