SEMICONDUCTOR INDUSTRY ASSOCIATION

Strengthening the Global Semiconductor Supply Chain in an Uncertain Era

Briefing deck

JUNE 8, 2021

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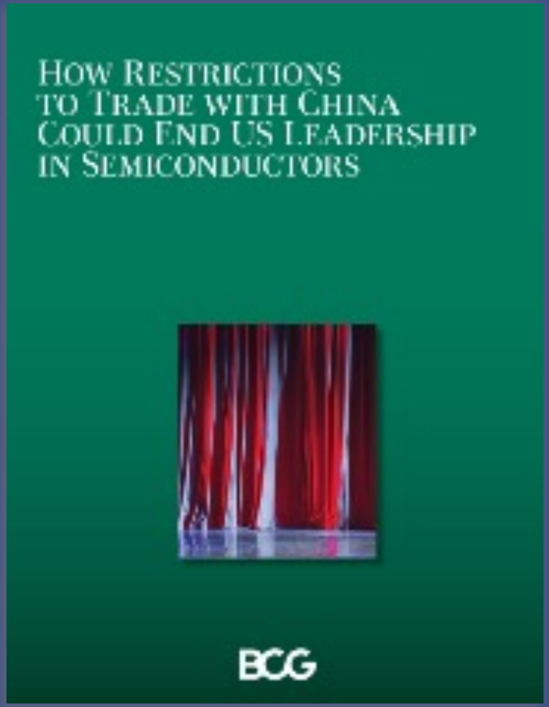
Third BCG x SIA report focuses on the global semiconductor supply chain

BOSTON CONSULTING GROUP + SEMICONDUCTOR INDUSTRY ASSOCIATION

3 thought leadership reports on critical policy-related issues for the semiconductor industry



March 2020

September 2020

March 2021

Objectives of this report

1. Provide a robust fact base of reference about the semiconductor value chain

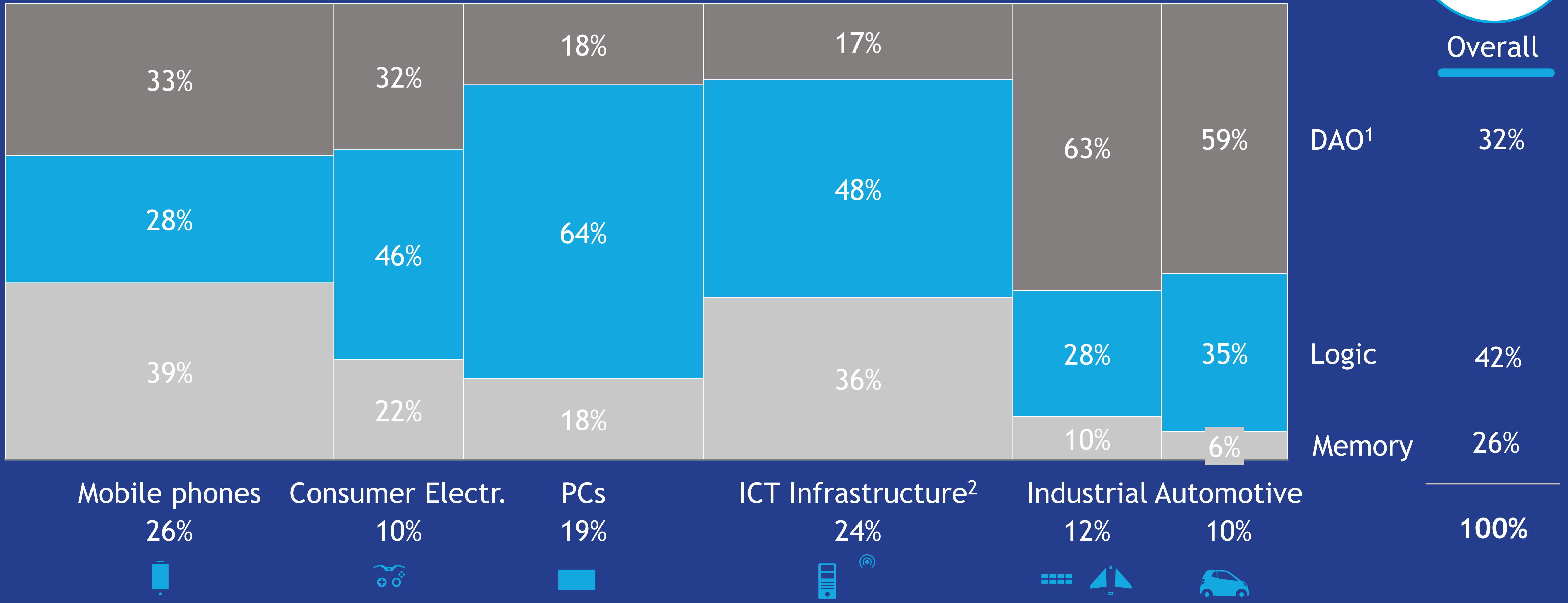
2. Educate the public on the global nature of the semiconductor value chain: why it is like this and the value it creates

3. Discuss the key risks and challenges that the semiconductor value chain faces, and the broad policy directions to address them

All types of semiconductors are indispensable in today's economy, powering all sorts of electronic devices

$412B
Global 2019 sales

GLOBAL SEMICONDUCTOR SALES BY APPLICATION MARKET, 2019 (%)



1. Discrete, analog and optoelectronics and sensors 2. Information and Communications Technology infrastructure, including data centers and communication networks
Sources: SIA WSTS, Gartner

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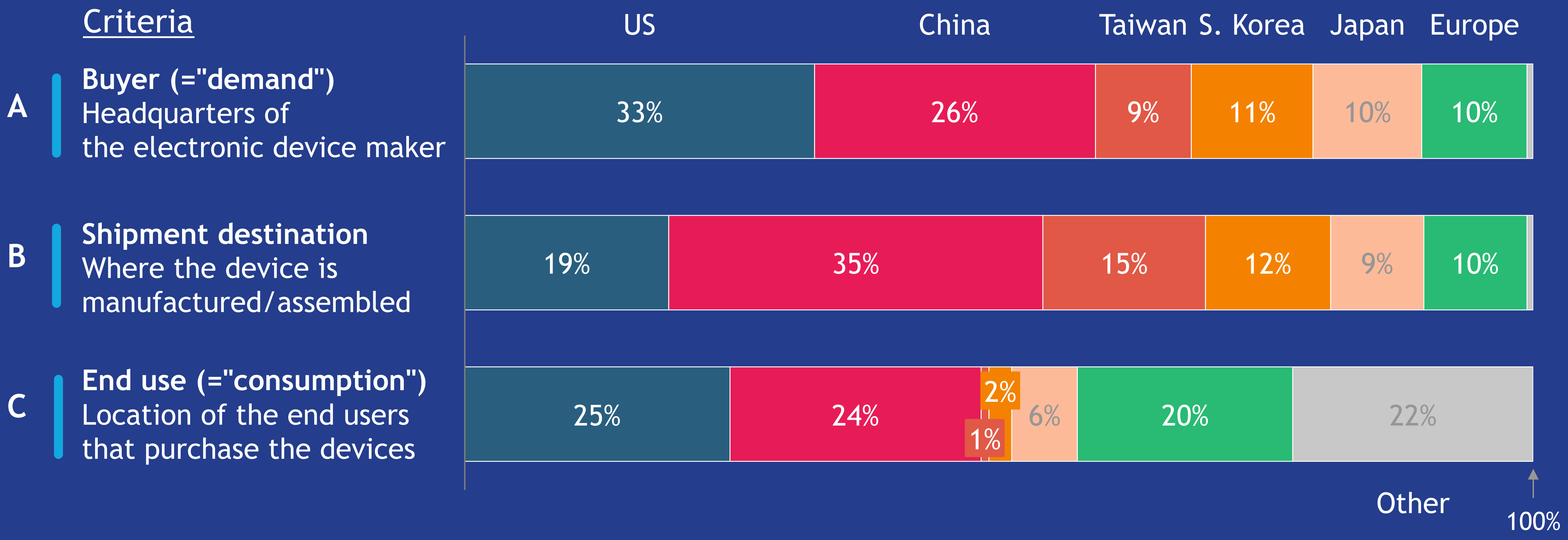
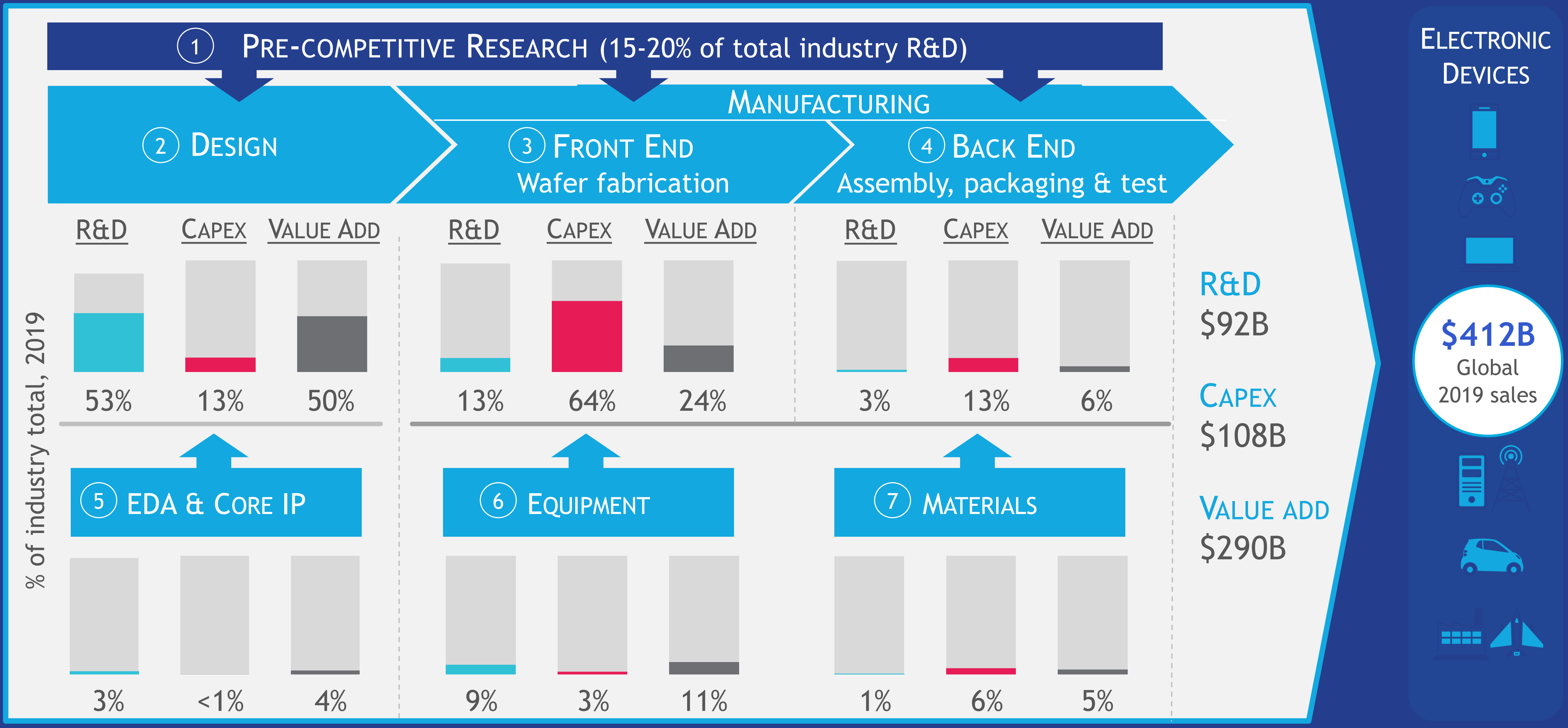
Semiconductor consumption is global.
The US accounts for ~25% of consumption, but drives 33% of demand

Global semiconductor sales by geographic area, 2019 (%)



Sources: BCG analysis with data from SIA WSTS, Gartner, IDC

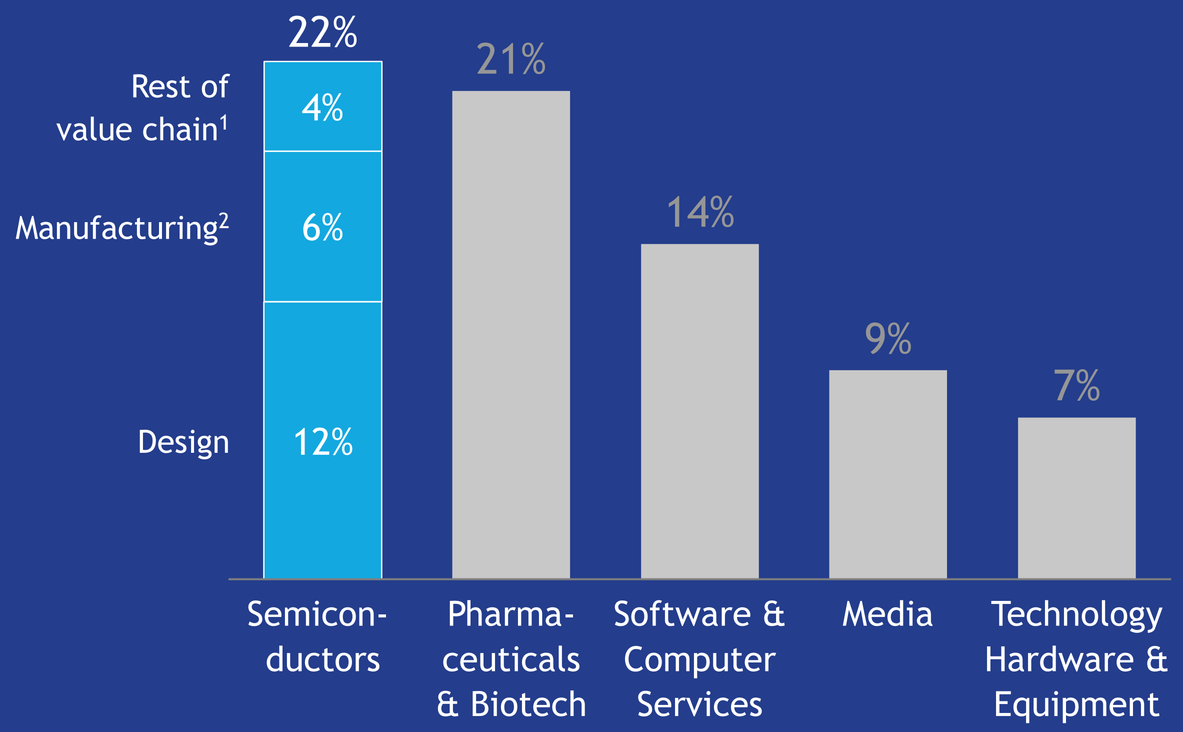
The semiconductor value chain includes seven differentiated activities



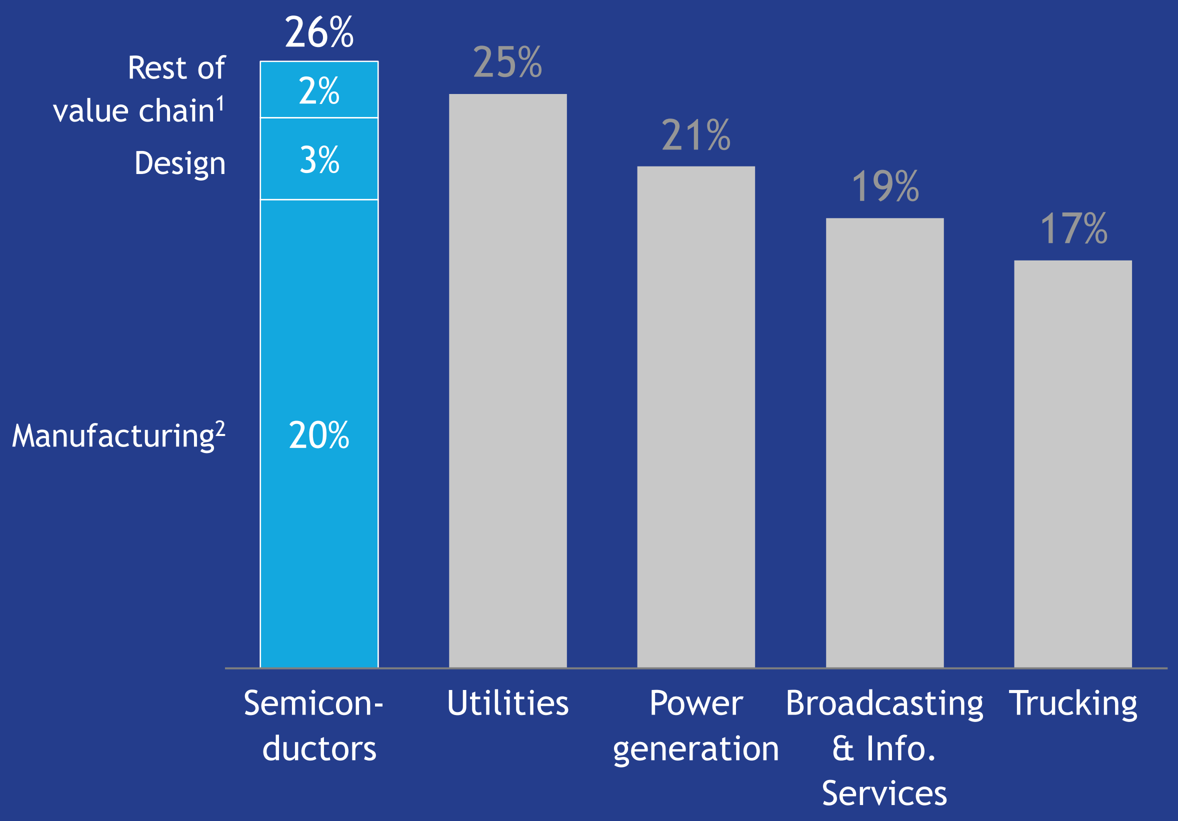
Sources: BCG analysis using data from Capital IQ (company financial reports) and Gartner (total market sizes)

The semiconductor industry ranks high simultaneously in both R&D and capital intensity

R&D as % of Revenues, 2019

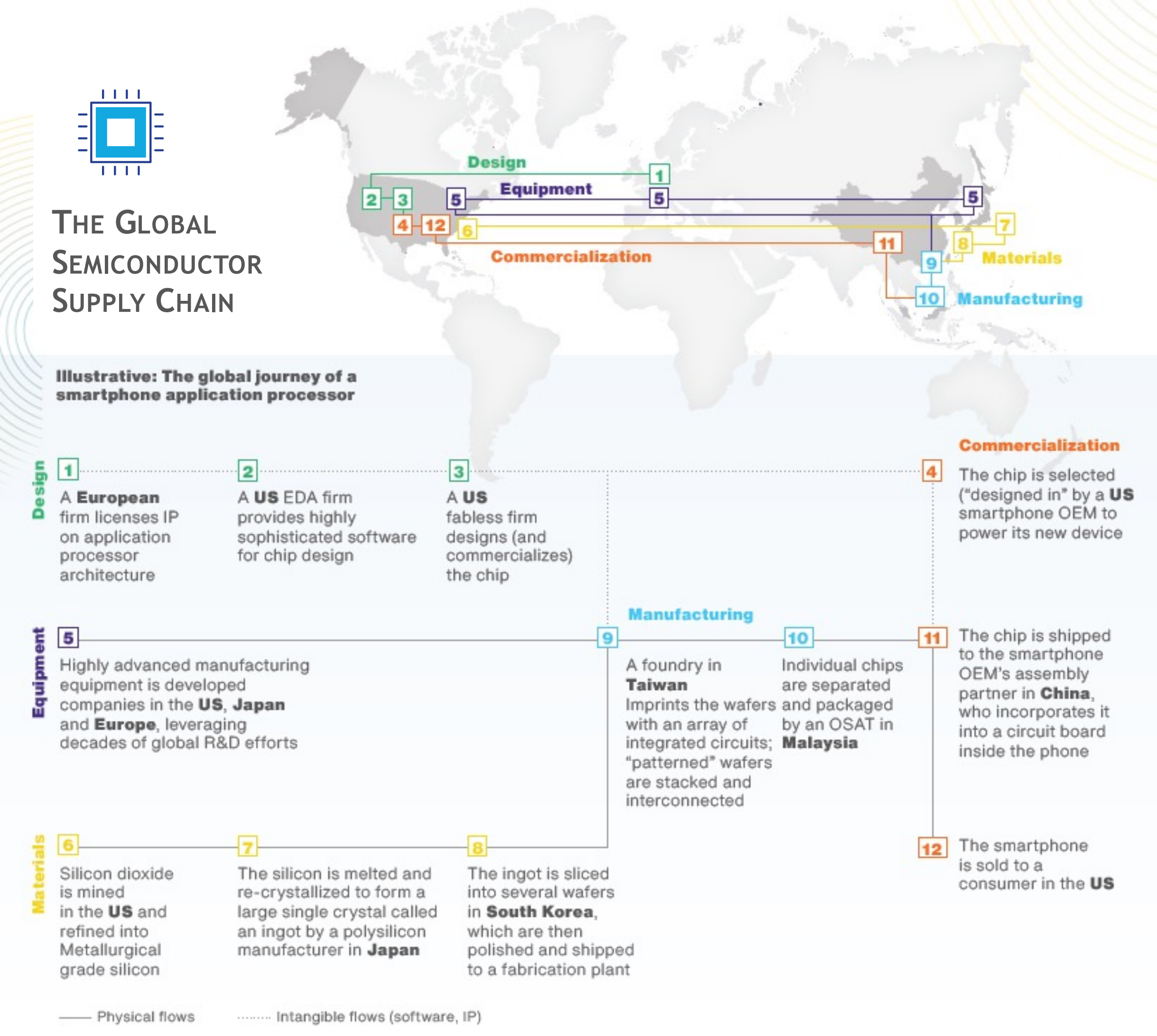


Capital Expenditure as % of Revenues, 2019



1. Includes EDA and Core IP, Equipment and Materials 2. Includes Wafer Fabrication and Assembly & Test
Sources: BCG analysis based on Capital IQ data

Need for deep technology expertise and massive scale has resulted in a complex global semiconductor supply chain structure



KEY CHARACTERISTICS OF THE GLOBAL SEMICONDUCTOR SUPPLY CHAIN

- Global R&D networks for basic, pre-competitive research
- Specialized business models focused on specific layers of the value chain (i.e. IDM co-existing with fabless/foundry/OSAT)
- Geographic specialization based on comparative advantage, enabled by global free trade

Example: EUV technology essential for < 10 nm manufacturing was developed through several decades of global R&D collaboration

Development of early concept demo | **Development of key EUV technology** | **Commercialization of EUV**

Early 80s
- Early demo of EUV concept (US, Japan)
- 2-mirror/3-mirror imaging system demo (US, Japan)

Early 90s
- Imaging system demo; Soft-X-ray source and liquid-droplet system (EU)
- Exposure wavelength determination (US, Japan)
- Reflective imaging system (US, Japan)
- Fabrication of mirrors (EU, US, Japan)
- Multilayer coating and mask development (EU, US, Japan)
- EUV resist development (US, Japan)
- MOS device demo (US)
- EUV light source development (US)

Late 90s to early 00s
- EUV commercial prototype development (EU, US, Japan)
- Prototype for research institute (EU)

Present
- EUV for commercial production in use (2018) (EU)

Currently a global network of 5,000 specialized suppliers enables EUV commercial use

% of supplier base

EU	46%
US	27%
Japan	27%

Source: EUV lithography book; ASML; ASML; BCG analysis

Technology complexity and need for scale have also led to emergence of business models focused on a specific layer of the value chain

DESIGN | MANUFACTURING: FRONT END | BACK END

INTEGRATED DEVICE MANUFACTURERS (IDMS)

	CAPACITY (2019)	SALES (2019)
Logic	21%	53%
Memory	98%	98%
DAO[1]	94%	75%
OVERALL	67%	71%

LAYER SPECIALIZATION

Fabless design

Foundries

Outsourced Assembly & Testing (OSATs)

IDMs rely on foundries for a portion of their manufacturing needs

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

	CAPACITY (2019)	SALES (2019)
Logic	79%	47%
Memory	2%	2%
DAO[1]	6%	25%
OVERALL	33%	29%

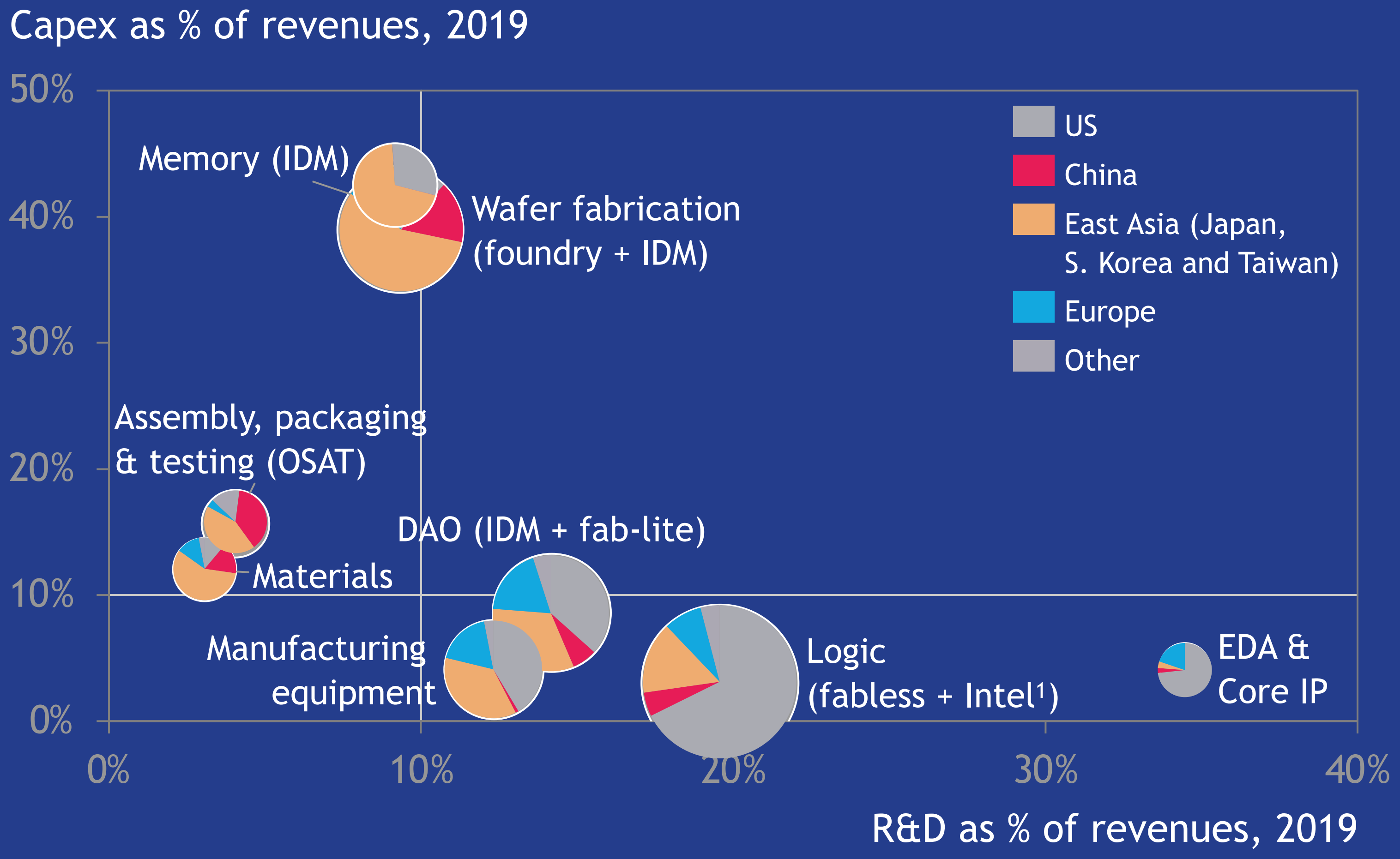
1. Discrete, analog and optoelectronics and sensors

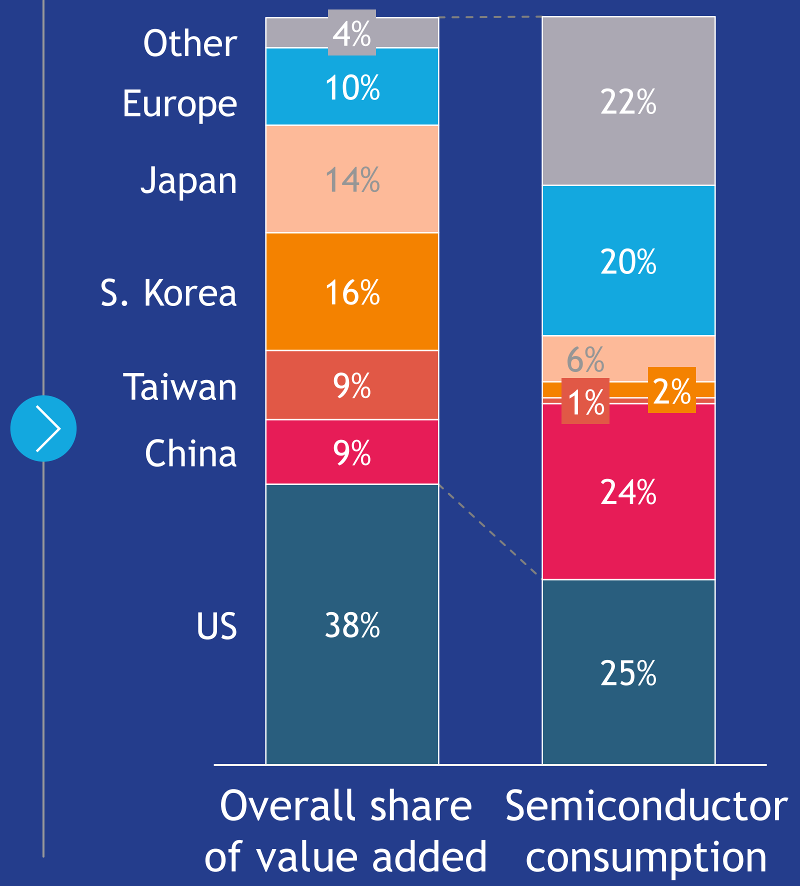
Sources: BCG analysis with data from SIA WSTS, Gartner, SEMI

GEOGRAPHIC SPECIALIZATION BASED ON COMPARATIVE ADVANTAGE

Regions specialize in different activities of the supply chain: US leads in R&D-intensive activities; Asia leads in the most capital-intensive

REGIONAL SHARES BY ACTIVITY IN THE VALUE CHAIN VS. R&D AND CAPEX INTENSITY, 2019 (%)





1. Majority of Intel's Capex assumed to be for wafer fabrication and not included here. Majority of Intel's R&D assumed to be for design and included here
NOTE: Regional breakdown calculated as: EDA, design, manufacturing equipment and raw materials based on company revenues and company headquarters location. Wafer fabrication and assembly packaging & testing based on installed capacity and geographic location of the facilities
Sources: BCG analysis with data from Gartner, SEMI, IHS Markit

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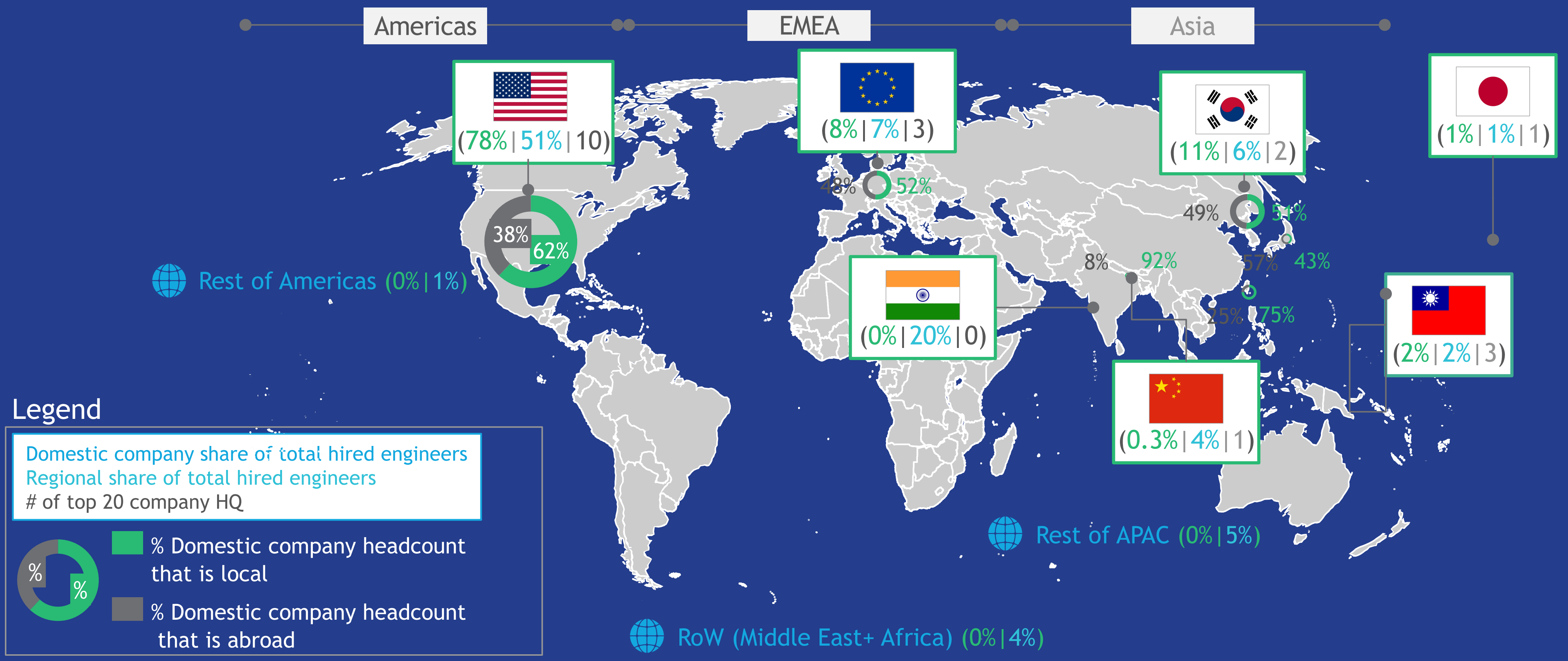
GEOGRAPHIC SPECIALIZATION BASED ON COMPARATIVE ADVANTAGE

10 of the top 20 semiconductor design firms are headquartered in the US. Over 50% of the world's semiconductor design engineers are based in the US

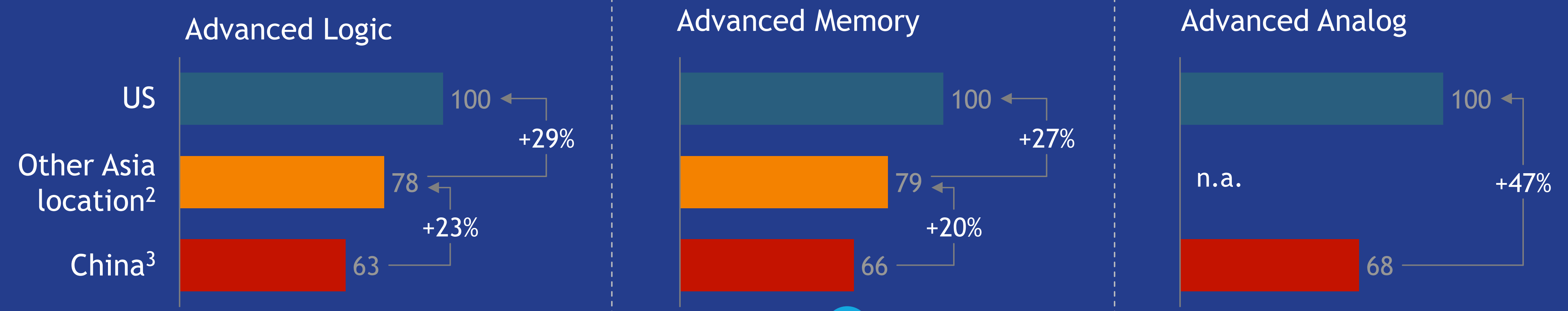
Estimated location of semiconductor design engineers from top global companies, 2020



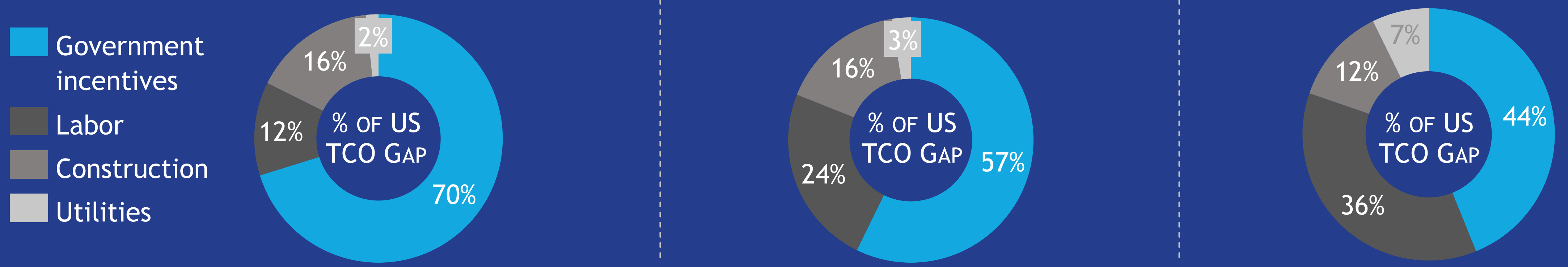
Note: Total number of design related positions are approximated based on publicly available profiles in Linkedin for top 10 fabless and top 10 IDM players, number can be underestimated for certain regions (e.g., China) due to availability of publicly available data
Sources: BCG analysis

Manufacturing economics are significantly more favorable in Asia, with government incentives driving 45-70% of the cost advantage

ESTIMATED 10-YEAR TOTAL COST OF OWNERSHIP (TCO[1]) OF REFERENCE FABS BY LOCATION (US INDEXED TO 100)



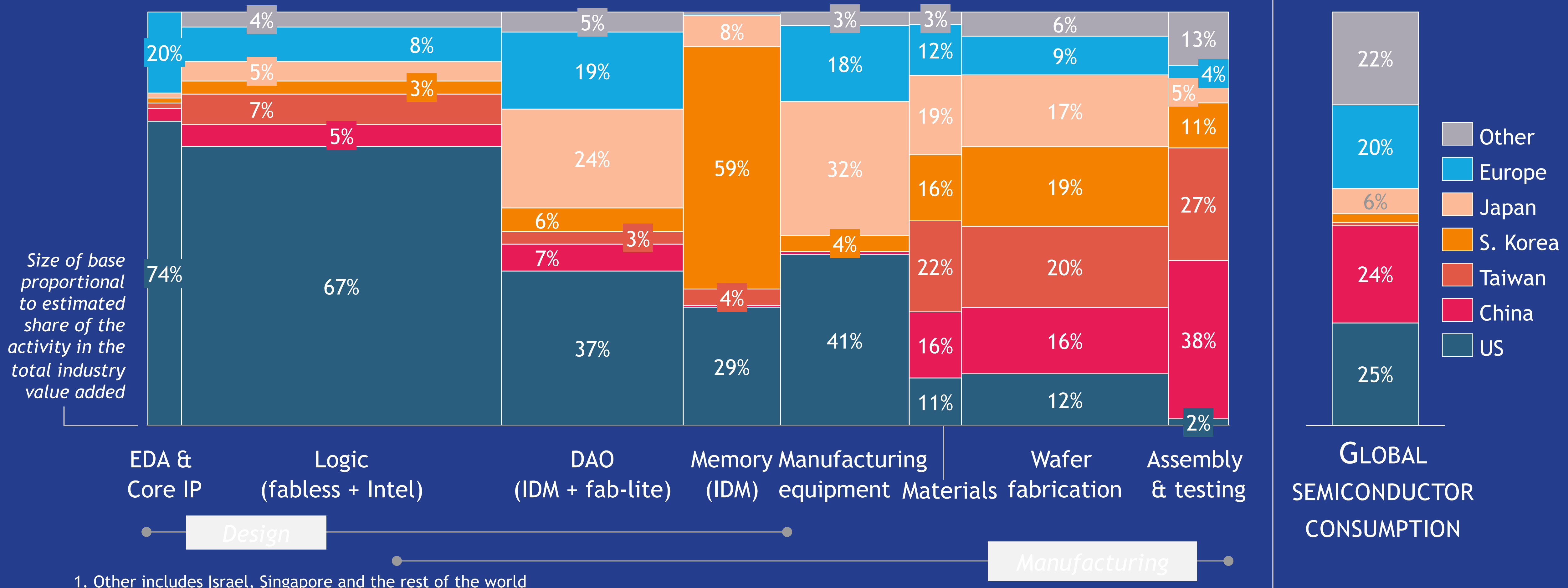
What drives the higher TCO of US-based fabs vs. other locations



1. TCO includes capital expenditure (upfront land, construction and equipment) + 10 years of operating expenses (labor, utilities, materials, taxes) 2. Refers to Taiwan and South Korea for logic, South Korea and Singapore for memory 3. With technology sharing agreements that give access to additional incentives such as equipment lease back with advantageous terms
Source: BCG analysis

As a result of geographic specialization, no single country/region has a fully self-sufficient supply chain

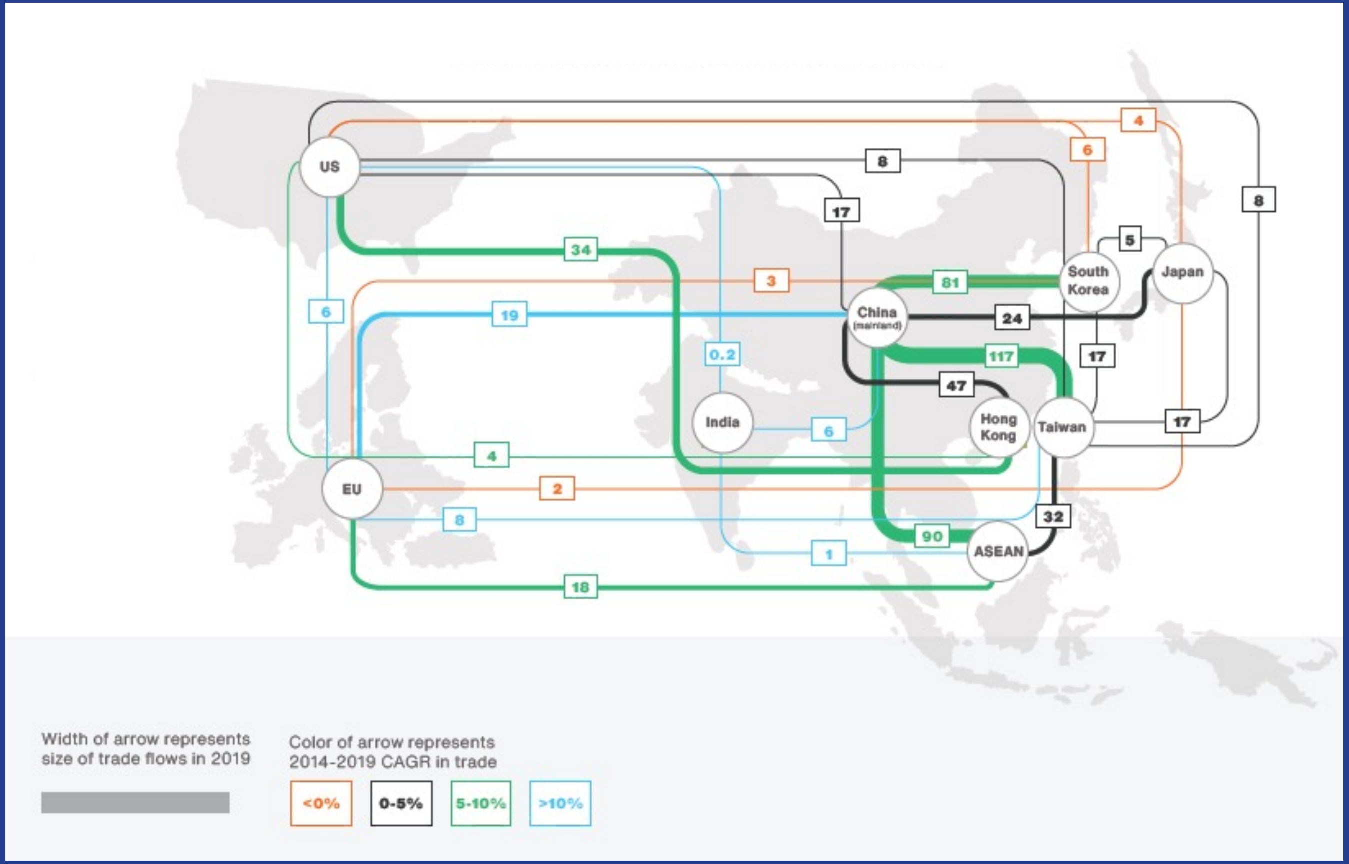
Regional Shares by Activity in the Value Chain, 2019 (%)



1. Other includes Israel, Singapore and the rest of the world
NOTE: Regional breakdown calculated as: EDA, design, manufacturing equipment and raw materials based on company revenues and company headquarters location.
Wafer fabrication and assembly packaging & testing based on installed capacity and geographic location of the facilities
Sources: BCG analysis with data from Gartner, SEMI, IHS Markit

A large web of global trade flows supports the geographic specialization in the semiconductor value chain

MAJOR SEMICONDUCTOR TRADE CORRIDORS[1] (2019, $ BILLION)



~$1.7T
Global trade[2] of semis in 2019

4th Most traded product in the world in 2019 only after crude oil, refined oil and automotive

20% of semiconductor global trade enabled by WTO's ITA agreement signed in 1997 and expanded in 2015

China At the center of global semiconductor trade due to its leadership in electronics manufacturing

1. HS codes 8541, 8542, minus HS 854140, excludes semiconductor equipment 2. Includes both exports and imports. *Note:* Significant disparities in reported data by each country. Importer data used where possible; Source: IHS Global Trade Atlas, UN Comtrade; BCG analysis

The global structure of the semiconductor supply chain delivers enormous value that ultimately benefits electronic device makers and end users

? Hypothetical Scenario

Every region would need to develop its own fully self-sufficient value chain

- Local semiconductor manufacturing capacity (both front-end and back-end) to match domestic semiconductor consumption
- 1-3 local suppliers for:
  - EDA and core IP
  - 14 major semiconductor product groups typically provided by different vendors
  - 7 major types of manufacturing equipment typically provided by different vendors
  - 7 major families of materials

Potential Impact on the Industry

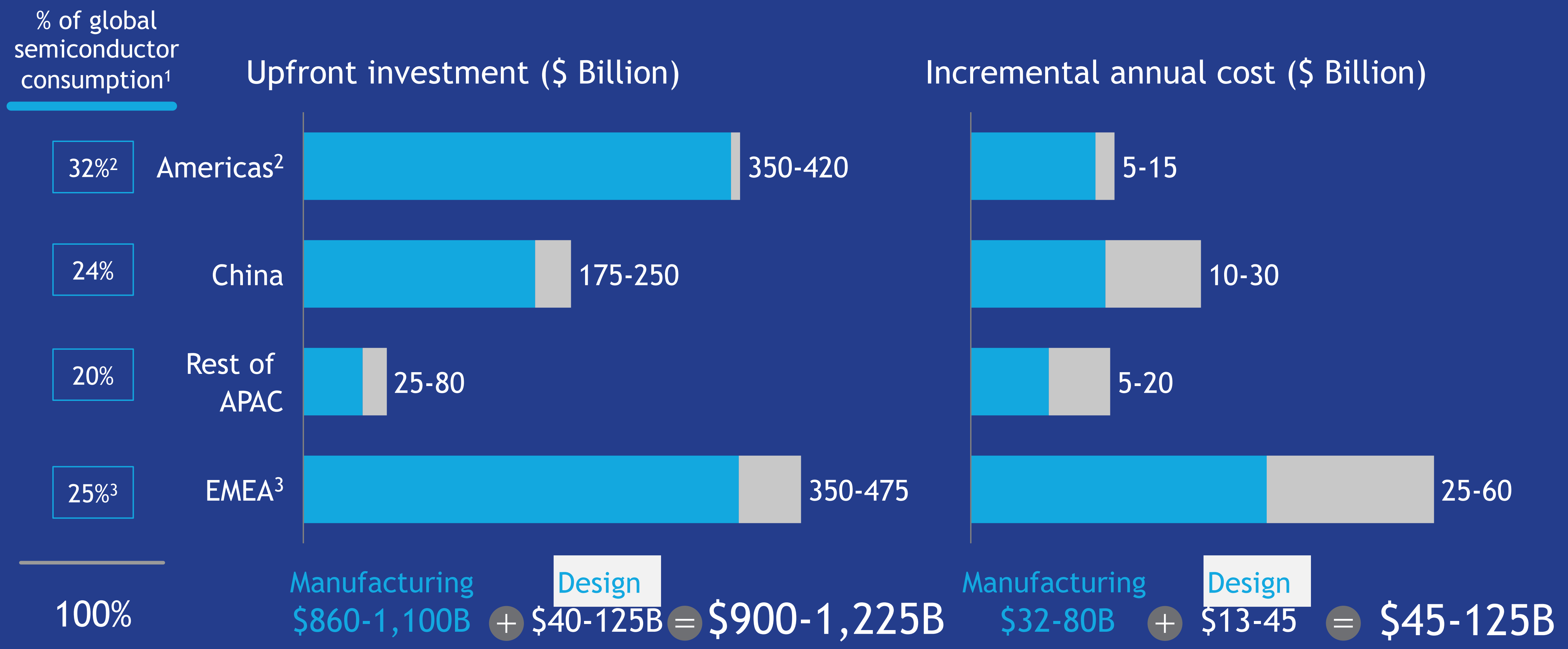
Assuming execution feasibility, and not considering cost of failed investments and potential overcapacity

- ! **$900-1,225B** upfront investments (capex & R&D)
- ! **$45-125B** incremental annual operating costs
- ! **+35-65%** increase in overall semiconductor prices

Sources: BCG analysis

All regions benefit from the efficiencies of the global value chain

INCREMENTAL COST TO COVER 2019 DEMAND WITH FULLY "SELF-SUFFICIENT" LOCALIZED SEMICONDUCTOR SUPPLY CHAINS



1. Calculated as the estimated semiconductor content in electronic devices sold to end users in each geography in 2019 2. Includes Canada, Latin America 3. Includes Middle East and Africa
Note: Range defined primarily by number of local companies assumed to be required to meet the local needs in each activity of the value chain: from just 1 player to supply the entire local market to 3 players typically found in the current global market structure
Sources: BCG analysis

Five key vulnerabilities identified in the semiconductor supply chain

Risk factor	Description	Current examples
High geographic concentration of some activities	Single points of failure which may be disrupted by natural disasters, infrastructure failures, cyberattacks or geopolitical frictions	• Wafer fabrication • Assembly, packaging & testing • Some specialty materials Focus Area in Report
Geopolitical frictions	Broad export controls over inputs or technologies with no viable alternative suppliers in other countries	• US-China frictions • Japan – S. Korea frictions
National self-sufficiency policies	National industrial policies that seek broad import substitution or broadly discriminate against foreign suppliers, leading to distortion in global competition and risk of overcapacity	• China policies in pursuit of "self sufficiency" across the semiconductor value chain
Talent constraints	Current growth in talent pool of Science & Engineering graduates is insufficient to meet the industry demand for technical talent	• All countries, but US in particular given leadership in R&D intensive activities and reliance on attracting & retaining global talent
Stagnation in funding of basic research	Government programs and funding play a critical role in basic research, which is essential for the semiconductor industry	• US government-funded R&D in semiconductors has stagnated and is below overall level across all sectors

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50+ points of high geographical concentration across the supply chain (but not all with the same level of associated risk)

VALUE CHAIN ACTIVITIES WHERE ONE SINGLE REGION ACCOUNTS FOR ~65% OR MORE OF GLOBAL SHARE[1]

DESIGN

Advanced processors (CPU, GPU, FPGA) and DSP

RFFE and cellular basebands

Data converter, switchers, multiplexers and other analog

DRAM

MANUFACTURING

FRONT END
Wafer fabrication

+ Logic: leading nodes (< 10nm)

+ + Logic: mature nodes (>= 10nm)

+ Memory

BACK END
Assembly & Test

+ + Outsourced Assembly and Test (OSAT)

EDA & CORE IP

EDA

IP (Arm architecture)

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

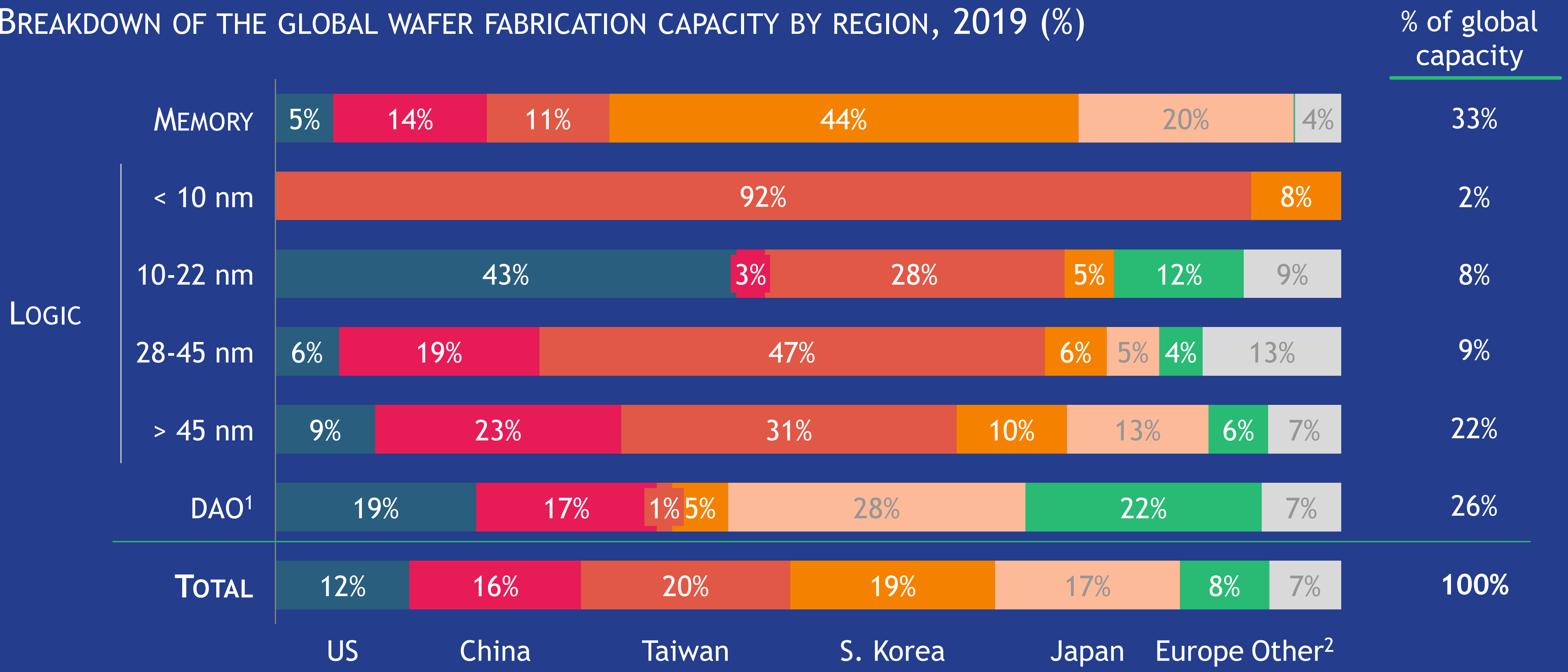
Specialty gases (in aggregate)

US
China
Taiwan
South Korea
Japan
EU
UK

1. For Design, EDA & Core IP, Equipment & Tools and Raw Materials: global share measured as % of revenues, based on company headquarter location. For Manufacturing (both Front End and Back End) measured as % of installed capacity, based on location of the facility
Sources: BCG analysis with data from Gartner, SEMI, UBS; SPEEDA

East Asia + China concentrate ~75% of the wafer fabrication capacity; in particular, ~90% of advanced logic capacity <10 nm is located in Taiwan

BREAKDOWN OF THE GLOBAL WAFER FABRICATION CAPACITY BY REGION, 2019 (%)



1. Discrete, analog and optoelectronics and sensors 2. Other includes Israel, Singapore and the rest of the world
Sources: BCG analysis with data from SEMI fab database

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Impact of disruptions in semiconductor manufacturing have a multiplier effect downstream in the electronics supply chain

Example: Logic

Taiwan alone concentrates ~40% of the world's total logic production capacity, including >90% of the capacity for advanced processors

A hypothetical disruption of Taiwan-based manufacturing capacity due to a natural disaster, infrastructure failure or geopolitical conflict could put at risk:

- $40B revenue for Taiwanese foundries
- $80B revenue loss for global fabless companies
- $500B revenue loss for electronic device OEMs

Example: Memory

S. Korea concentrates ~44% of the world's total memory production capacity

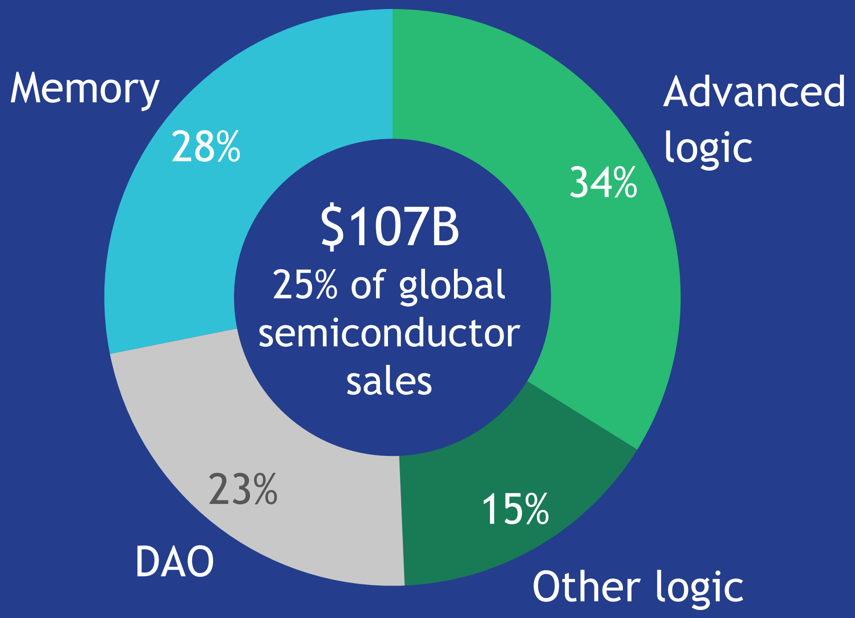
The ongoing Japan-S. Korea tensions restricted Japanese exports of 3 materials used to produce memory – if sustained over time, this could put at risk:

- $0.4B revenue for Japanese suppliers
- $65B revenue risk for Korean semi companies
- $750B revenue risk for electronic device OEMs

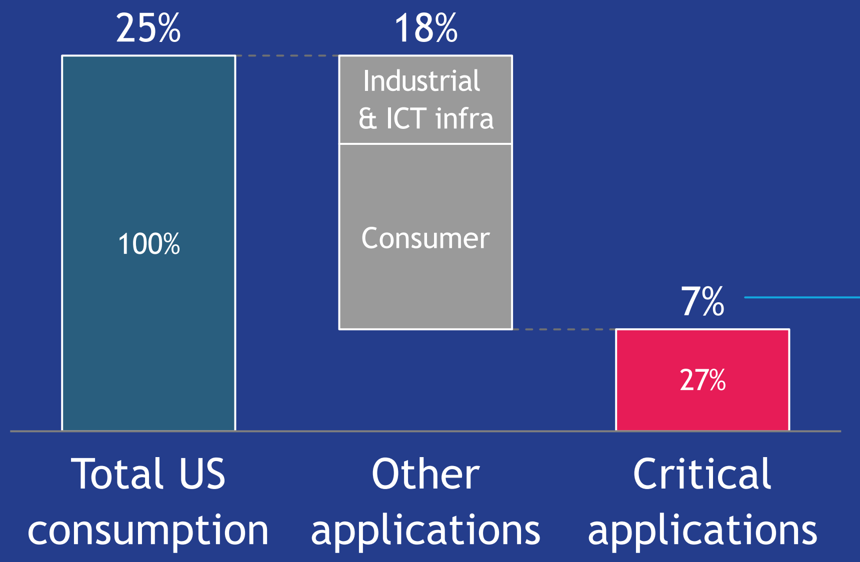
In addition to economic impact, a disruption of supply of semiconductors used in "critical applications" could also have severe implications for national security

A new $50B federal incentive program will enable establishing a minimum viable capacity to cover the US consumption from critical applications

US ANALYSIS: BREAKDOWN OF TOTAL US SEMICONDUCTOR CONSUMPTION, 2019



US consumption as % of global semiconductor sales



Includes:
- Defense & Aerospace
- Telecom networks
- Energy, security and medical equipment
- Data centers of Government and essential sectors (telecoms, energy & utilities, healthcare and financial services)

10-year investment[1] in new fabs for onshore coverage in 2030 ($B)
Private sector + Gov. incentives

Full manufacturing self-sufficiency
~980+410
~60 new fabs

Minimum viable capacity
~230+95
~15 new fabs

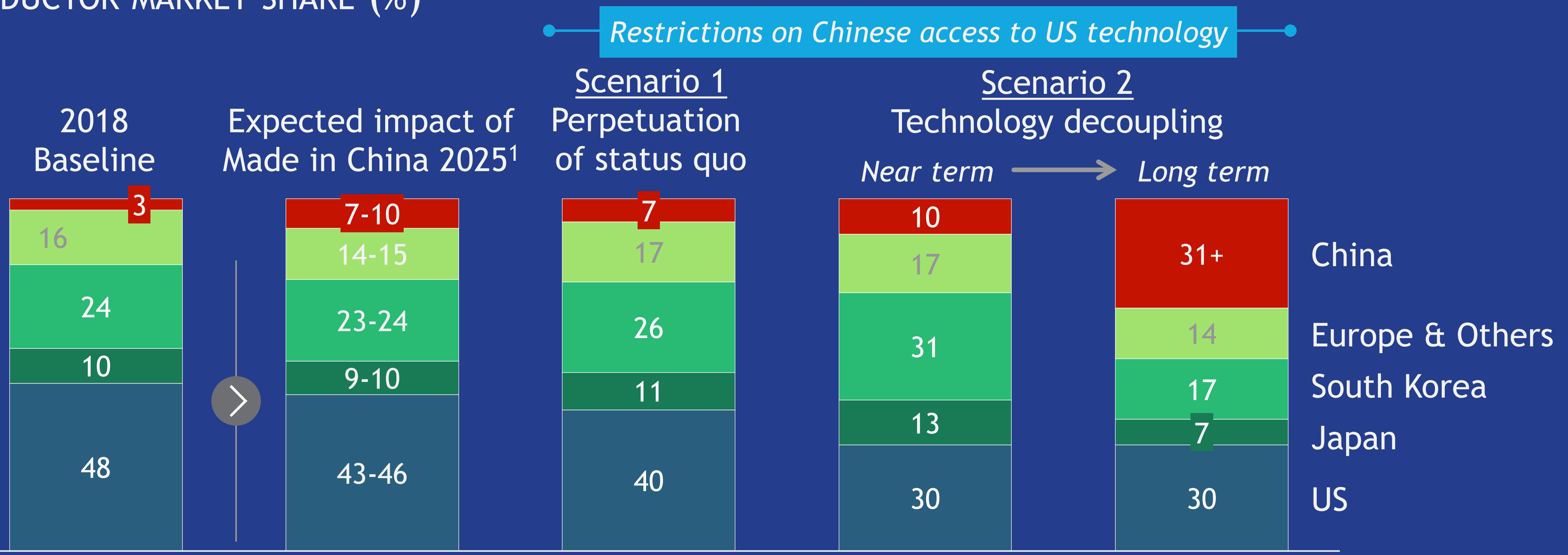
$45B already available (state & local)

$50B of new federal incentives

1. Total Cost of Ownership - includes capex and 10 years of opex, before government incentives
Sources: BCG analysis

Impact of US restrictions to trade with China on the US semiconductor industry could be much higher than the "Made in China 2025" plan alone

Global semiconductor market share (%)



		2018 Baseline	Made in China 2025	Scenario 1	Scenario 2 – Near term	Scenario 2 – Long term
US market share loss	To China		2-5	4	7	(No further direct impact)
	To other countries		-	4	11	
	Total		2-5 points	8 points	18 points	
China's self-sufficiency in semiconductor design[2]		14%	25-40%	25%	40%	85%+

Source: BCG analysis and estimates using data from Gartner and company reports, Morgan Stanley, IC Insights

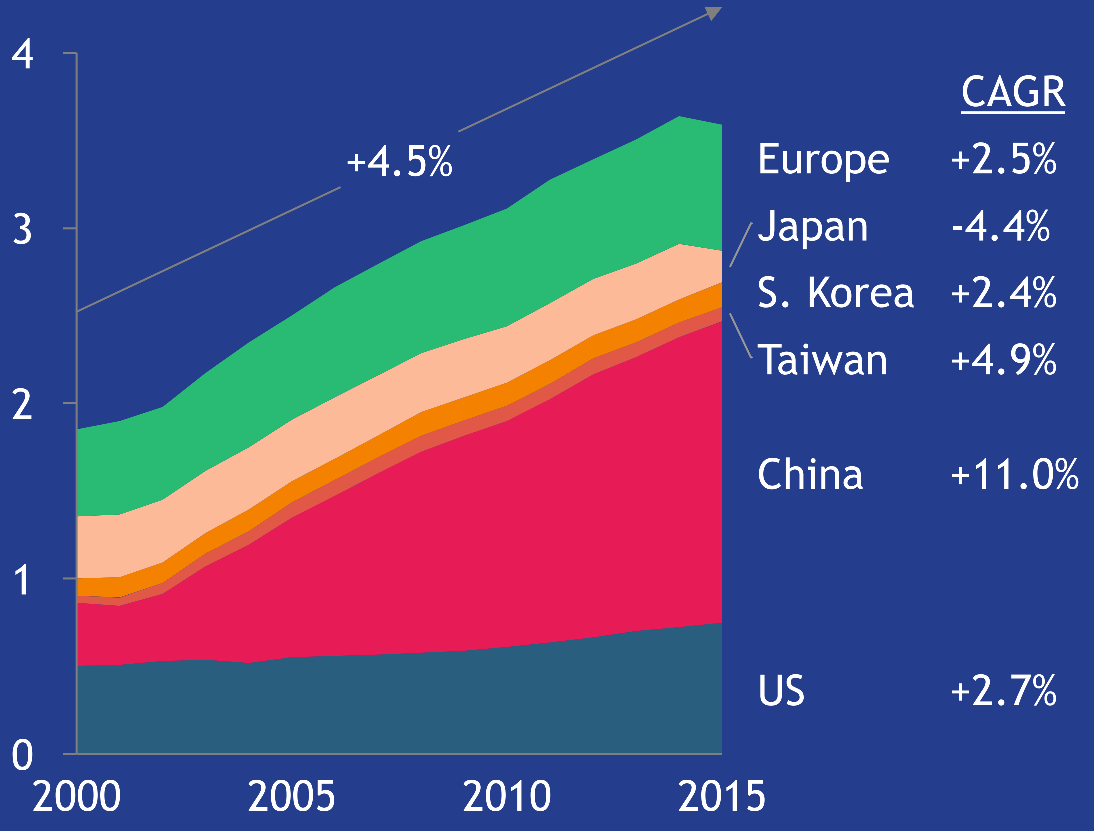
[1] Assuming that Chinese share gains come at the expense of foreign suppliers proportionally to the current shares in each product line

[2] Calculated as China supply (revenues of Chinese fabless design + IDM companies) over China demand (value of semiconductors in end devices designed by Chinese device makers)

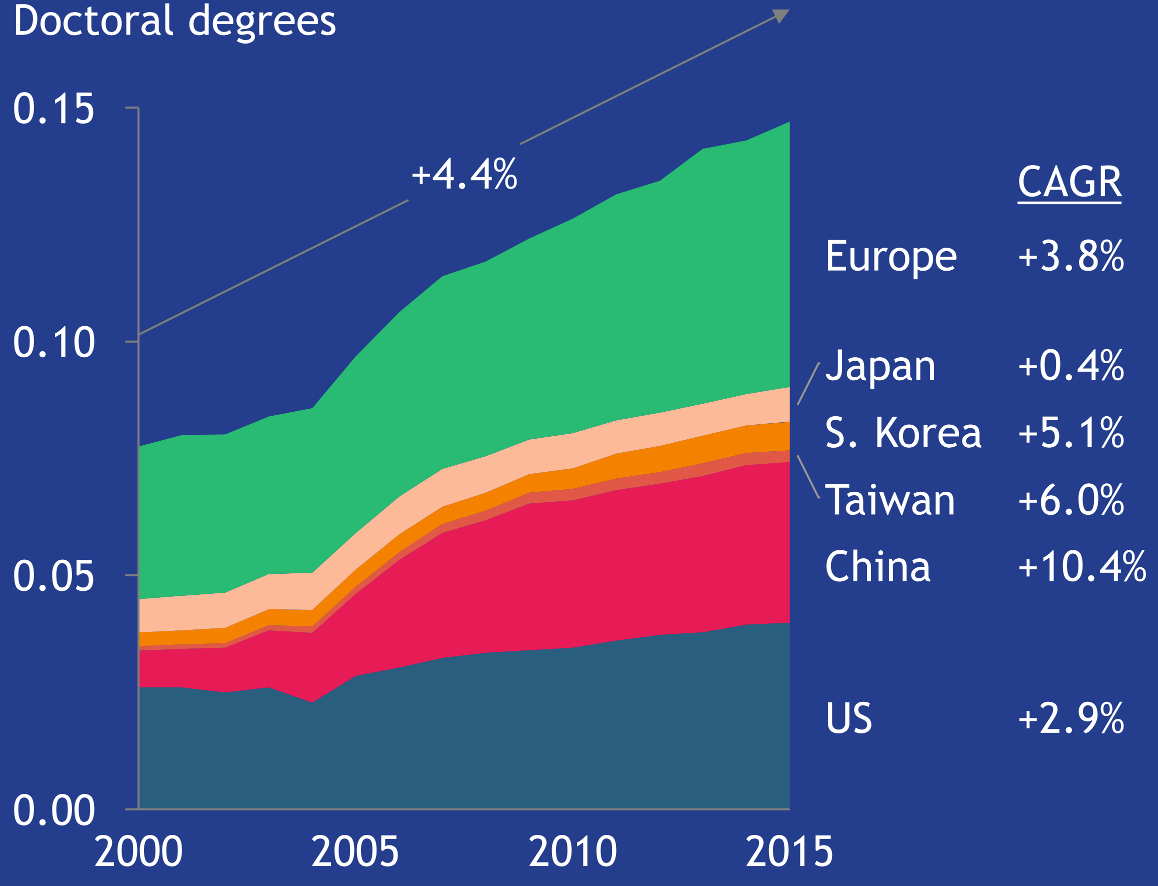
The historical growth rate of the total global talent pool is likely insufficient to meet the industry demand for talent

Annual Graduates in Science and Engineering (millions)

First university degrees



Doctoral degrees



Sources: BCG analysis with data from US National Center for Science and Engineering Statistics (NCSES)

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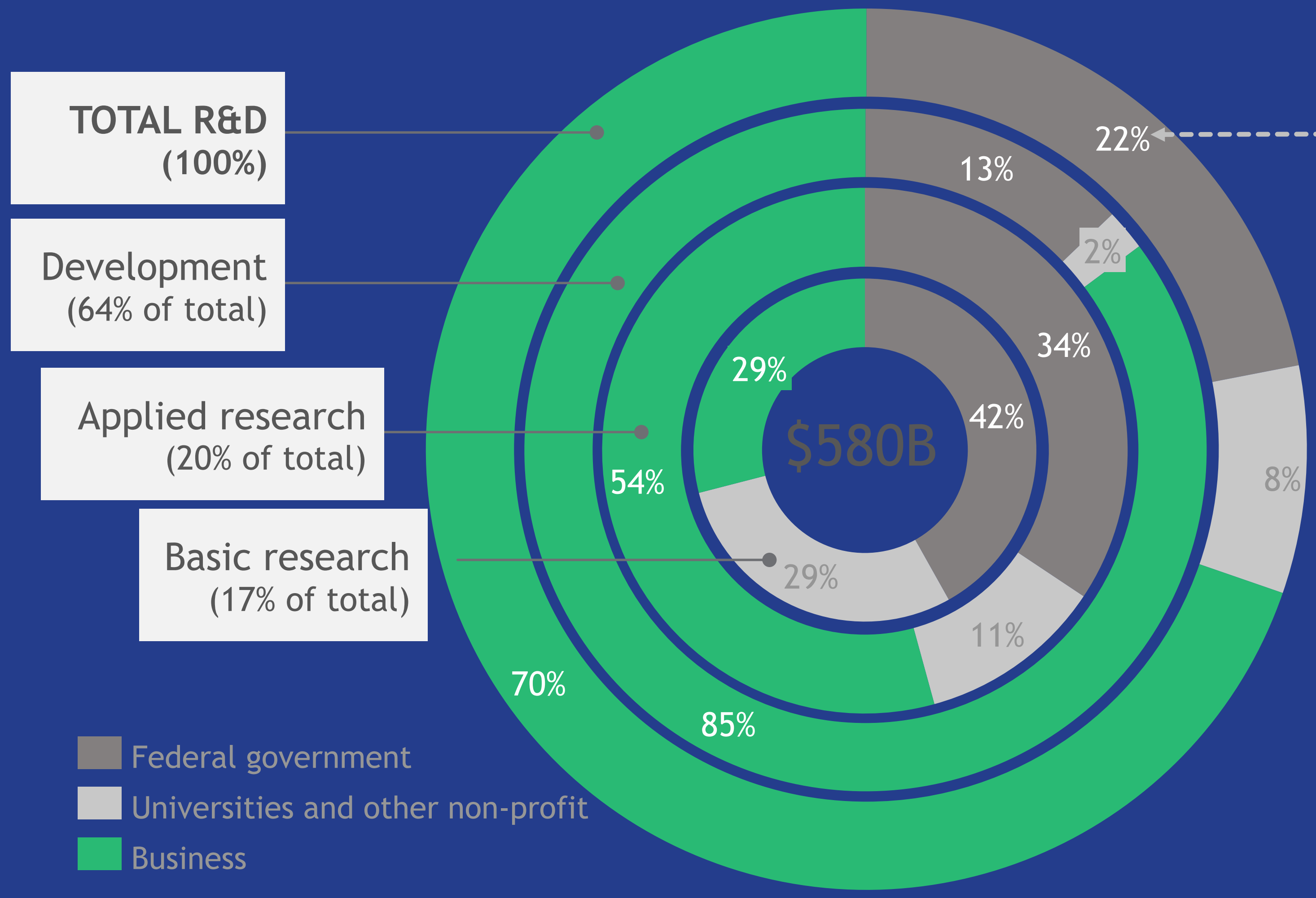
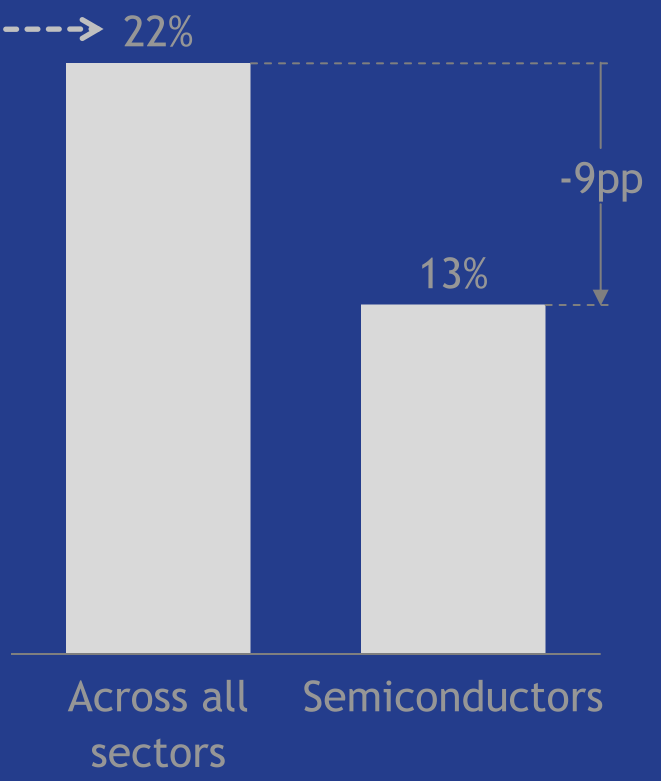
Government has a critical role in R&D – particularly in basic research. US Government participation in semiconductor research is trailing behind

Total US R&D Investment across All Sectors, 2018



Comparison of US Federal Government Share in Total R&D Investment, 2018



Sources: BCG analysis with US National Science Foundation and OECD data, SIA

STRENGTHENING THE GLOBAL SEMICONDUCTOR SUPPLY CHAIN FOR THE NEXT DECADES OF INNOVATION

Policies in pursuit of blanket “self-sufficiency”, with staggering cost and questionable feasibility, are not the answer…

… INSTEAD, TARGETED POLICIES THAT:

- Improve global resiliency by promoting a more geographically diversified global manufacturing footprint
  - Construction of new semiconductor manufacturing capacity in US, Europe (e.g. minimum viable capacity for consumption from critical applications)
  - Supplier/plant diversification of location for key materials
- Expand market access and promote open trade, while also balancing the needs of national security
  - Levelled playing field and IP protection
  - International collaboration in research and global technology standards
  - Clear, stable policy framework for targeted controls on semiconductor trade
- Stimulate basic research in semiconductors with appropriate government-funded programs
- Invest further in Science & Engineering education, complemented with immigration policies that enable the US to continue attracting world-class talent

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