引領半導體未來：
台灣的創新突破和全球競爭的挑戰

Konrad Young
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楊光磊 Konrad Young

現任：台灣大學 領導學程、重點科技研究學院 兼任教授
逢甲大學 創能學院 講座教授
- 「台灣ICT產業鏈之連結與前瞻專題」

政治大學 IMBA, 國際創新學院 兼任教授
- 「Semiconductor industry in the era of techno-geopolitics”

LeadBest Consulting Group 資深顧問、
LeadAgilex 產業賦能加速平台 合夥創辦人、
商業思維學院 Mentor 、新加坡GIC外部顧問

經歷：半導體產業37年、 Intel 資深顧問、台積電全球研發處長、
其他5家美國/新加坡/台灣半導體公司技術運營經理人
鼎恒科技獨立董事、中芯半導體 獨立董事

Konrad Young

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大綱

- 全球半導體產業的天時地利人和
- 上天賜福的台灣半導體產業: 創新突破
- 台灣半導體產業未來全球競爭的挑戰
- 總結, Q&A

天時 Time

以銅為鏡，可以正衣冠
以史為鏡，可以知興替

全球半導體產業簡史(I)

- Early Beginnings (Early to Mid-20th Century)
  - 1904: Development of the vacuum tube.
  - 1947: Invention of the point-contact transistor by John Bardeen and Walter Brattain at Bell Labs.
  - 1948: Invention of the junction transistor by William Shockley.
- The Transistor Era (Late 1940s to Early 1960s)
  - 1950s: Mass production of transistors begins.
  - 1956: Shockley, Bardeen, and Brattain win the Nobel Prize in Physics for their work on semiconductors.
  - 1957: Transistor radio becomes a popular consumer product.

全球半導體產業簡史(II)

- The Integrated Circuit Revolution (Mid-1950s to 1970s)
    - 1958: Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor independently invent the integrated circuit (IC)
    - 1960s: Rapid development of IC technology leads to smaller, more powerful devices
    - 1971: Intel introduces the 4004, the world's first microprocessor
- DRAM Development (1960s to 1970s)
    - 1966: Robert H. Dennard at IBM invented the one-transistor dynamic memory cell, the foundation for DRAM technology. 1967: IBM introduced the first commercial DRAM chip.
    - 1970s: DRAM technology rapidly evolved, with increasing density and decreasing cost.
- Early Foundry Beginnings (1960s to 1970s)
    - 1960s: The concept of semiconductor foundries began to emerge as companies specialized in manufacturing ICs for other companies.
    - 1970s: Early foundries focused on producing simple ICs for various applications.

全球半導體產業簡史(III)

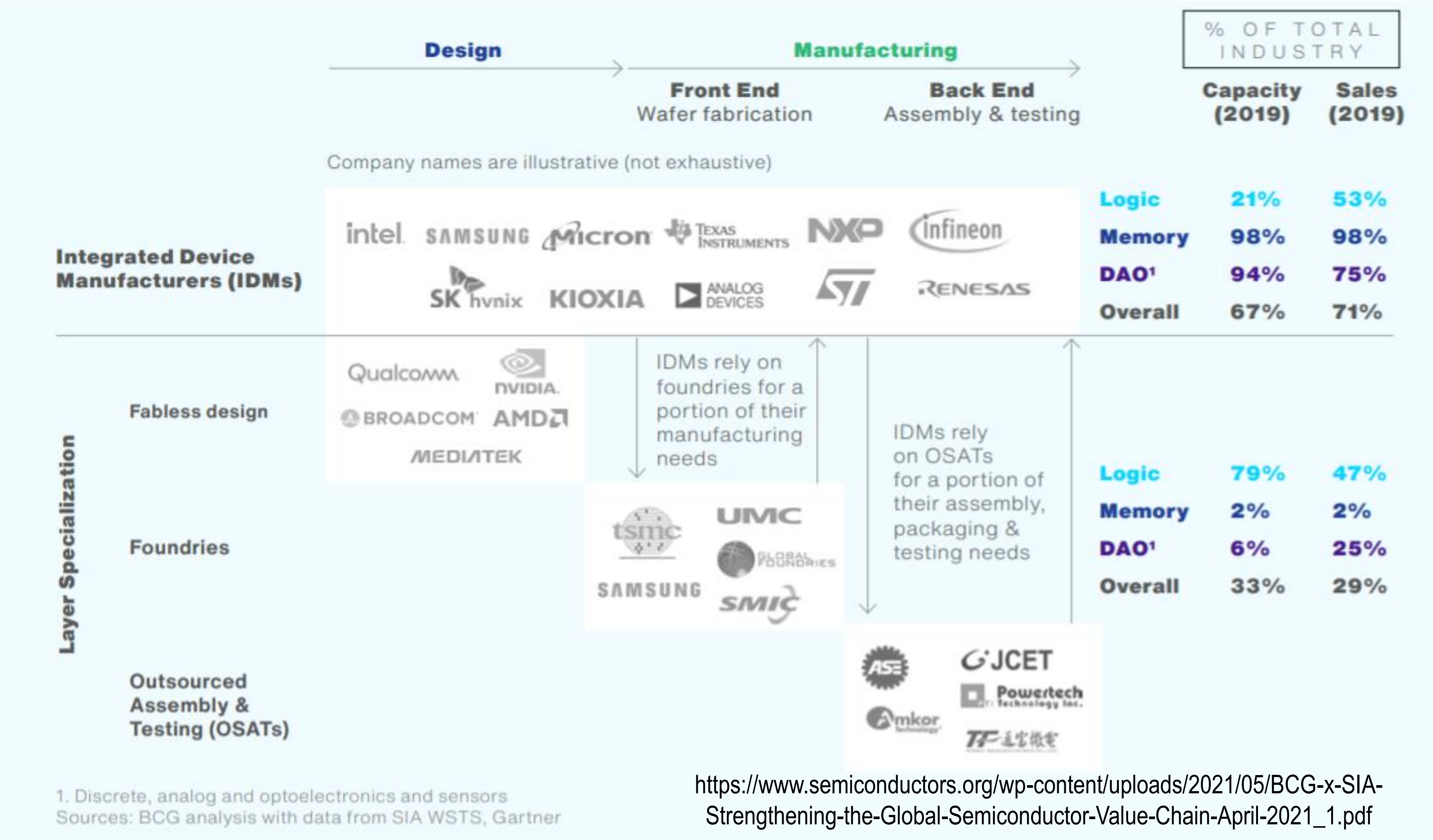
- The Japanese, then Korean DRAM Dominance (1980s to 2000s)
  - 1980s: Japanese companies, such as Toshiba, Hitachi, and NEC, gained a significant market share in DRAM production.
  - 1990s: The Japanese dominance continued, although Korean & American companies fight to gain their market shares.
  - 2000s: Korean companies continued to invest heavily in DRAM technology, eventually surpassing Japanese.
- The Modern Semiconductor Era (2000s to Present)
  - 2000s: Rising foundry/fabless model for logic products.
  - 2010s: Continued miniaturization of semiconductors leads to the development of smartphones and other mobile devices.
  - 2020s: Global semiconductor shortages highlight the industry's critical role in the global economy. The Internet of Things (IoT) and artificial intelligence (AI) drive demand for semiconductors.
  - The US-China conflicts lead to global semiconductor geo-political issues

全球半導體產業的天時

- **美國**
  - 1990年代全球化趨勢、美國製造業外移
  - 成也摩爾、敗也摩爾
    - ✓ 定律/標準助力Fabless 的產業分工
- **日本**
  - 地緣政治1.0: 美國80年代後期的棒打出頭鳥
  - 失落30年的日本半導體產業

IDM - 成也摩爾、敗也摩爾

順勢而為：生態圈定律的重要



Design → Manufacturing →

Front End: Wafer fabrication

Back End: Assembly & testing

Company names are illustrative (not exhaustive)

Integrated Device Manufacturers (IDMs): intel, SAMSUNG, Micron, Texas Instruments, NXP, infineon, SK hynix, KIOXIA, Analog Devices, ST, Renesas

Layer Specialization

- **Fabless design**: Qualcomm, NVIDIA, BROADCOM, AMD, MEDIATEK
- **Foundries**: tsmc, UMC, SAMSUNG, GLOBALFOUNDRIES, SMIC
- **Outsourced Assembly & Testing (OSATs)**: ASE, JCET, Amkor, Powertech Technology Inc., 通富微电

IDMs rely on foundries for a portion of their manufacturing needs

IDMs rely on OSATs for a portion of their assembly, packaging & testing needs

% OF TOTAL INDUSTRY

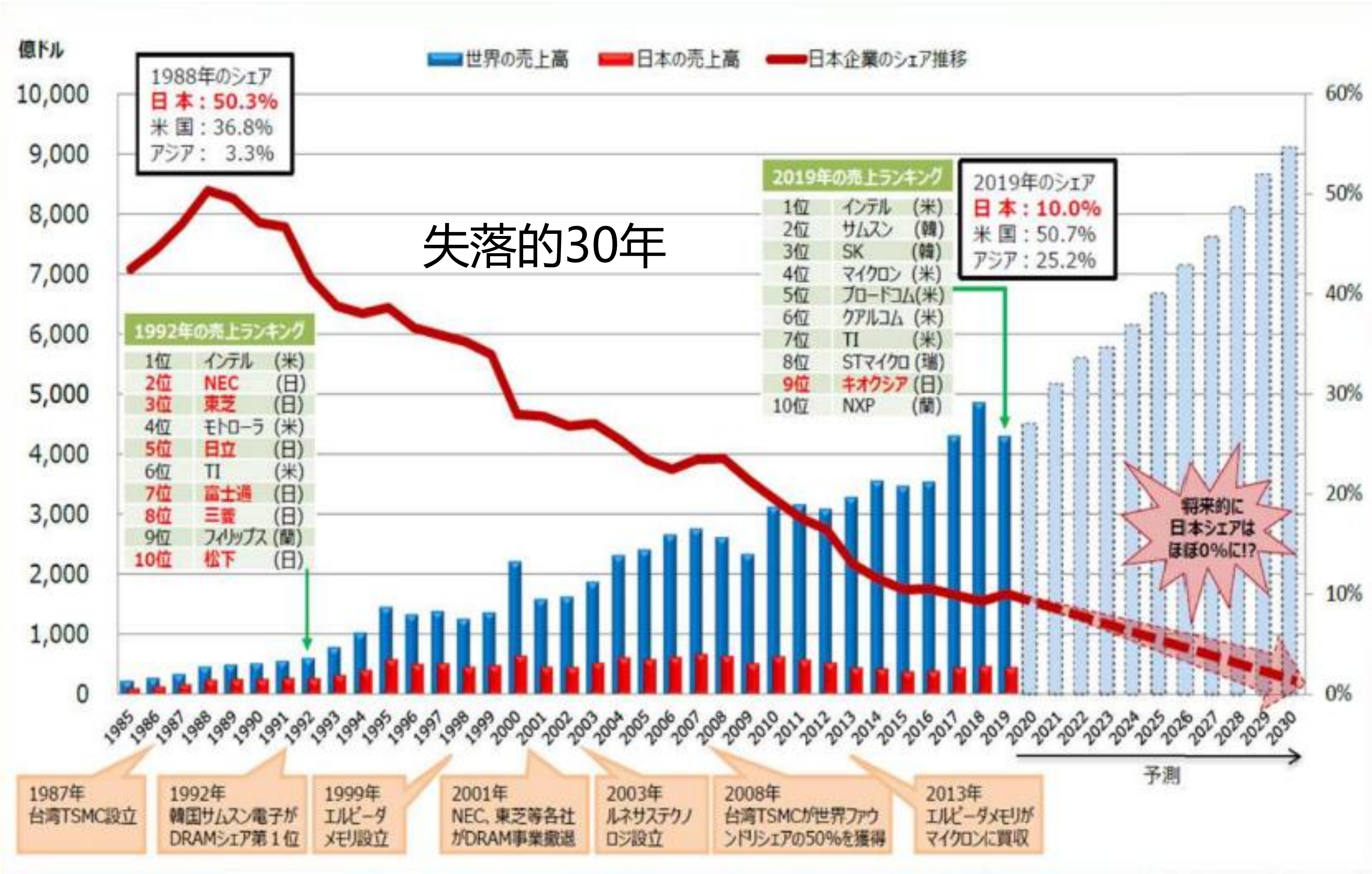
		Capacity (2019)	Sales (2019)
Integrated Device Manufacturers (IDMs)	Logic	21%	53%
	Memory	98%	98%
	DAO¹	94%	75%
	Overall	67%	71%
Layer Specialization	Logic	79%	47%
	Memory	2%	2%
	DAO¹	6%	25%
	Overall	33%	29%

1. Discrete, analog and optoelectronics and sensors

Sources: BCG analysis with data from SIA WSTS, Gartner

https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

日本半導體產業歷史



1988年のシェア
日 本：50.3%
米 国：36.8%
アジア： 3.3%

1992年の売上ランキング

1位	インテル	(米)
2位	**NEC**	(日)
3位	**東芝**	(日)
4位	モトローラ	(米)
5位	**日立**	(日)
6位	TI	(米)
7位	**富士通**	(日)
8位	**三菱**	(日)
9位	フィリップス	(蘭)
10位	**松下**	(日)

2019年の売上ランキング

1位	インテル	(米)
2位	サムスン	(韓)
3位	SK	(韓)
4位	マイクロン	(米)
5位	ブロードコム	(米)
6位	クアルコム	(米)
7位	TI	(米)
8位	STマイクロ	(瑞)
9位	**キオクシア**	(日)
10位	NXP	(蘭)

2019年のシェア
日 本：10.0%
米 国：50.7%
アジア：25.2%

将来的に
日本シェアは
ほぼ0%に!?

1987年
台湾TSMC設立

1992年
韓国サムスン電子が
DRAMシェア第１位

1999年
エルピーダ
メモリ設立

2001年
NEC、東芝等各社
がDRAM事業撤退

2003年
ルネサステクノ
ロジ設立

2008年
台湾TSMCが世界ファウ
ンドリシェアの50%を獲得

2013年
エルピーダメモリが
マイクロンに買収

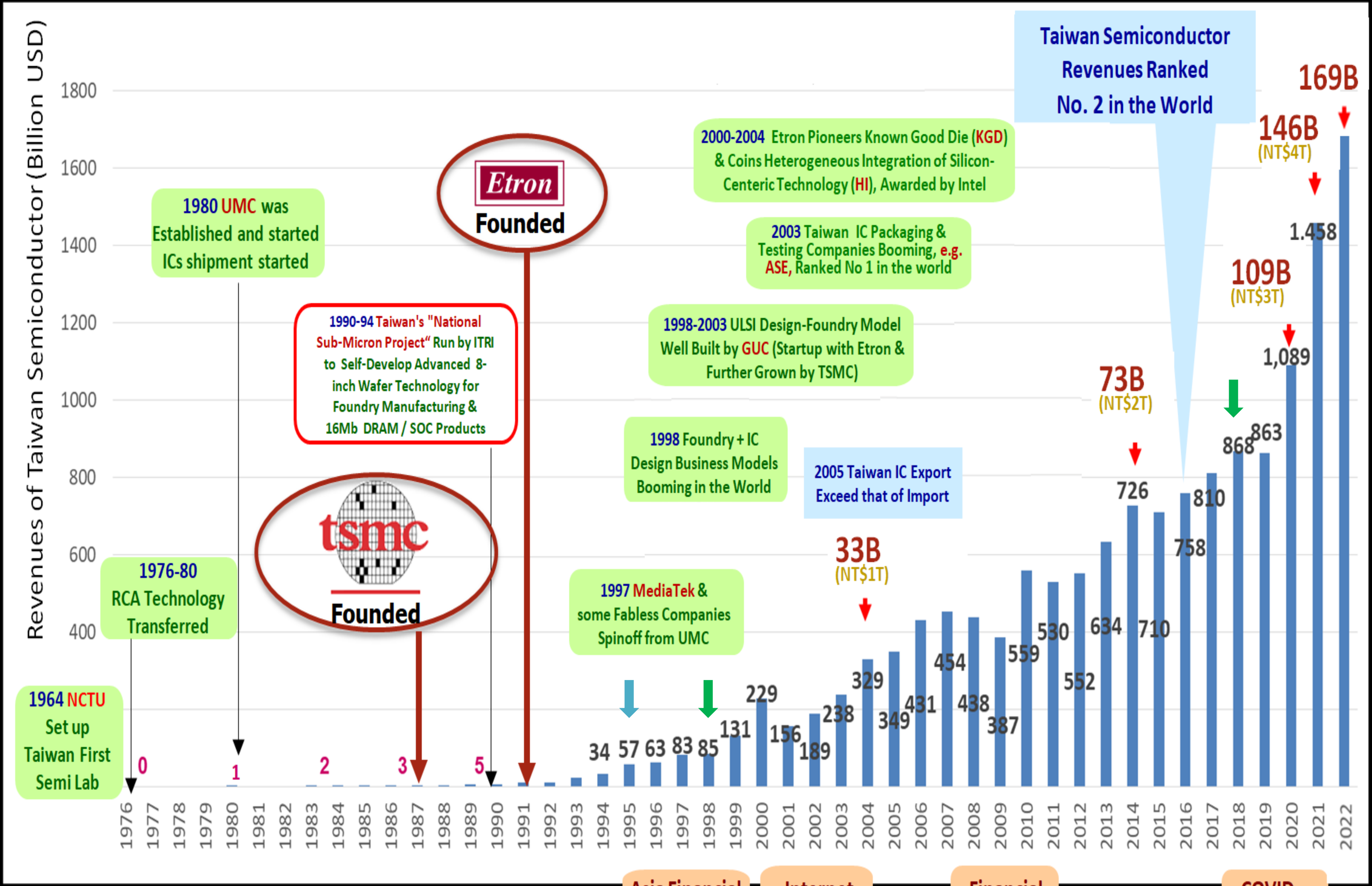
失落的30年

Source: 日本經濟產業省 MITI (Ministry of International Trade and Industry)

上天賜福的台灣半導體產業

- 基礎數理教育孕育的台灣理工人才
  - 30年儲備的全美半導體大聯盟人才庫，在工作中培養格局能力
    - ✓ 1990年代台灣股票分紅制度驅動的海歸潮
  - 20年工研院培養的本地人才、在1995年前後結合爆發
  - 1995年後半導體產業高速發展、留住更多本土人才
- 錯位發展:不強出頭、起始極少全球競爭的晶圓代工產業
- Covid造成的全球供應斷鏈，凸顯台灣半導體產業的重要

Growth of Taiwan Semiconductor Industry & Key Milestones



1964 NCTU Set up Taiwan First Semi Lab

1976-80 RCA Technology Transferred

1980 UMC was Established and started ICs shipment started

1990-94 Taiwan's "National Sub-Micron Project" Run by ITRI to Self-Develop Advanced 8-inch Wafer Technology for Foundry Manufacturing & 16Mb DRAM / SOC Products

1997 MediaTek & some Fabless Companies Spinoff from UMC

1998 Foundry + IC Design Business Models Booming in the World

1998-2003 ULSI Design-Foundry Model Well Built by GUC (Startup with Etron & Further Grown by TSMC)

2003 Taiwan IC Packaging & Testing Companies Booming, e.g. ASE, Ranked No 1 in the world

2000-2004 Etron Pioneers Known Good Die (KGD) & Coins Heterogeneous Integration of Silicon-Centeric Technology (HI), Awarded by Intel

2005 Taiwan IC Export Exceed that of Import

Taiwan Semiconductor Revenues Ranked No. 2 in the World

Asia Financial Crisis

Internet Bubble

Financial Tsunami

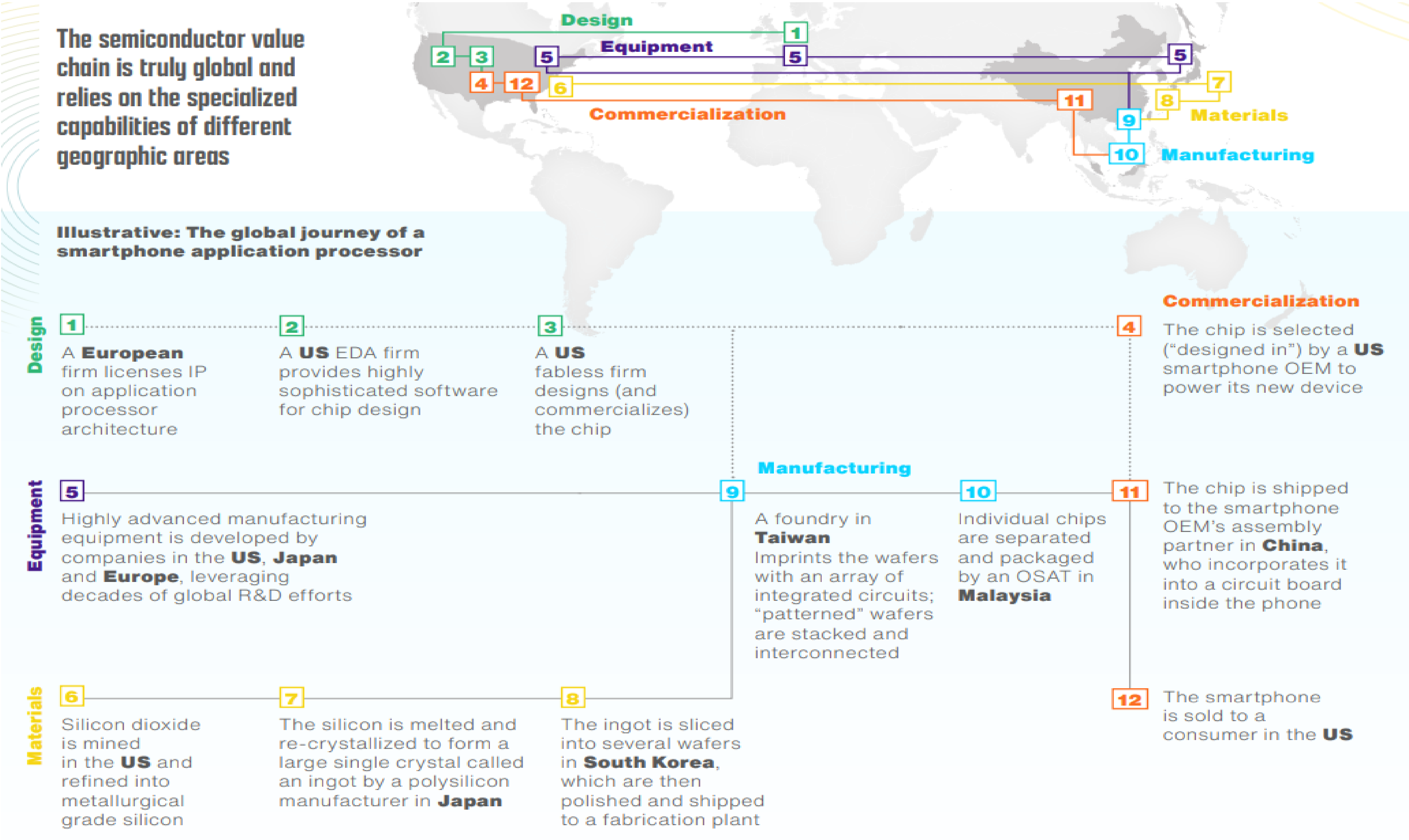
COVID Pandemic

Source：ITRI (2023), Etron

地利 Location/Environment

軍備競賽
全球資源的競爭

Global Semiconductor Supply Chain



The semiconductor value chain is truly global and relies on the specialized capabilities of different geographic areas

Illustrative: The global journey of a smartphone application processor

Design

1 A **European** firm licenses IP on application processor architecture

2 A **US** EDA firm provides highly sophisticated software for chip design

3 A **US** fabless firm designs (and commercializes) the chip

Commercialization

4 The chip is selected ("designed in") by a **US** smartphone OEM to power its new device

Equipment

5 Highly advanced manufacturing equipment is developed by companies in the **US**, **Japan** and **Europe**, leveraging decades of global R&D efforts

Materials

6 Silicon dioxide is mined in the **US** and refined into metallurgical grade silicon

7 The silicon is melted and re-crystallized to form a large single crystal called an ingot by a polysilicon manufacturer in **Japan**

8 The ingot is sliced into several wafers in **South Korea**, which are then polished and shipped to a fabrication plant

Manufacturing

9 A foundry in **Taiwan** Imprints the wafers with an array of integrated circuits; "patterned" wafers are stacked and interconnected

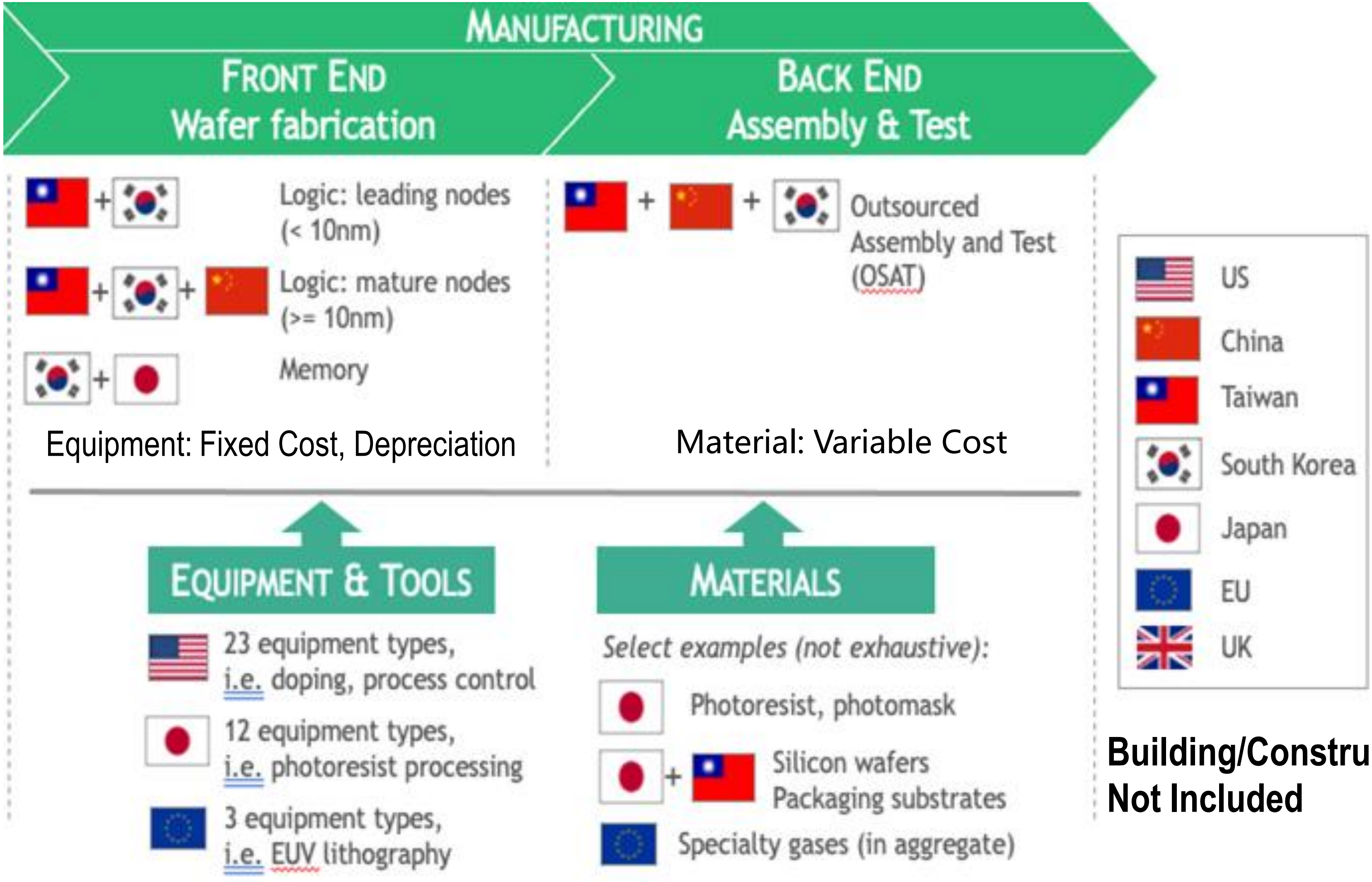
10 Individual chips are separated and packaged by an OSAT in **Malaysia**

11 The chip is shipped to the smartphone OEM's assembly partner in **China**, who incorporates it into a circuit board inside the phone

12 The smartphone is sold to a consumer in the **US**

https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/

Global Supply Chain of Semiconductor Manufacturing



MANUFACTURING

FRONT END
Wafer fabrication

🇹🇼 + 🇰🇷 Logic: leading nodes (< 10nm)

🇹🇼 + 🇰🇷 + 🇨🇳 Logic: mature nodes (>= 10nm)

🇰🇷 + 🇯🇵 Memory

Equipment: Fixed Cost, Depreciation

BACK END
Assembly & Test

🇹🇼 + 🇨🇳 + 🇰🇷 Outsourced Assembly and Test (OSAT)

Material: Variable Cost

EQUIPMENT & TOOLS

🇺🇸 23 equipment types, i.e. doping, process control

🇯🇵 12 equipment types, i.e. photoresist processing

🇪🇺 3 equipment types, i.e. EUV lithography

MATERIALS

Select examples (not exhaustive):

🇯🇵 Photoresist, photomask

🇯🇵 + 🇹🇼 Silicon wafers
Packaging substrates

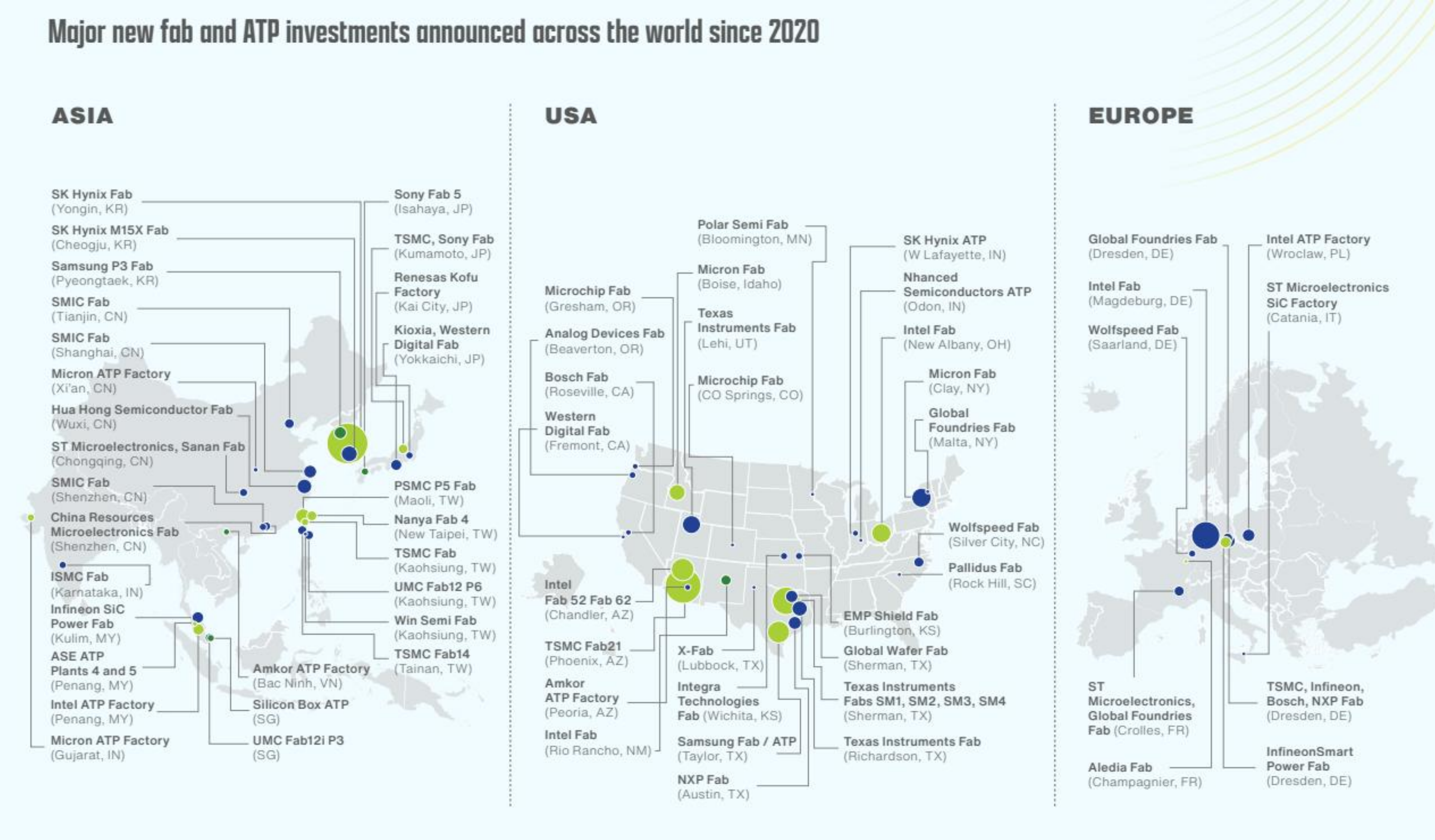
🇪🇺 Specialty gases (in aggregate)

🇺🇸	US
🇨🇳	China
🇹🇼	Taiwan
🇰🇷	South Korea
🇯🇵	Japan
🇪🇺	EU
🇬🇧	UK

Building/Construction Not Included

https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/

Global IC Fab Distribution

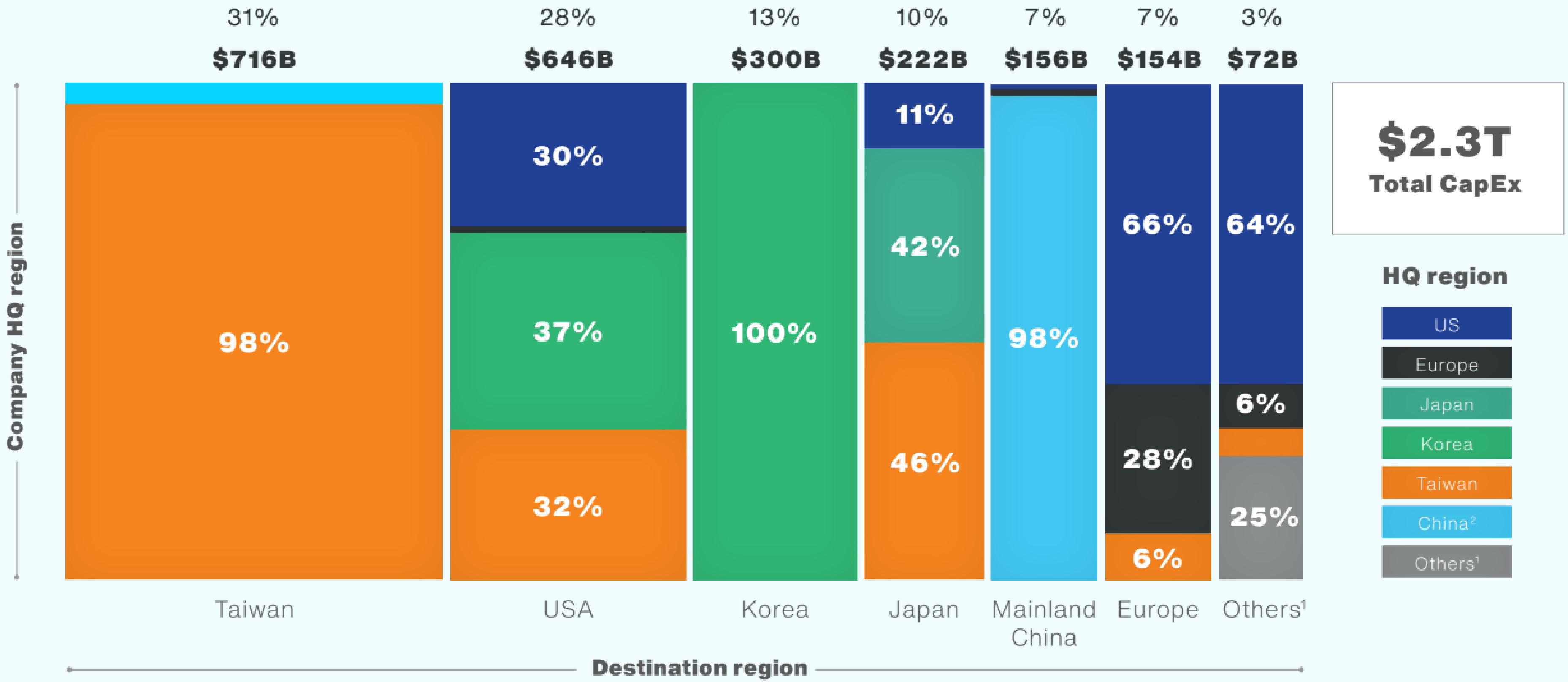


Major new fab and ATP investments announced across the world since 2020

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

Global Semiconductor CapEx Distribution

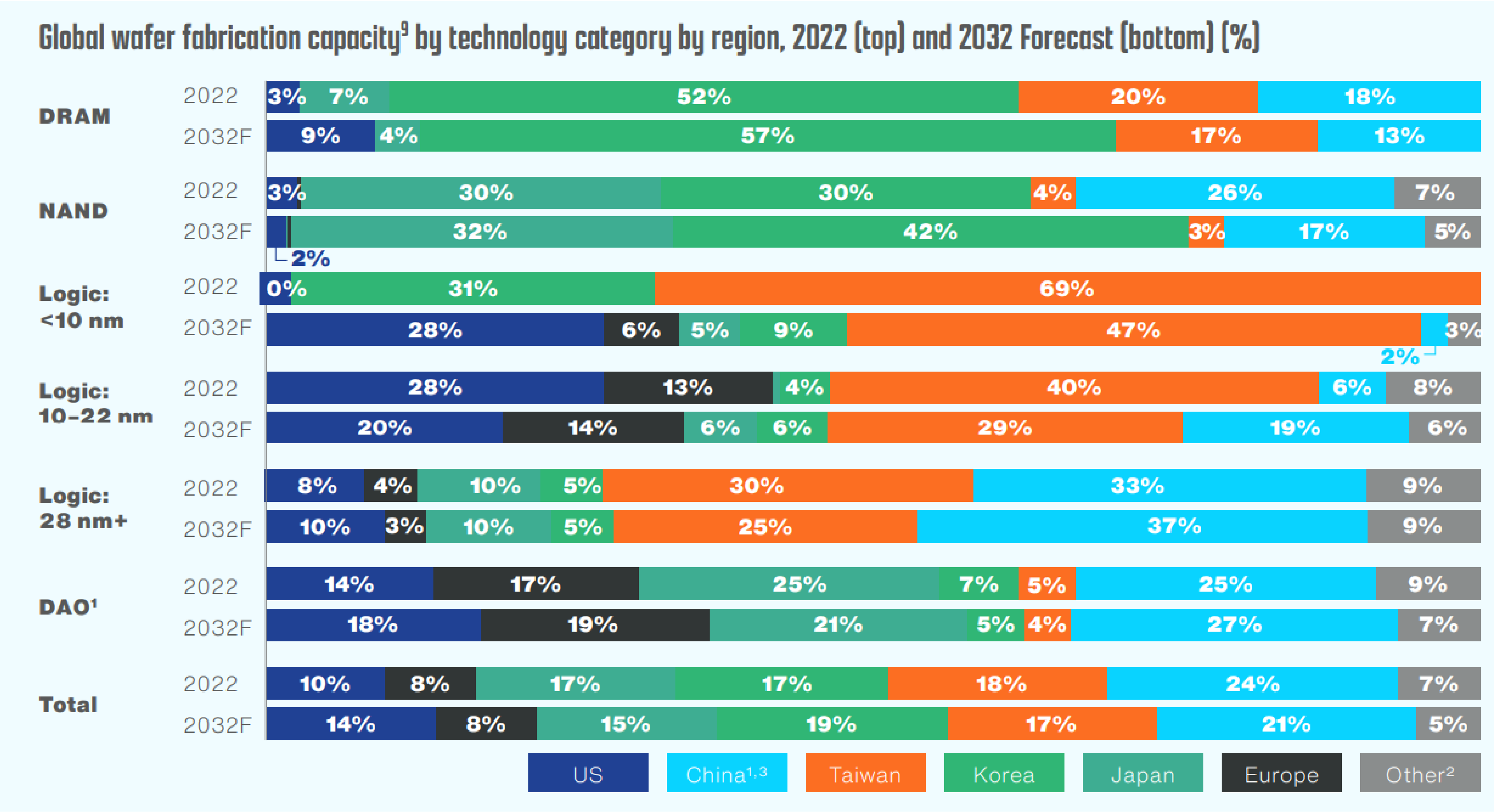
Future flows of CapEx[6] from company HQ region to destination region, 2024-2032F



1. Others includes Israel, Malaysia, Singapore, India and the rest of the world
2. Mainland China
Source: SEMI; BCG Analysis

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

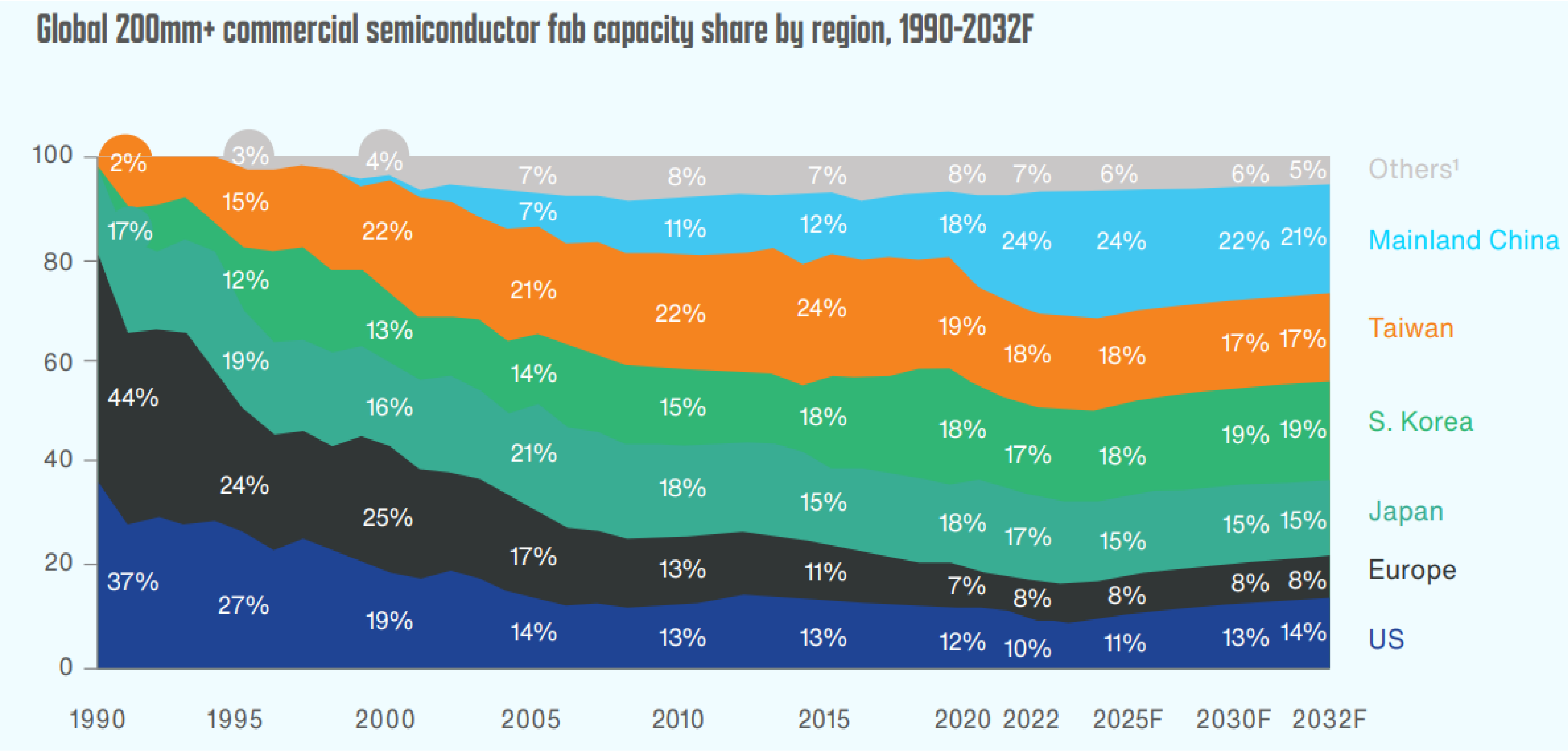
Global IC Wafer Fab Capacity by Technology



Global wafer fabrication capacity[9] by technology category by region, 2022 (top) and 2032 Forecast (bottom) (%)

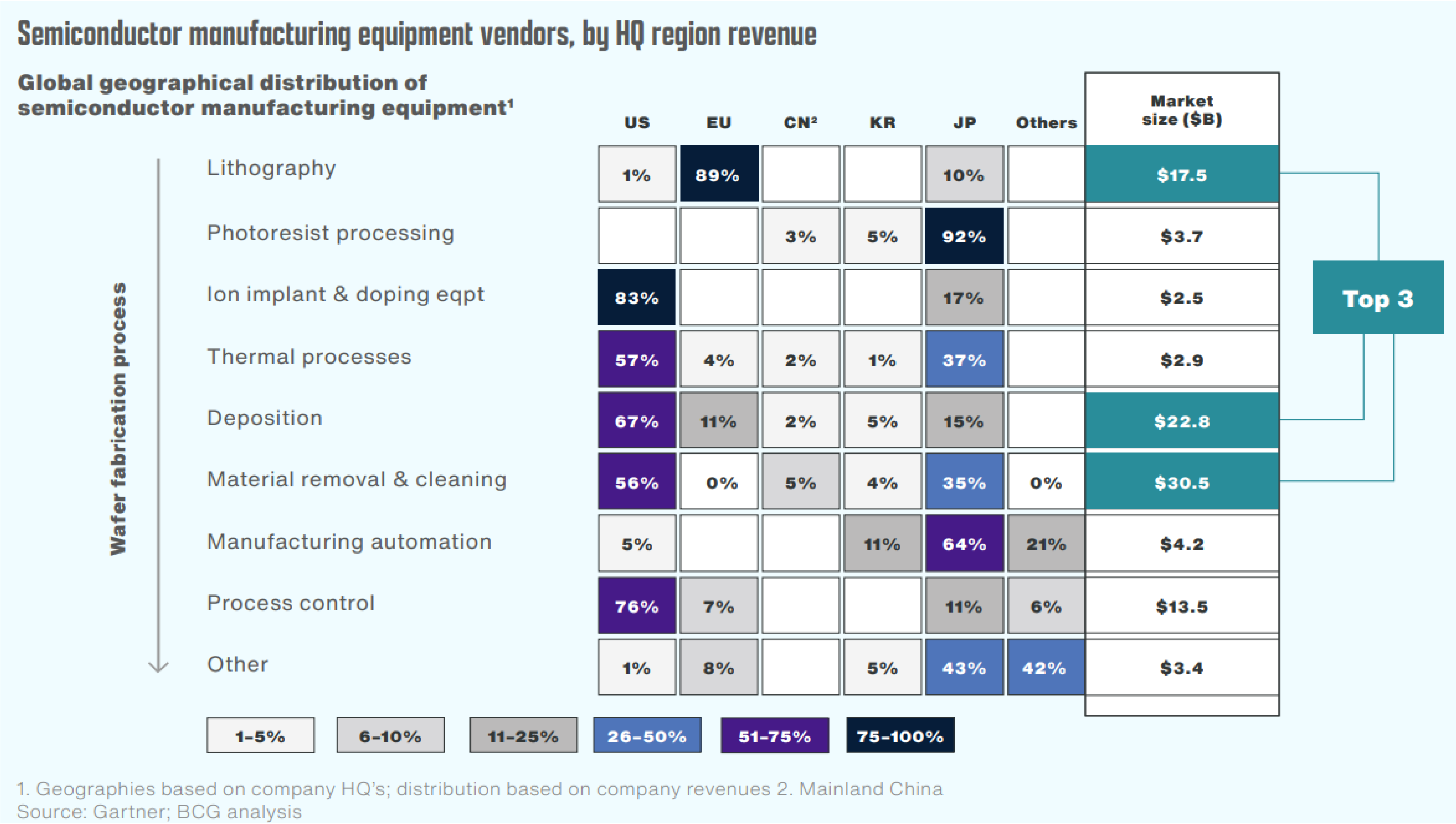
https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

Global IC Wafer Fab Capacity by Region



https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

Global Semiconductor Equipment Distribution



Semiconductor manufacturing equipment vendors, by HQ region revenue

Global geographical distribution of semiconductor manufacturing equipment[1]

Wafer fabrication process

	US	EU	CN[2]	KR	JP	Others	Market size ($B)
Lithography	1%	89%			10%		$17.5
Photoresist processing			3%	5%	92%		$3.7
Ion implant & doping eqpt	83%				17%		$2.5
Thermal processes	57%	4%	2%	1%	37%		$2.9
Deposition	67%	11%	2%	5%	15%		$22.8
Material removal & cleaning	56%	0%	5%	4%	35%	0%	$30.5
Manufacturing automation	5%			11%	64%	21%	$4.2
Process control	76%	7%			11%	6%	$13.5
Other	1%	8%		5%	43%	42%	$3.4

1-5% | 6-10% | 11-25% | 26-50% | 51-75% | 75-100%

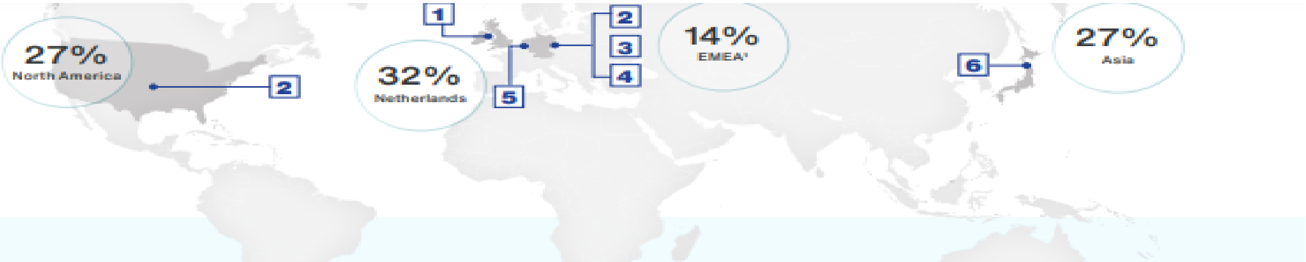
1. Geographies based on company HQ's; distribution based on company revenues 2. Mainland China

Source: Gartner; BCG analysis

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

EUV Equipment Global Supplier Distribution

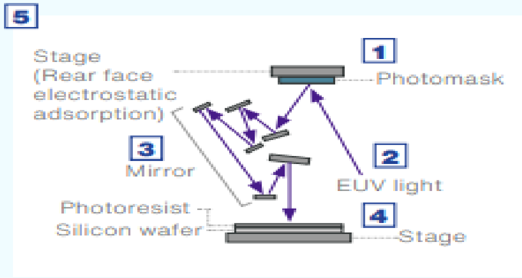
EUV equipment integrates components from a global network of more than 5,000 specialized suppliers



Share of total number of suppliers

Sample EUV key components

5



1 UK

Vacuum system
Edwards: Keeps system in vacuum to minimize EUV absorption by air

2 US

EUV light source
Cymer[2] : System uses CO2 laser to vaporize 50k molten tin droplets to generate EUV light (13.5nm wavelength)
Note: ¾ of light source costs are from Europe

Other tool parts
Mechatronics/electronics, ultra low thermal expansion glass for optics

2 Germany

Laser & power source
Trumpf: CO2 laser supported by 1MW power supply and advanced cooling system

3 Germany

Optical system
Zeiss[3] : Precise mirrors that project light on wafer for patterning

4 Germany

Wafer chuck
Berliner Glass[2]: Electrostatic chuck used to clamp wafer during litho process

5 Netherlands

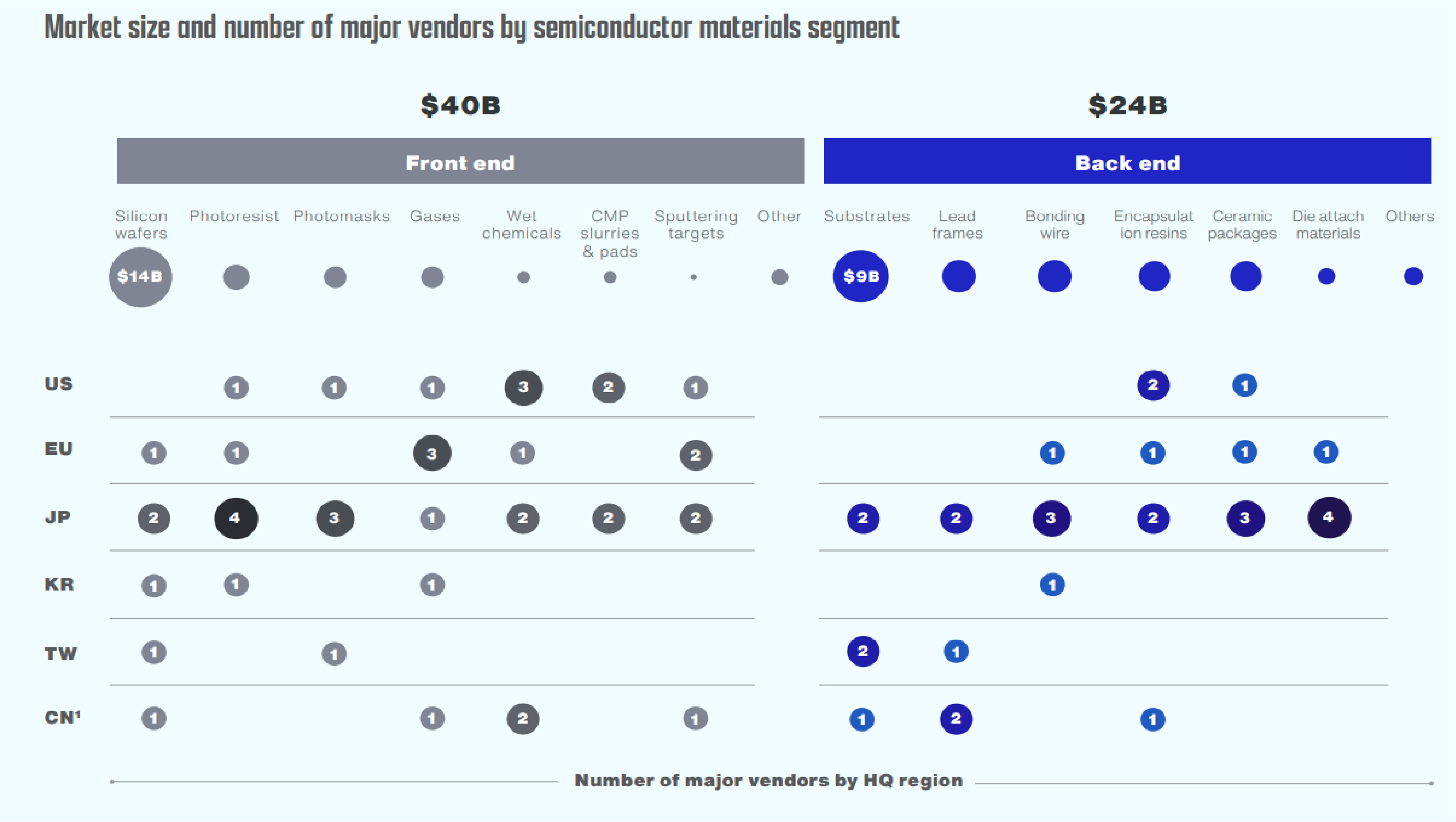
Vessel
VDL: Modular housing for EUV light source

6 Japan

Other tool parts
Structural ceramics, photoresist and photomask

https://www.bcg.com/publications/2021/strengthening-the-global-semiconductor-supply-chain

Global Semiconductor Materials Distribution



Market size and number of major vendors by semiconductor materials segment

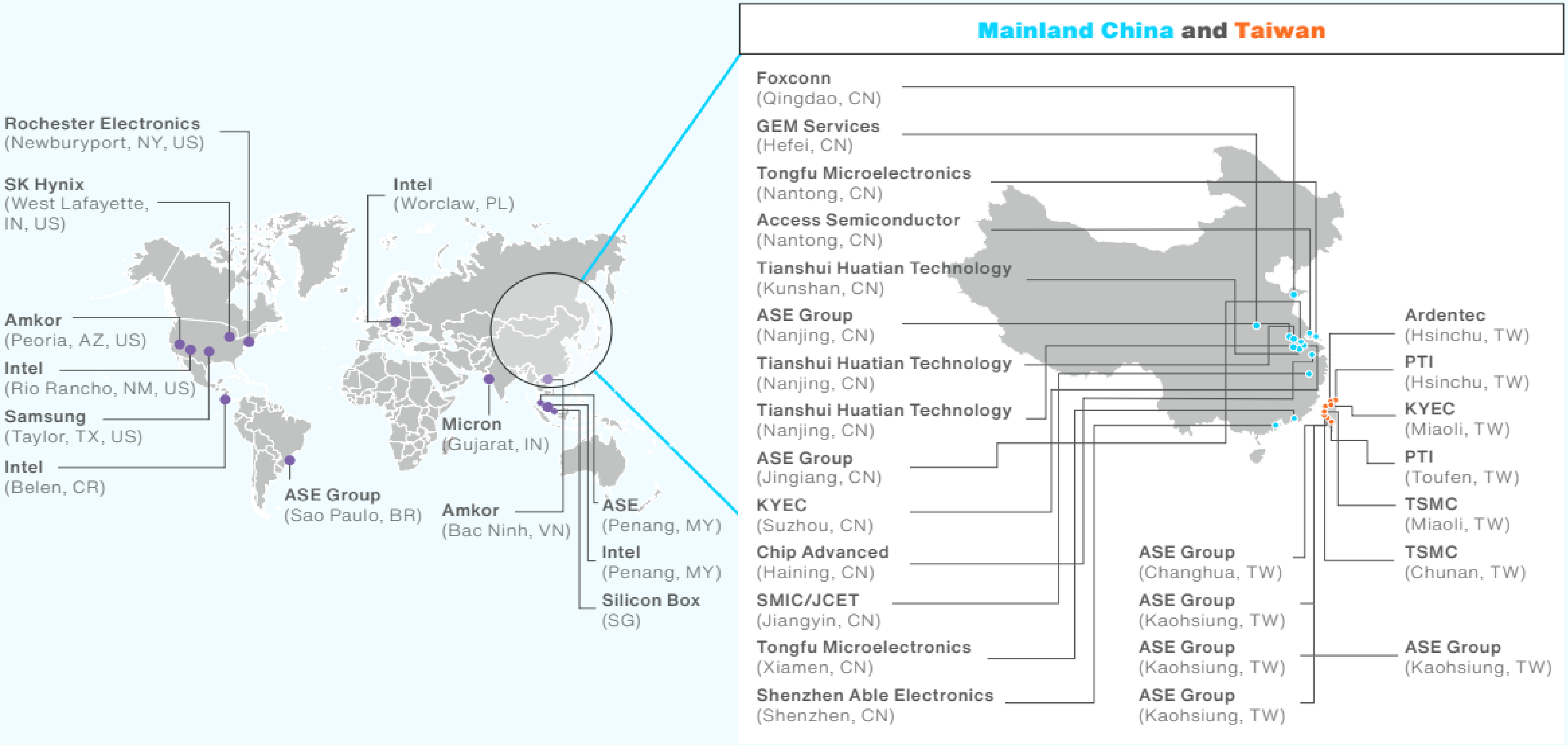
	$40B								$24B						
	Front end								Back end						
	Silicon wafers	Photoresist	Photomasks	Gases	Wet chemicals	CMP slurries & pads	Sputtering targets	Other	Substrates	Lead frames	Bonding wire	Encapsulation resins	Ceramic packages	Die attach materials	Others
	$14B								$9B						
US		1	1	1	3	2	1					2	1		
EU	1	1		3	1		2				1	1	1	1	
JP	2	4	3	1	2	2	2		2	2	3	2	3	4	
KR	1	1		1							1				
TW	1		1						2	1					
CN¹	1			1	2		1		1	2		1			

Number of major vendors by HQ region

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

Global New ATP Investment Distribution

New ATP investments by region, 2020-2023

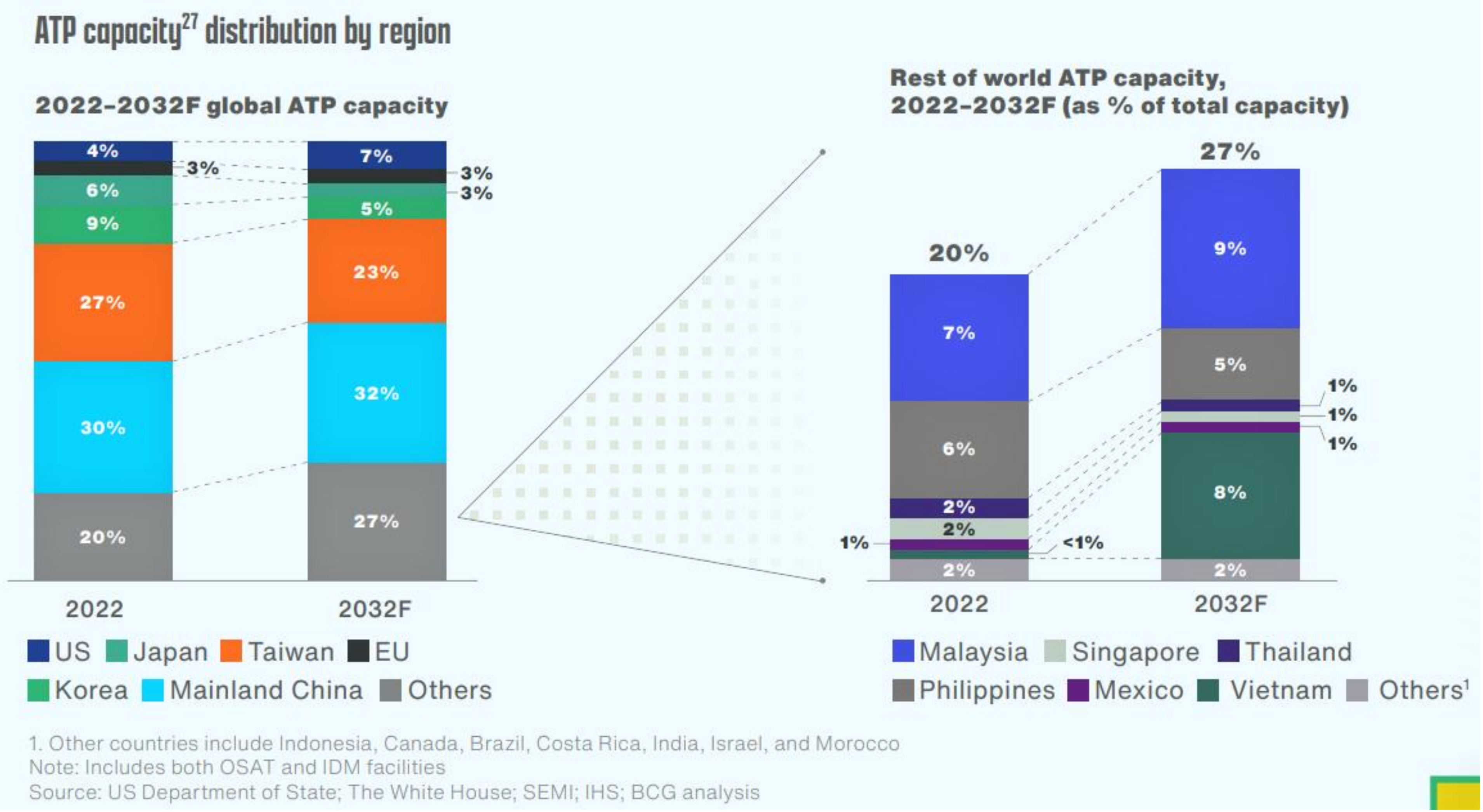


	Mainland China	Taiwan	Rest of World
Facilities	14	11	13

Note: Includes both IDM internal ATP facilities and OSATs
Source: SEMI; BCG Analysis

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

Global ATP Capacity Distribution



ATP capacity[27] distribution by region

1. Other countries include Indonesia, Canada, Brazil, Costa Rica, India, Israel, and Morocco

Note: Includes both OSAT and IDM facilities

Source: US Department of State; The White House; SEMI; IHS; BCG analysis

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

人和 People

Find right people to do right things right

全球生態圈與人才的競爭

IC 設計生態鏈的例子 TSMC OIP

(TSMC + EDA/IP Partners) Support Customers

價值聚合 VCA
設計服務
（世芯等 8 家）

設計中心
DCA 聯盟
（Wipro 等 20 家）

在產品與服務中，融入
台積晶片製程技術。

應用台積公司與聯盟夥
伴的矽智財，達到晶
片功耗、效能、面積
（PPA）最佳化。

TSMC
台積電

提供逾 12,000 個技術檔案
及 450 個製程設計套件

OIP 聯盟
夥伴

協助客戶從設計初期縮短、
優化晶圓開發流程

客戶

雲端 Cloud 聯盟夥伴
（微軟、AWS 等 6 家）

矽智財 IP 夥伴
（安謀、M31 等 39 家）

電子設計自動化 EDA 夥伴
（Ansys、Mentor Graphics 等 18 家）

客戶首次投片良率提升，
實現先進製程的創新循環

- 台積電（特殊製程技術）：超低功耗／超低漏電、雙載子、互補式金氧半導體
- OIP 夥伴（三維積體電路技術）：系統整合晶片、晶圓堆疊、整合型扇出
- 客戶設計（使用先進製程技術）：7 奈米、6 奈米、5 奈米或更小製程

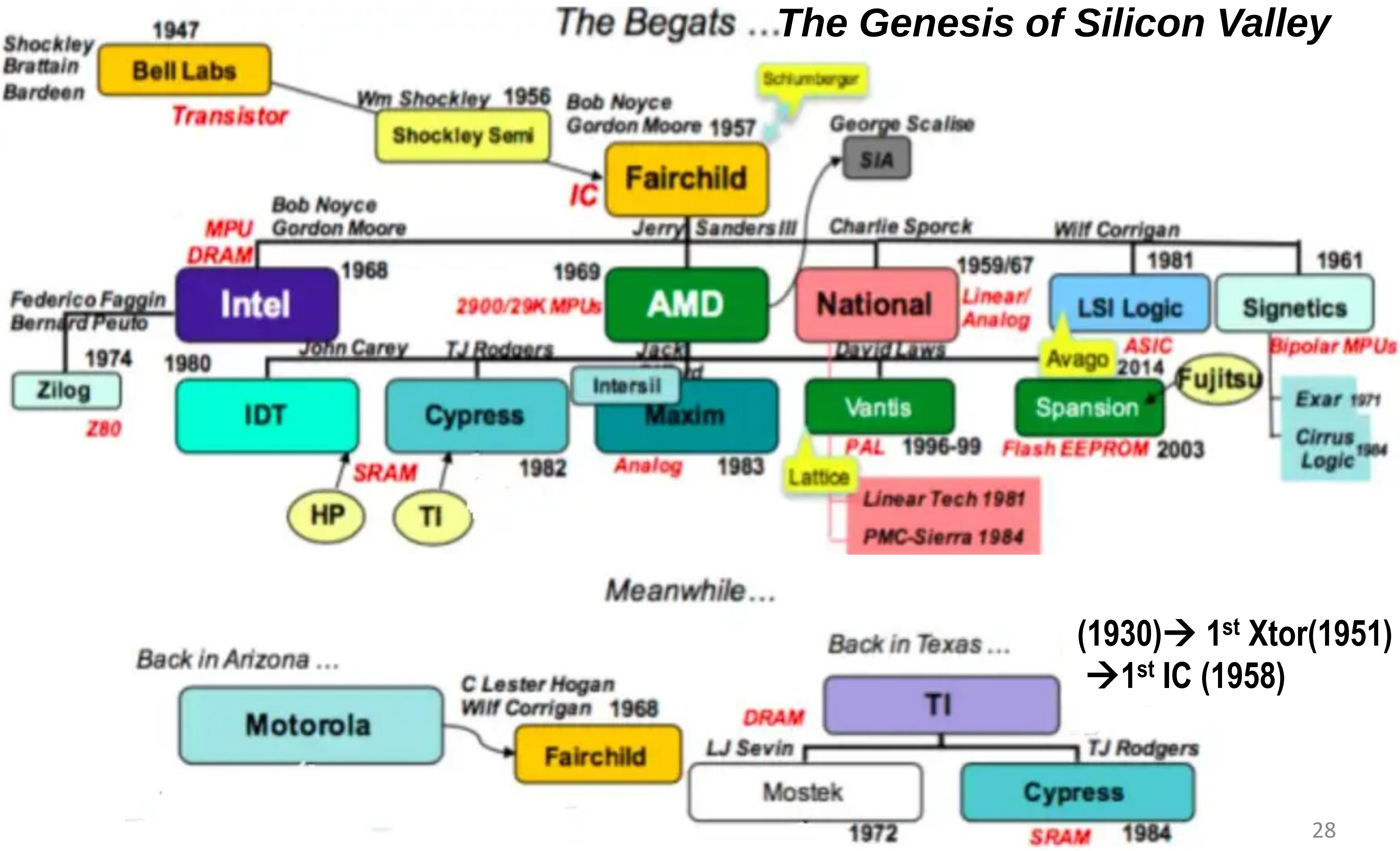
https://www.bnext.com.tw/article/62644/tsmc-oip-2021

全球半導體人才的例子

- Pre-2000 半導體人才1.0 US, Japan
- 1995 – 2010 半導體人才2.0 Taiwan, Korea
- After 2010 半導體人才 2.5 Taiwan, Korea, China
- 未來半導體人才 3.0

美國半導體1.0的人才鼎盛期

The Begats …*The Genesis of Silicon Valley*

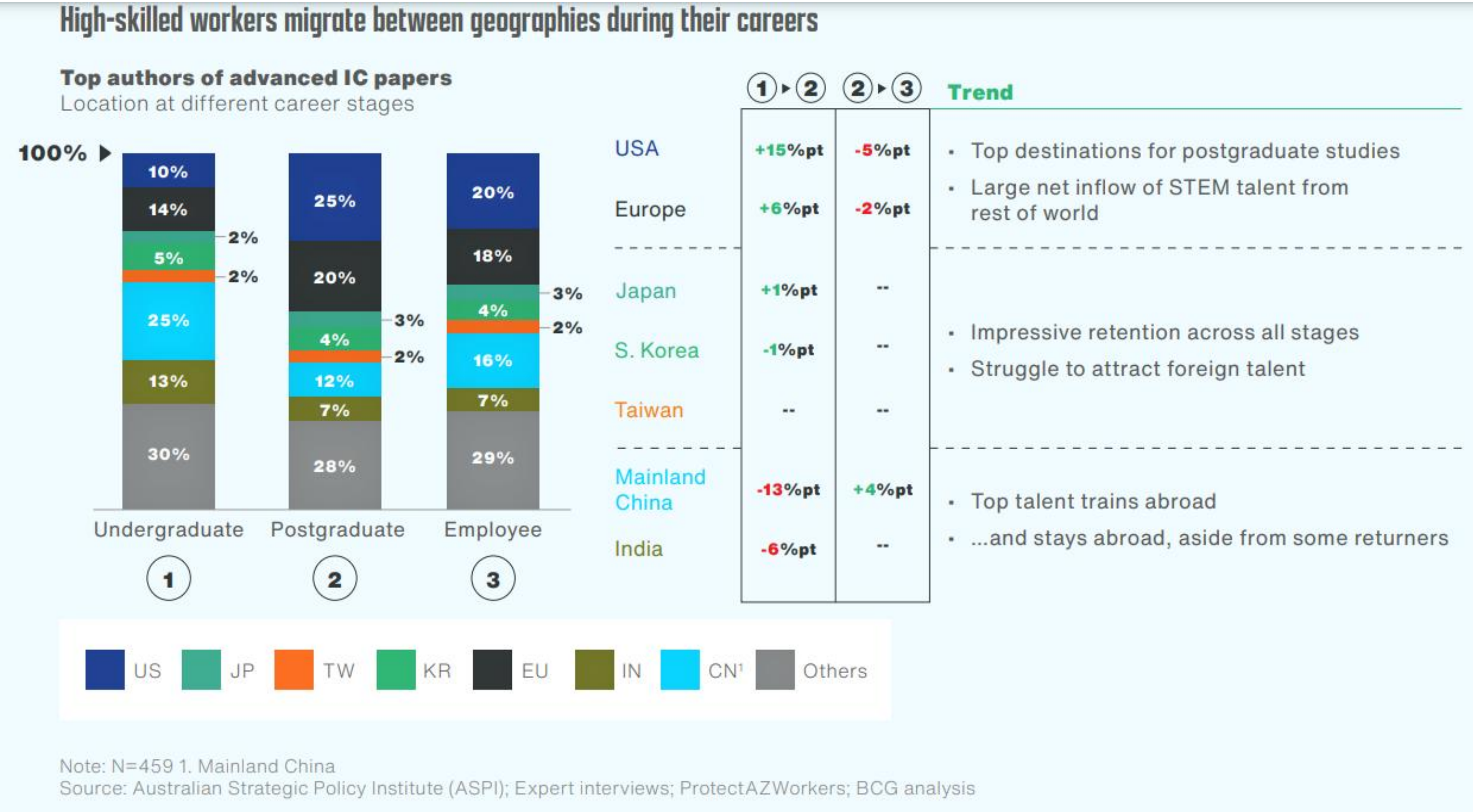


(1930)→ 1st Xtor(1951)
→1st IC (1958)

台灣半導體人才2.0的演變

- 時代、區域與學歷演變
  - ’80草創期:①工研院電子所,②大學/研究所, ③技職, ④出國留學生(儲備)
  - ’90成長期:①大學/研究所, ②歸國留學生 , ③電子所
  - ’00黃金期 & ’10穩定期以後: ①研究所, ②華人留學生
- 學程演變
  - 技職教育的瓦解 → 學歷貶值、學力衰微
  - 大規模增加大學/研究所學生，但產學差距越拉越大 → 高端、整合人才的嚴重匱乏
  - 擁有世界獨特資源、卻用分工極細模式糟蹋人才成為工具
  - Generation-Z vs. baby-boomer

Global Semiconductor Researcher Distribution



High-skilled workers migrate between geographies during their careers

Top authors of advanced IC papers

Location at different career stages

	①▸②	②▸③	Trend
USA	+15%pt	-5%pt	• Top destinations for postgraduate studies • Large net inflow of STEM talent from rest of world
Europe	+6%pt	-2%pt	
Japan	+1%pt	--	• Impressive retention across all stages • Struggle to attract foreign talent
S. Korea	-1%pt	--	
Taiwan	--	--	
Mainland China	-13%pt	+4%pt	• Top talent trains abroad • ...and stays abroad, aside from some returners
India	-6%pt	--	

Note: N=459 1. Mainland China

Source: Australian Strategic Policy Institute (ASPI); Expert interviews; ProtectAZWorkers; BCG analysis

https://www.bcg.com/publications/2024/emerging-resilience-in-semiconductor-supply-chain

總結

台灣半導體產業未來的挑戰

- 地緣政治2.0源自美國的風險
  - 如何保存既有的競爭力、突破既有的限制
  - 互補式合作雙贏、避免衝突式競爭兩傷

- 非美國地緣政治的合作機會與風險
  - 歐洲、日本、韓國、中國
  - 東南亞、中東、…

- 台灣內部的挑戰
  - 歷史重演的偏頗人才市場: 多元全球市場的產業人才
  - 少子化的危機與轉機: 生產力的倍升
    - ✓ 移民政策的兩難
  - ESG: 能源與環保的兩難

從台灣半導體產業學習的經驗

- 宏觀思維: 尋求天時、地利、人和的契機
- 結合自己的優勢切入
- Leverage 全球市場/客戶和生態圈: 打群架、團結力量大

Backup Materials

我的半導體產業人才培育經驗

- 萬丈高樓平地起：空降與本土人才的競爭
- 無心插柳柳成蔭：誤走悟出的人才發展
- 龍生龍、鳳生鳳、老鼠的兒子會打洞：人才的培養環境
- 人海戰術的迷思：極度分工的小螺絲釘
- 世代翻轉的困境: 大象翻身的困難
- 在五斗米中的態度：折腰、學習、突破