ICOS

International Cooperation On Semiconductors

Horizon Europe ICOS "*International Cooperation on Semiconductors*" :

EU and non-EU strengths, weaknesses, dependencies, opportunities for international collaboration

Francis Balestra - Grenoble INP/ CNRS/ SiNANO Institute

Semicon Europa 2024 - November 12, 2024

Funded by the European Union

ICOS: International Cooperation On Semiconductors

- ICOS Project starts in January 2023 for three years, funded by the Horizon Europe research program.

Coordinator

Technical co-Coordinator

- An ambitious project in the framework of the European strategy for semiconductors.

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Motivation & Objectives

- **Semiconductors & Semiconductor-based photonics** are pivotal technologies for almost all existing industrial sectors, as demonstrated by the recent chips shortages
- **International cooperation** is key for **speeding up** technological innovation (e.g. ITRS/IRDS, IPSR-I, ECS-SRIA, NEREID), reducing **cost** by avoiding duplicated research, strengthening complex supply and value chains, and is encouraged by the new **strategies** of leading semiconductor countries

=> To build **balanced semiconductor partnerships** with like-minded countries

=> To set out cooperative framework on *initiatives of mutual interest*

=> To identify and support the establishment of the **most promising scientific international collaborations**

=> To support the growth of the European Semiconductor industry through **focused research alliances** based on awareness of advanced research activities

=> To strengthen **Europe's position** in global value chains in this area and to contribute to the **EU Chips Act, Green deal and Digital Agenda**

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Objectives of ICOS

- **Investigated countries:**

  - The United States of America
  - India
  - The Republic of Korea
  - Japan
  - Taiwan
  - Singapore
  - China
  - Canada (for some analysis)

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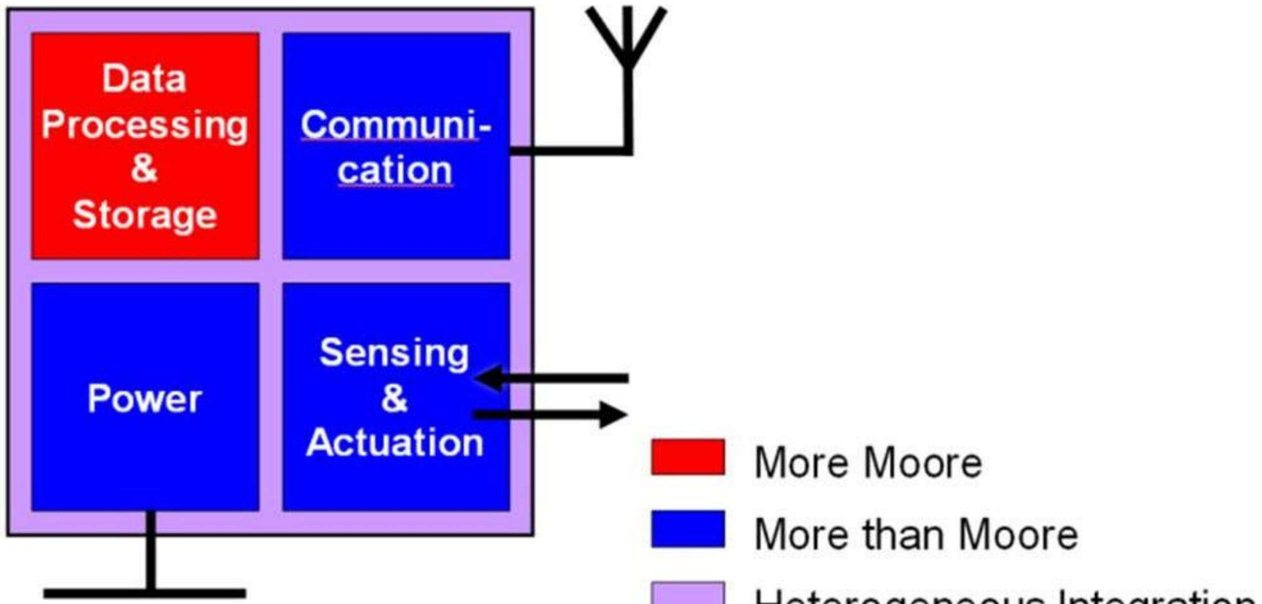
Main scientific topics

- Advanced computing & Advanced functionalities: sensing, RF & optical communications, optical devices, energy harvesting, power devices, …



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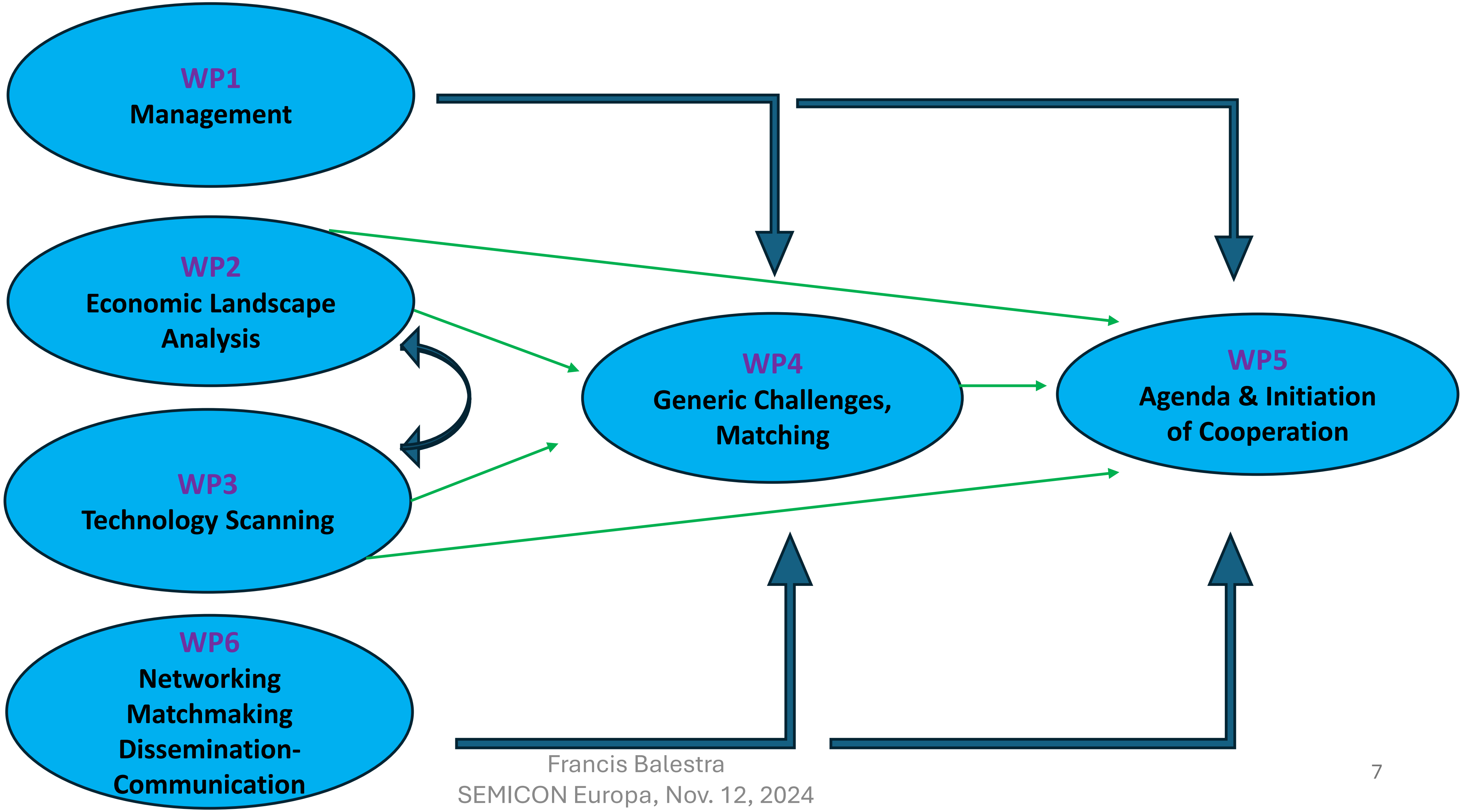
ICOS Concept



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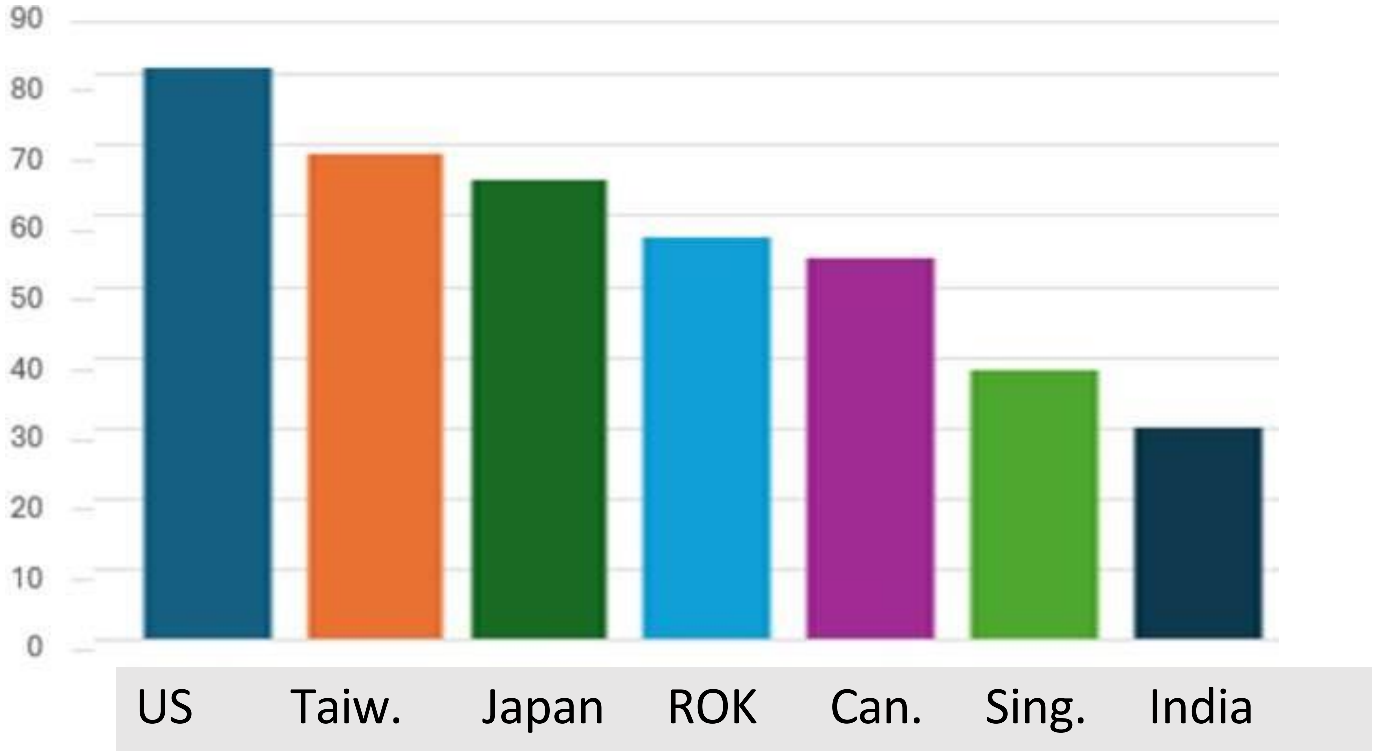
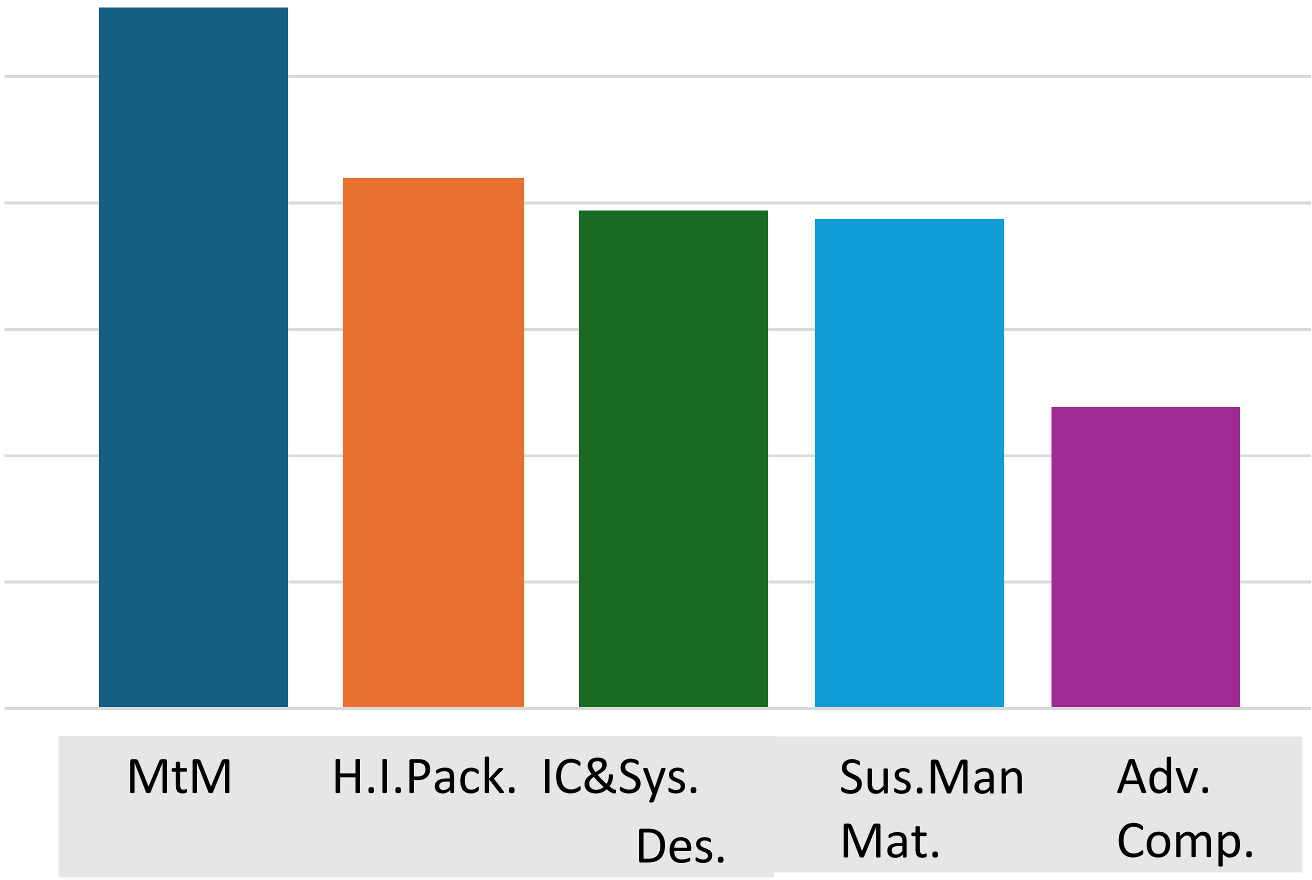
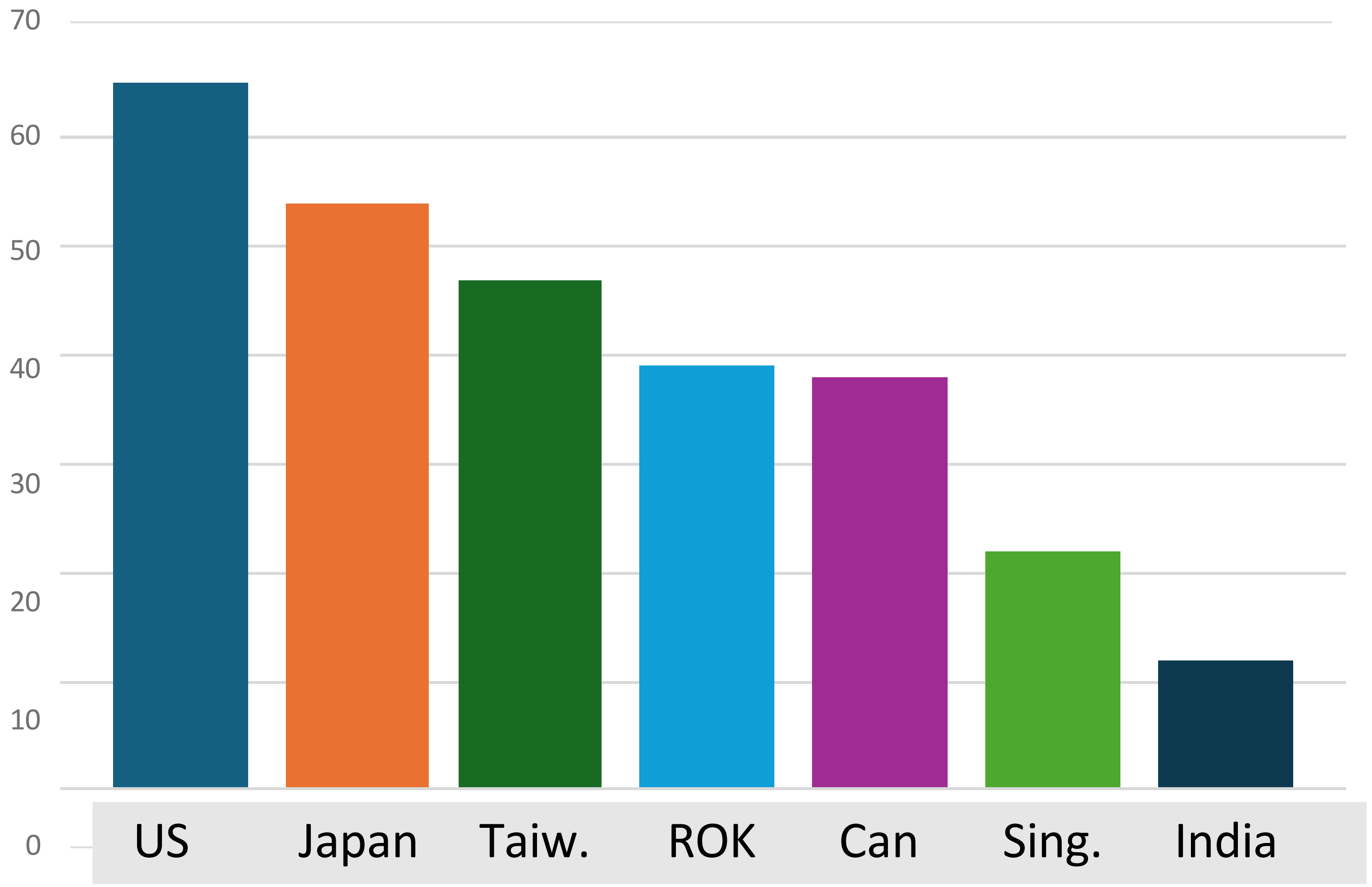
Countries for cooperation



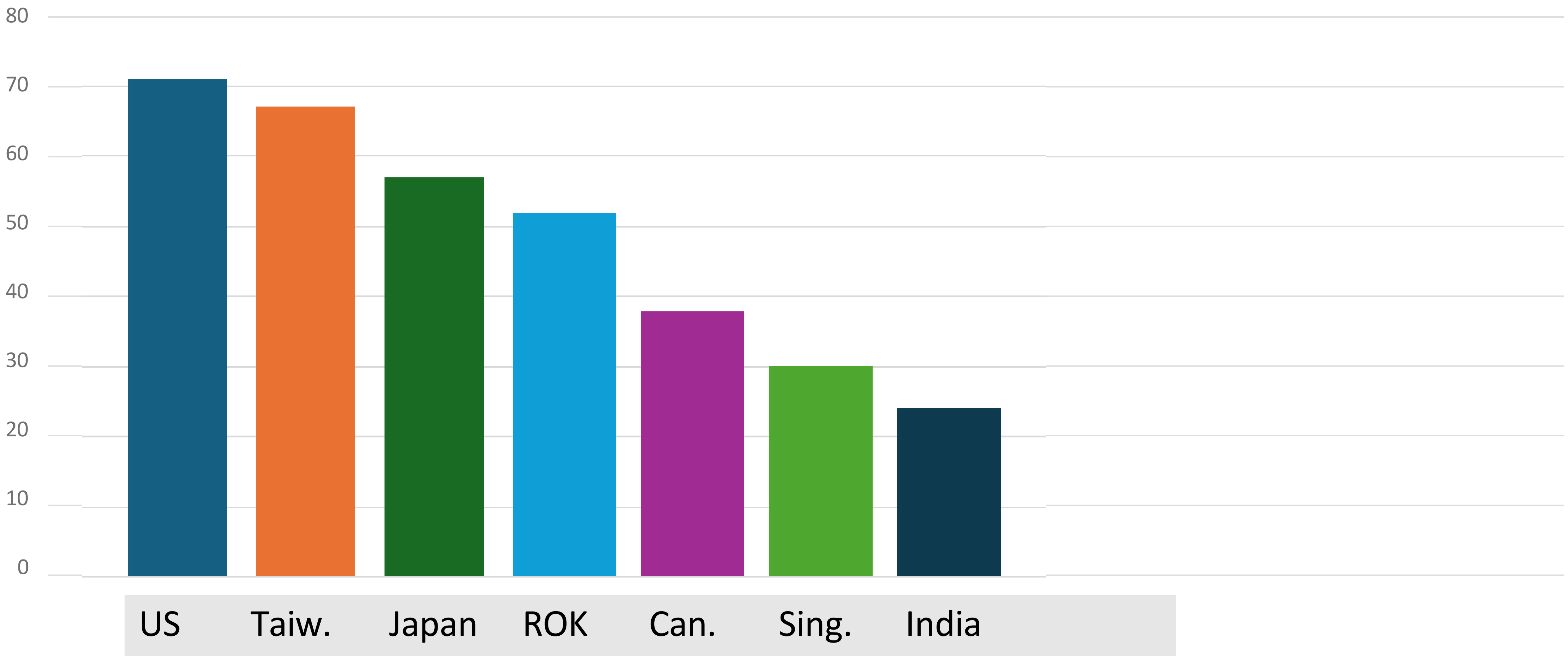
Topics for cooperation (average of the 7 countries)



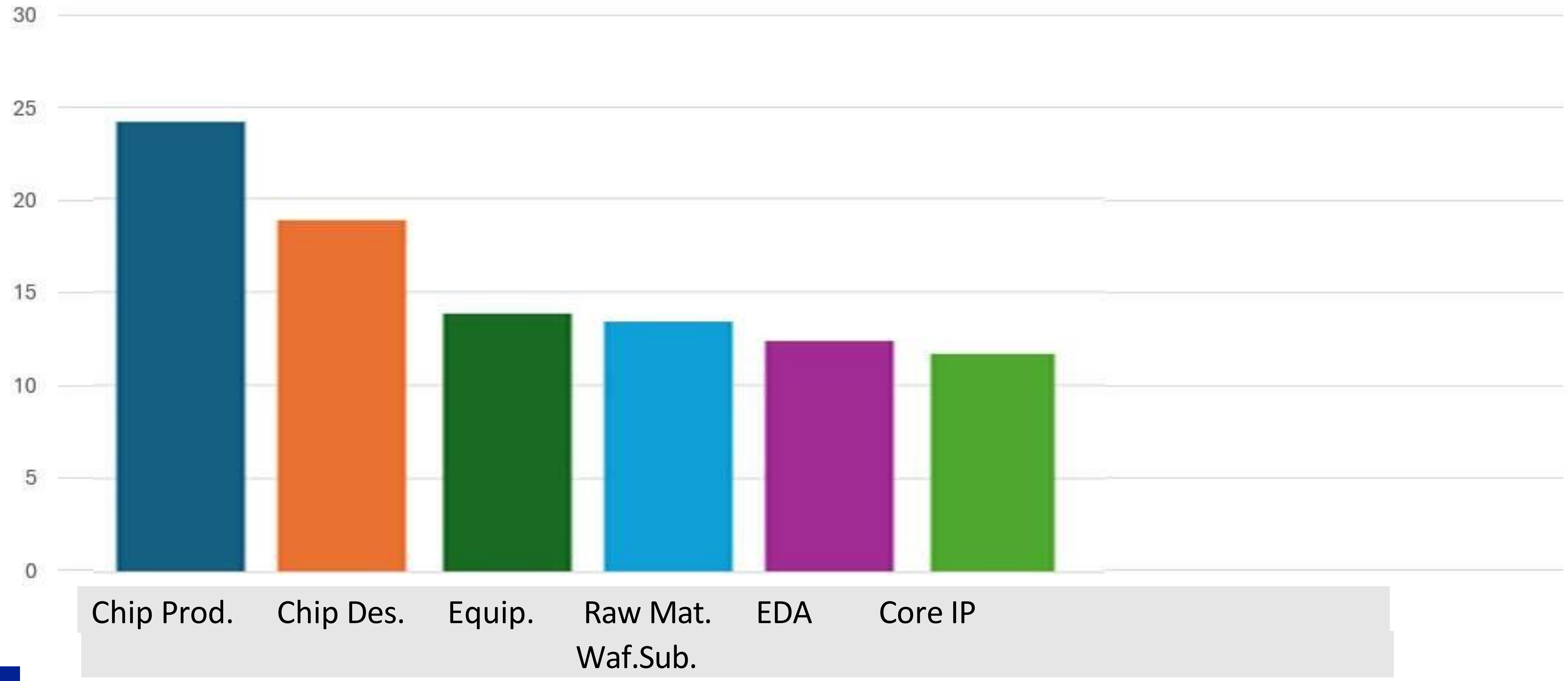
Access to Research Infrastructures



Cooperation in the semiconductor value chain



Topics for cooperation in the semiconductor value chain (average of the 7 countries)



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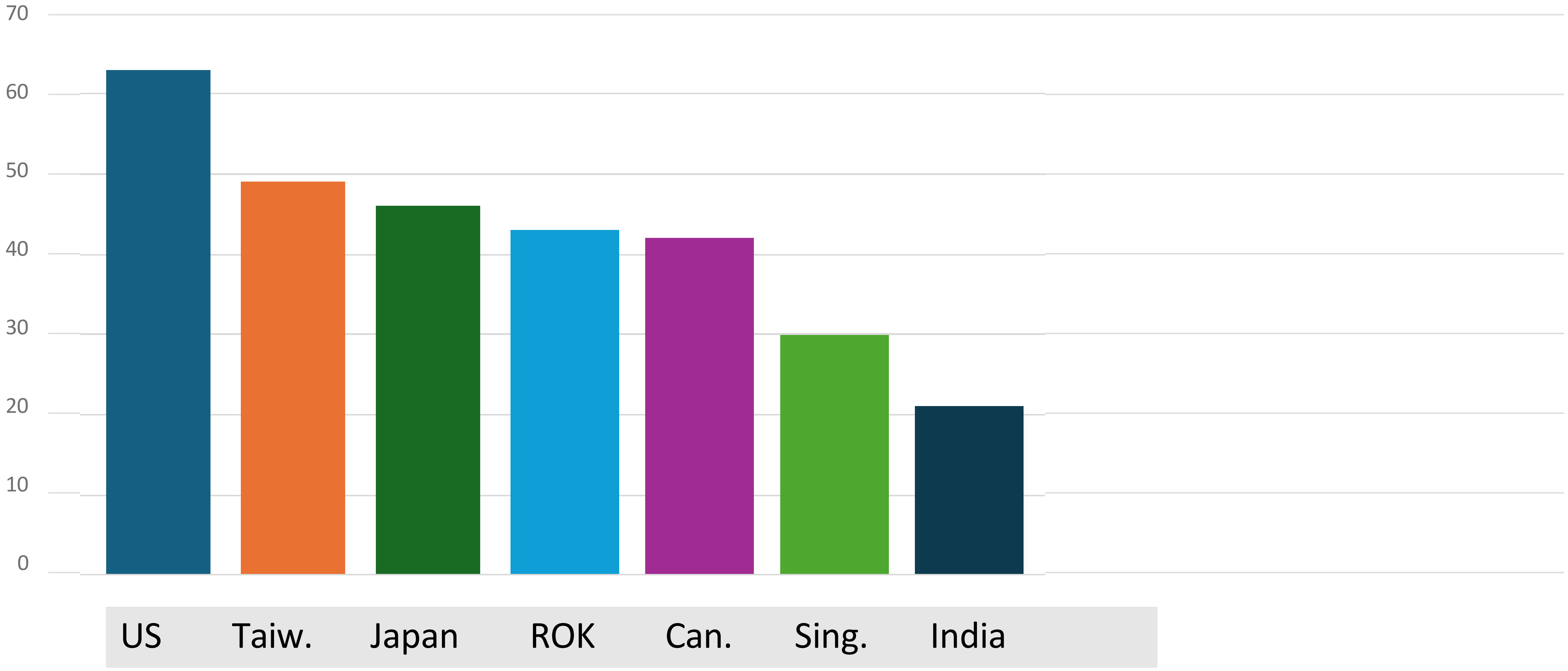
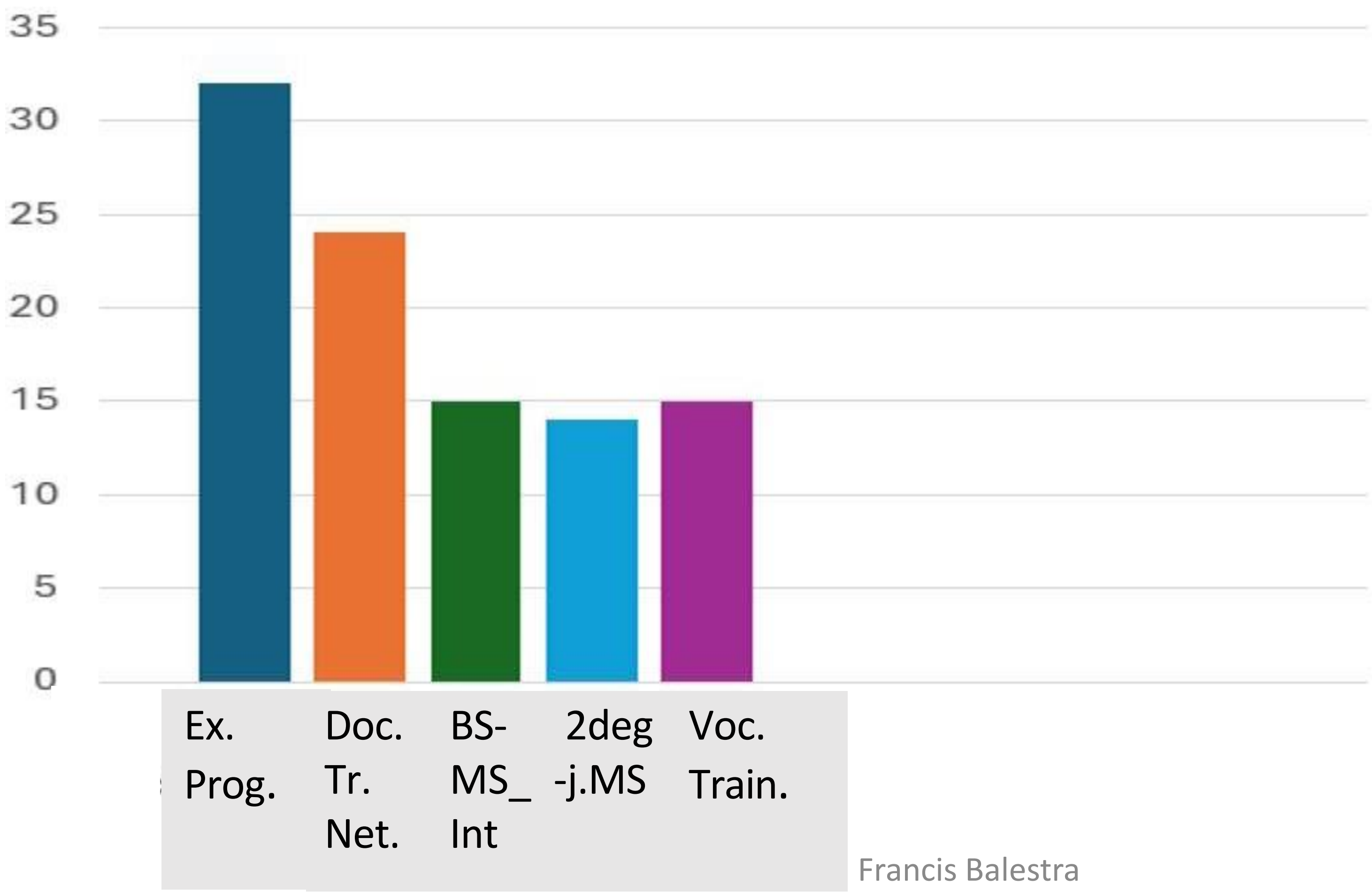
Cooperation in joint skill programmes



Which type of joint skill programmes would you be interested in? (average of the 7 countries)



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Analysis of the semiconductor industrial ecosystems

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WHERE EUROPE IS LEADING

Automotive Semiconductor Market Leaders

1. NXP Semiconductor NV
2. Infineon Technologies AG
3. Renesas Electronics Corporation
4. STMicroelectronics NV
5. Toshiba Electronic Devices & Storage Corporation (Toshiba Corporation)

Power Semiconductor Top Companies

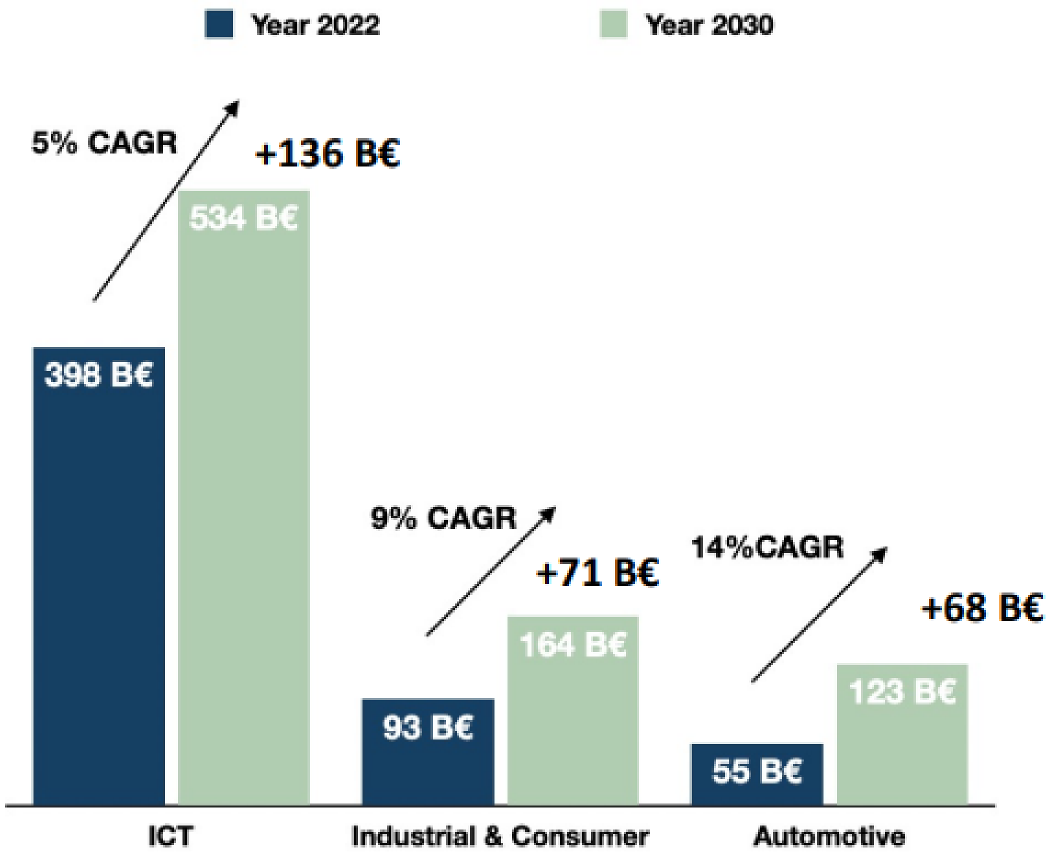
1. Infineon Technologies AG
2. Texas Instruments Inc.
3. STMicroelectronics NV
4. NXP Semiconductors NV
5. On Semiconductor Corporation

MEMS Market Leaders

1. Broadcom Inc.
2. Robert Bosch GmBH
3. STMicroelectronics N.V.
4. Texas Instruments Inc.
5. Qorvo Inc.

Source: Mordor Intelligence, 2022

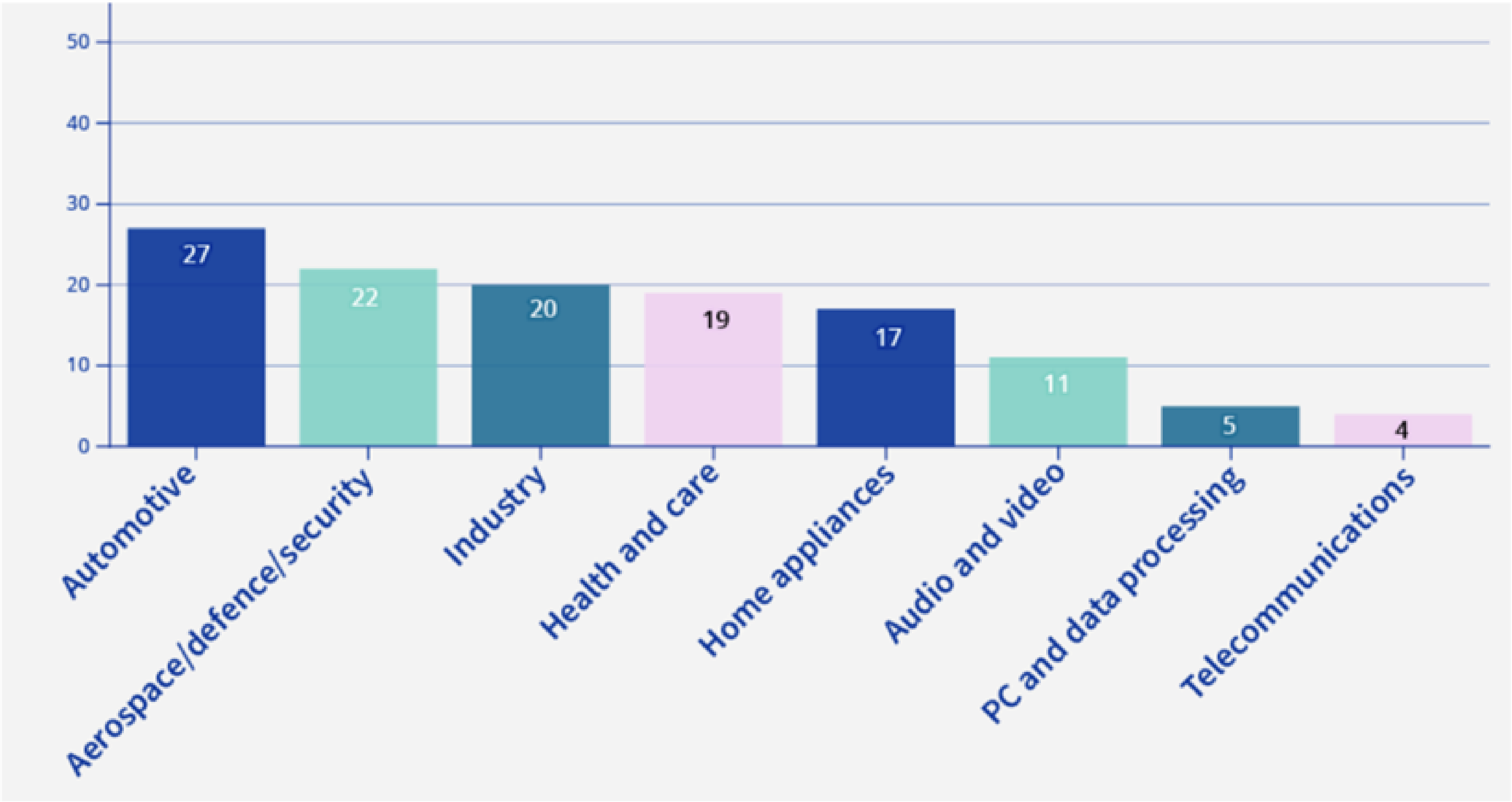
Semiconductor growth forecasts by 2030 by end-market



Source: DECISION Etudes & Conseil, Mc Kinsey, WSTS

- ICT remains the largest application, greatest growth expected on automotive

Europe’s market shares in chip production for different sectors in 2023 (in %)



Source: European Council of the EU, 2023

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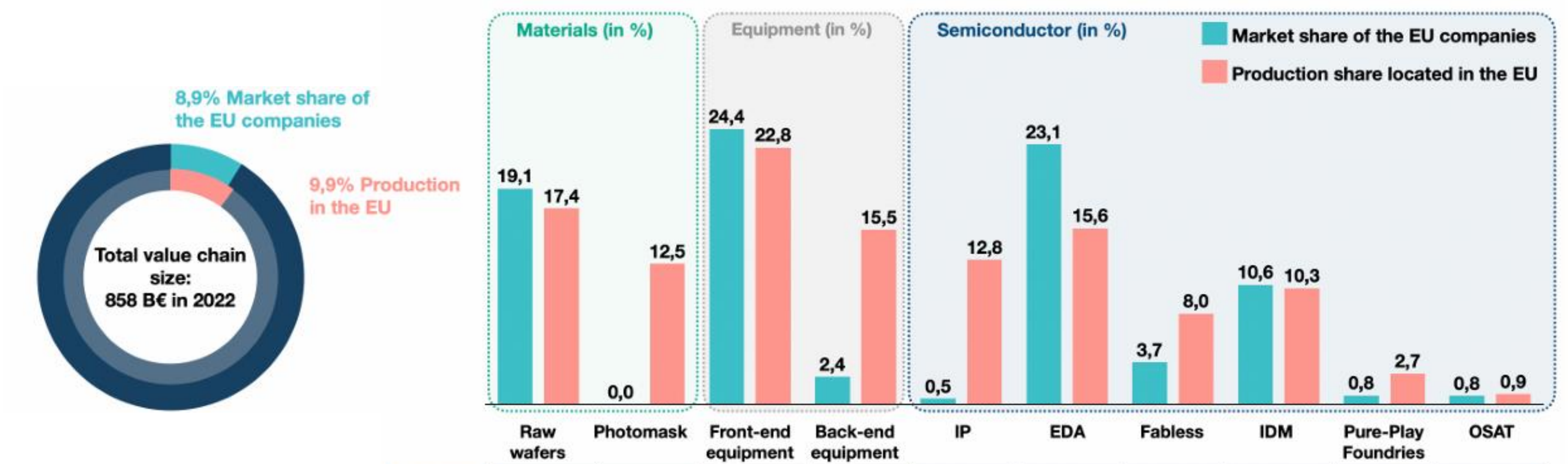
Market and production shares of EU players in 2022

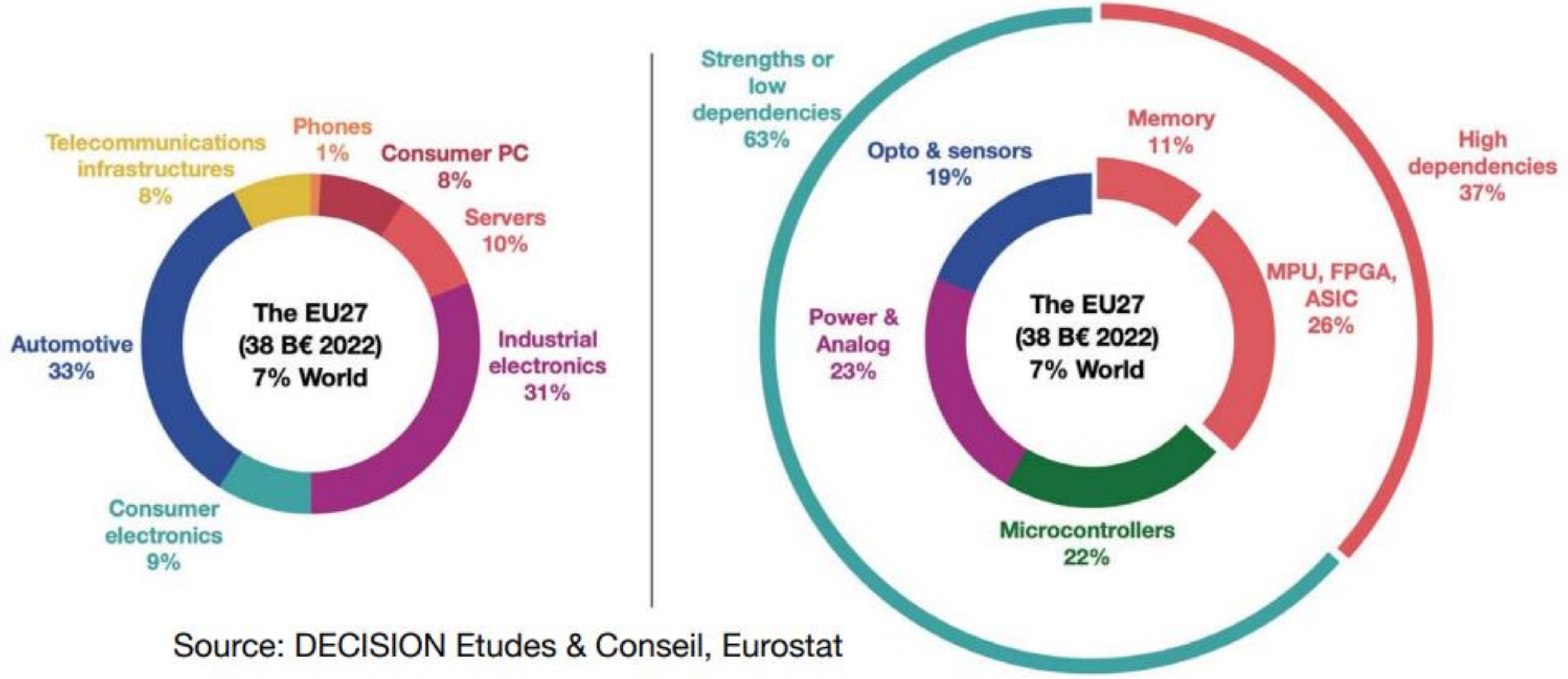


	Raw wafers	Photomask	Front-end equipment	Back-end equipment	IP	EDA	Fabless	IDM	Pure-Play Foundries	OSAT
Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

In comparison, the EU account for 17% of the global GDP in 2022[29].

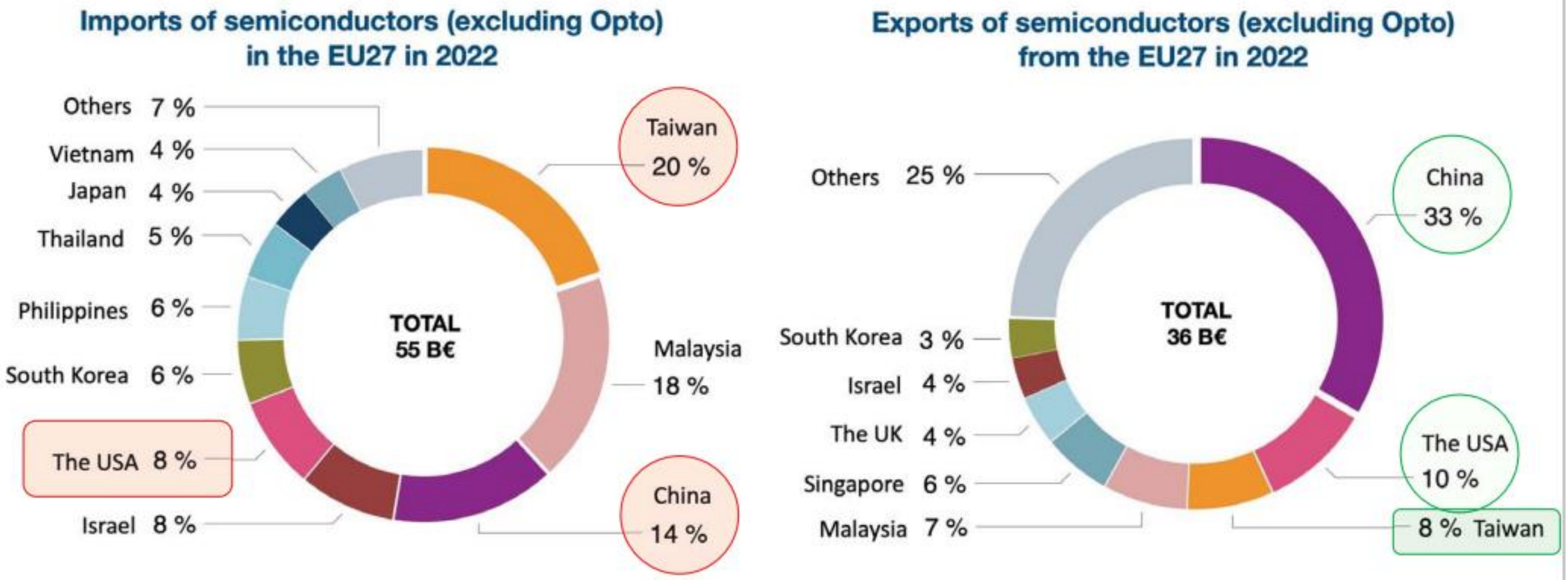
Source: DECISION Etudes & Conseil

Description of the semiconductor demand in the EU by application and products



Source: DECISION Etudes & Conseil, Eurostat

Semiconductor trade partners of the EU (by location)



Source: DECISION Etudes & Conseil, Eurostat, 2023

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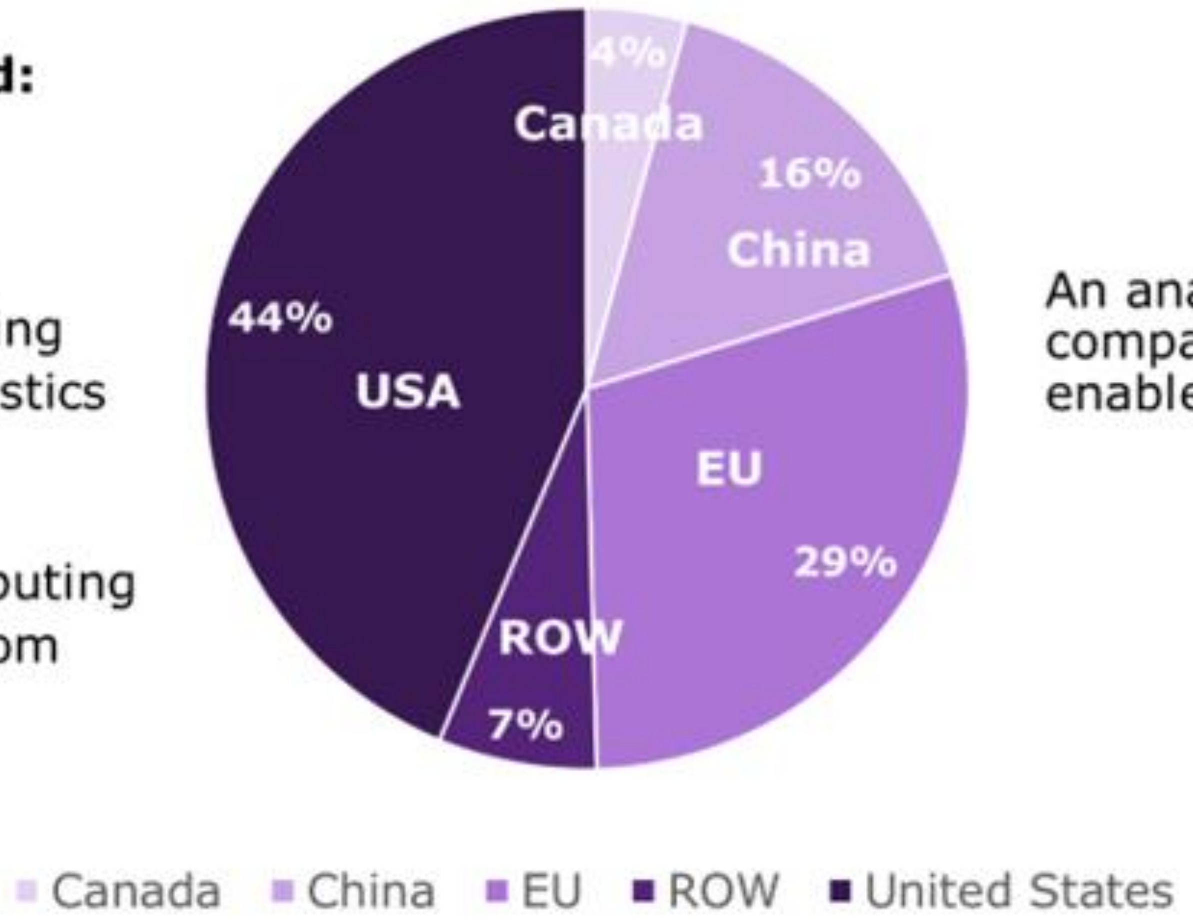
Global spread of silicon photonics end-users

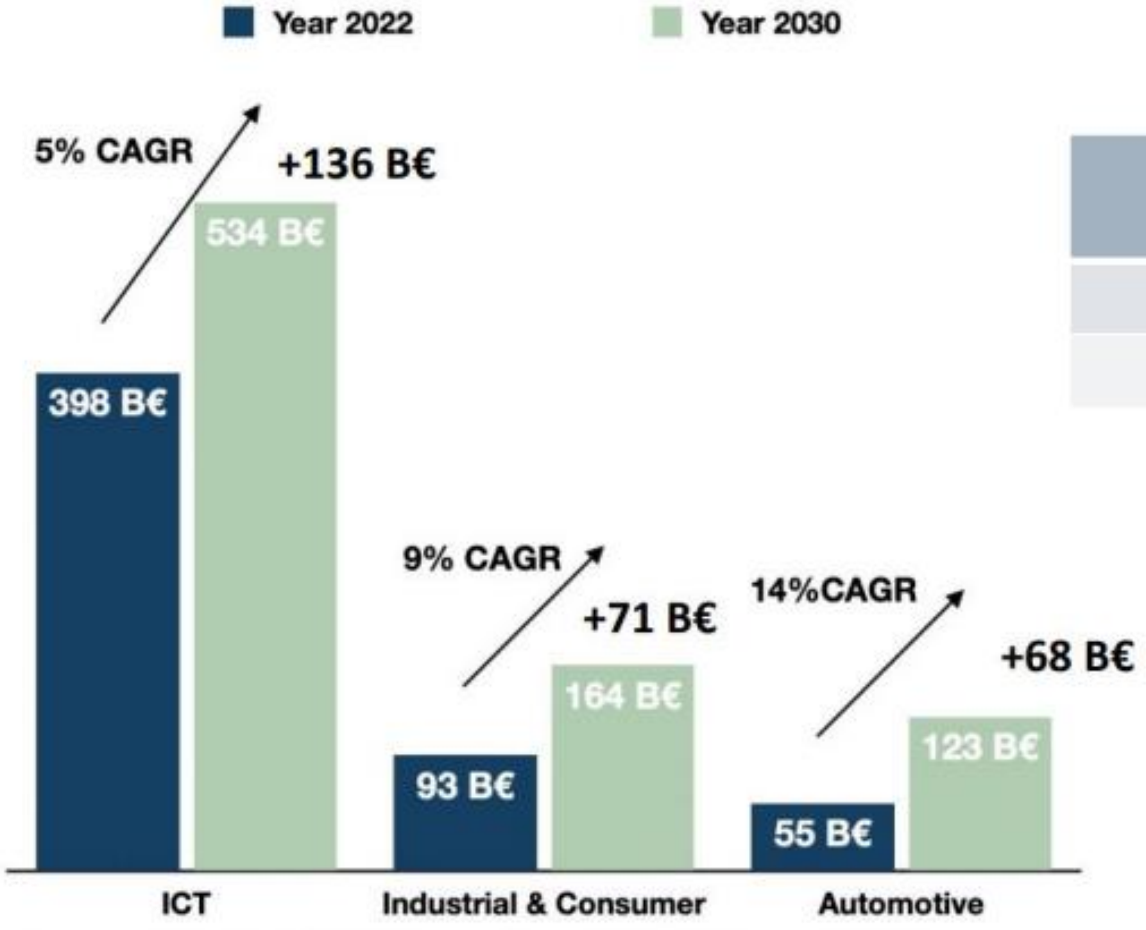
Industries served:

- ☐ Agrifood
- ☐ Automotive
- ☐ HPC
- ☐ Industrial sensing
- ☐ Medical Diagnostics
- ☐ Optical IO
- ☐ Photonics AI
- ☐ Quantum Computing
- ☐ Telecom/datacom



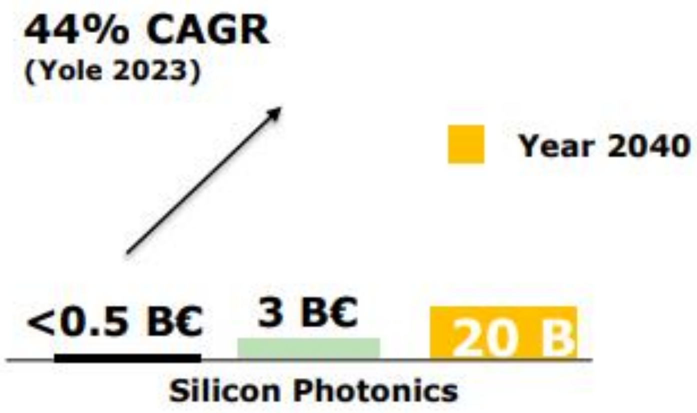
An analysis based on 125 companies developing SiPh-enabled products

Growth in Photonic Chips



Source: DECISION Etudes & Conseil, Mc Kinsey, WSTS

Silicon Photonics Market ÷ Semiconductor Market	
2023	< 0.1%
2040	> 1%



Source: Yole market studies; Roel Baets

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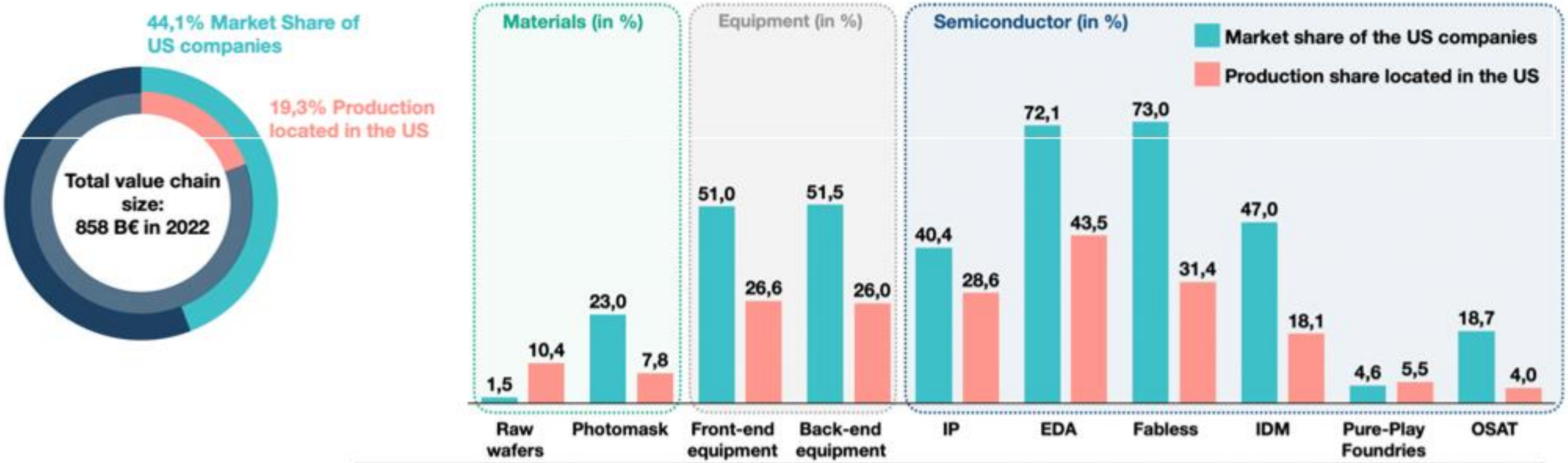
Market share and production share across the value chain: USA example



Global market size	16 B€	2.5 B€	96 B€	12 B€	6 B€	8 B€	168 B€	377 B€	127 B€	44 B€

Source: DECISION Etudes & Conseil

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The USA's main strengths against the EU

	Key Applications	Industry contenders (EU)	Industry leaders (USA)
Microprocessor Design and manufacturing	AI/HPC Automotive (ADAS)	NXP, KALRAY THE POWER OF MORE, 15 other start-ups	NVIDIA, AMD, intel, Qualcomm
Advanced front-end manufacturing	AI/HPC Automotive (ADAS)	ST, infineon, xfab	intel
Back-end equipment & Manufacturing / Advanced packaging	All applications	ST, infineon, imec, Besi, AT&S	Amkor Technology, TERADYNE, intel
Photomask	All applications	ZEISS, IMS Nanofabrication	APPLIED MATERIALS, PHOTRONICS
Front-end equipment (except EUV photolithography)	In particular etching & cleaning with LAM Research)	Deposition: ASM, AIXTRON Metrology & quality control: ASML	APPLIED MATERIALS, Lam RESEARCH, KLA Tencor
Nand Flash & DRAM Design & Manufacturing	Mobile phones, PC Consumer electronics		Micron, KIOXIA, WD Western Digital

Source: DECISION Etudes & Conseil

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Identification of the main technologies for international cooperation

"Advanced functionalities"

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Sensor Technologies

- Concept 1- Motion Sensors
- Concept 2 - Pressure Sensors
- Concept 3 - Advanced Drive Assistance Systems
- Concept 4 - Environmental Sensors
- Concept 5 - Agri-food Sensors
- Concept 6 - Sensors for Medical and Healthcare Applications
- Concept 7 - Molecular Diagnostics
- Concept 8 - Native CMOS-based physical sensor interfaces
- Concept 9 - Sensors for energy (new)
- Concept 10 - Sensors for Smart Cities (new)

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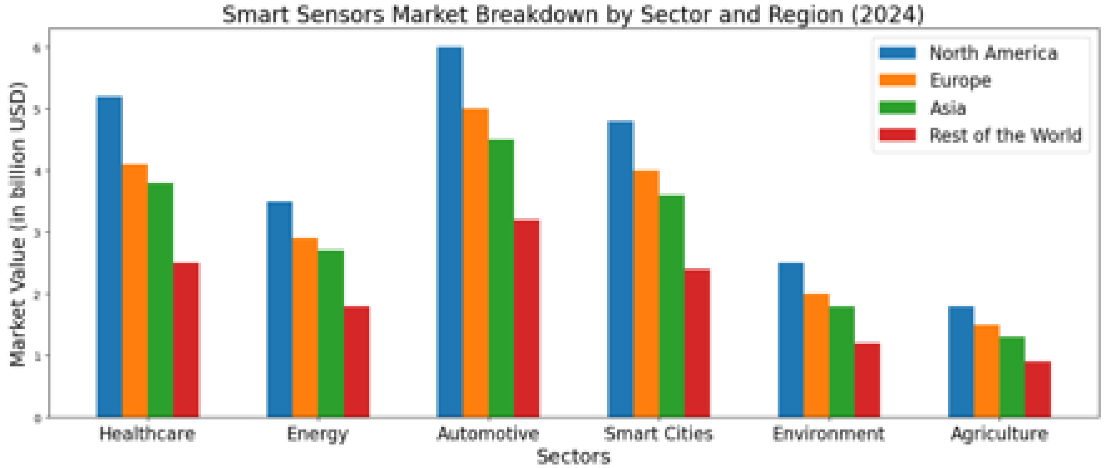
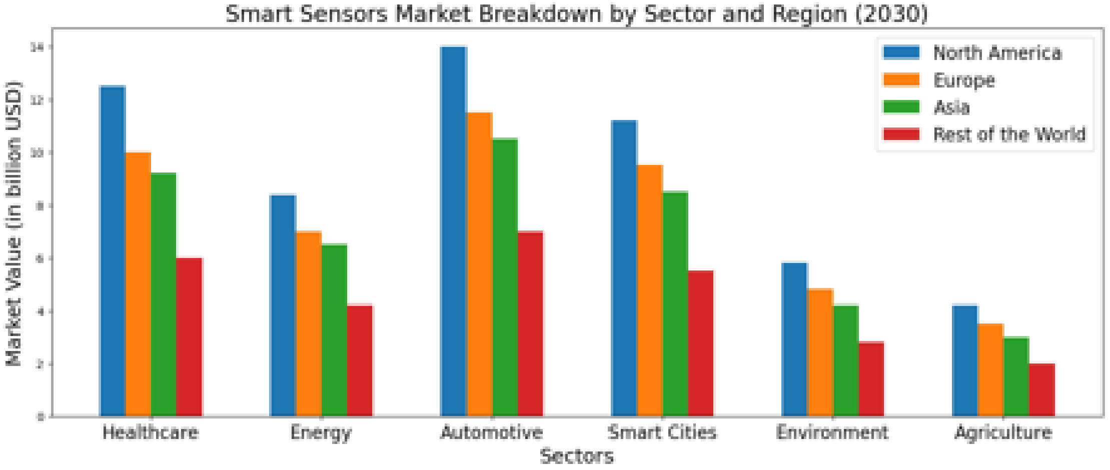
Sensor Technology Market by Sector





Global values 2024 ➔ 2030

Healthcare: $15.6 ➔ $37.7 billion

Energy: $10.9 ➔ $26.1 billion

Automotive:$18.7 ➔ $43 billion

Smart Cities:$14.8 ➔ $35 billion

Environment: $7.5 ➔ $17.6 billion

Agriculture: $5 ➔ $15 billion

Sources:
grandviewresearch.com
mordorintelligence.com
market.us
emergenresearch.com
theinsightpartners.com

Main Sensor Technology Markets

1. MEMS (Micro-Electro-Mechanical Systems): This segment is expected to hold a significant share of the market, driven by its applications in consumer electronics, automotive, and industrial sectors. **USD 35 billion** by 2030

2. CMOS (Complementary Metal-Oxide-Semiconductor): CMOS sensors, primarily used in imaging applications, are anticipated to grow substantially. USD 25 billion by 2030

3. Optical: With the increasing demand for miniaturized and integrated sensor solutions, **USD 20 billion** by 2030

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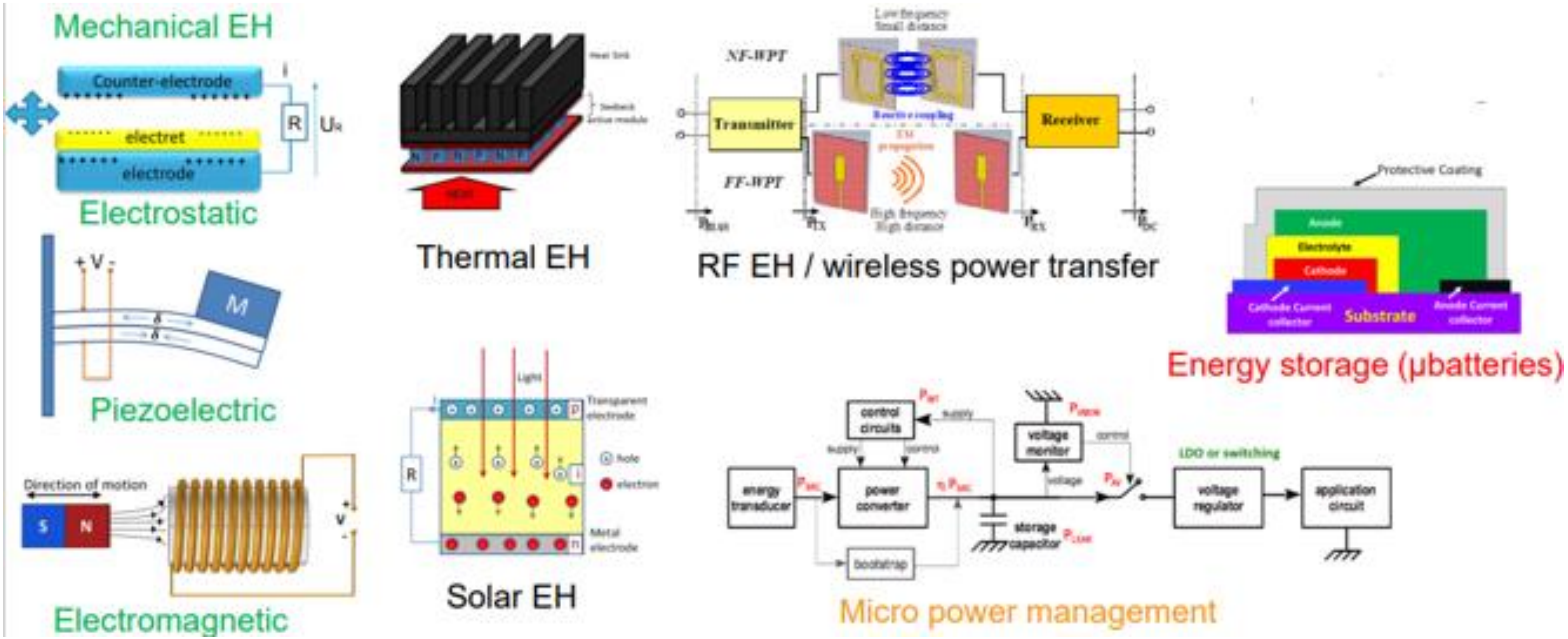
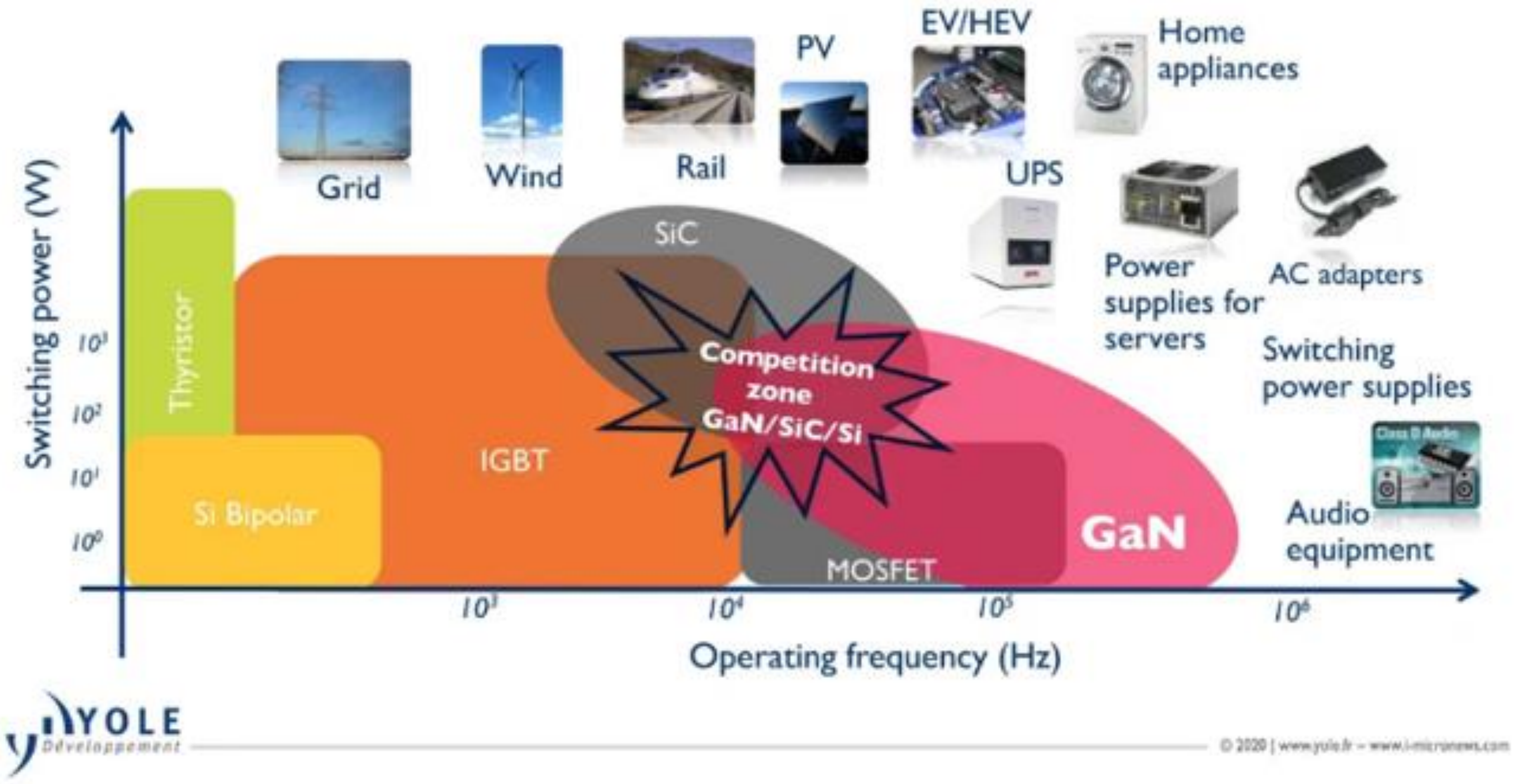
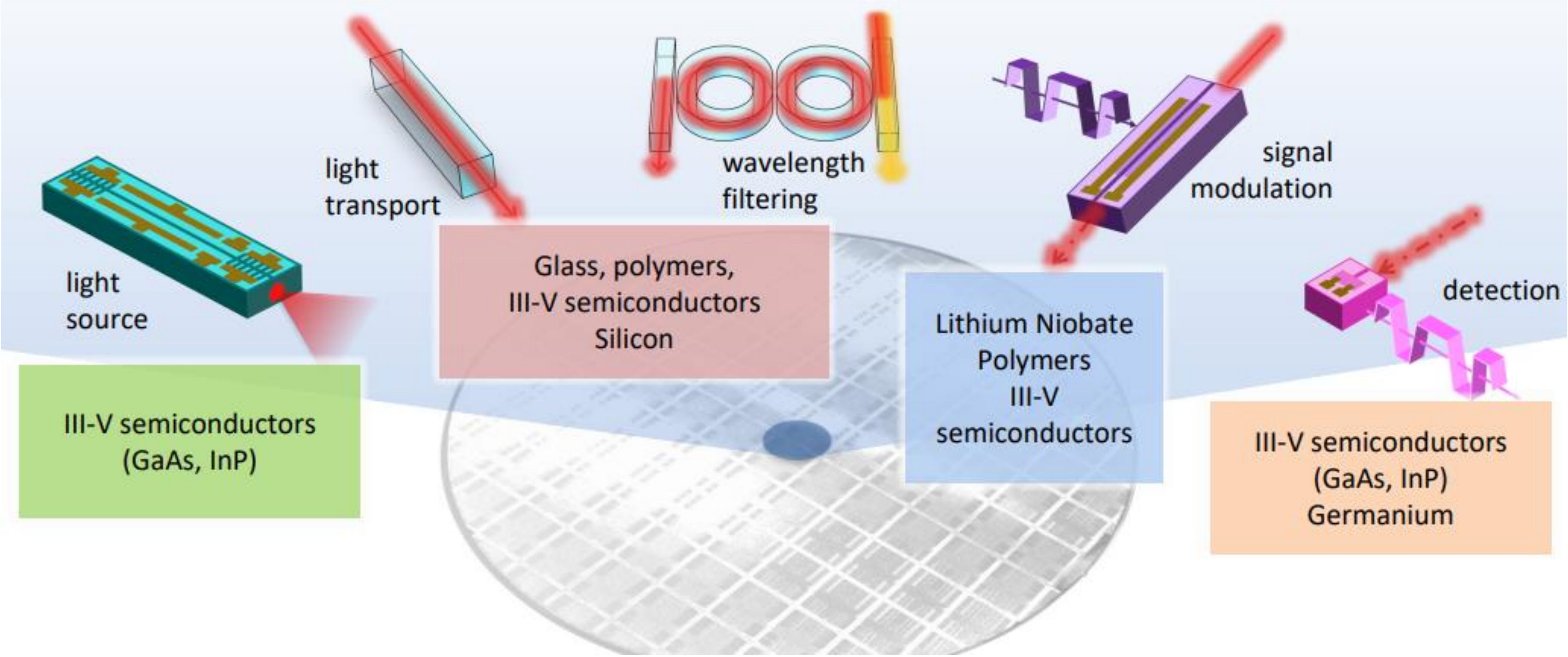
Energy Harvesting technologies



Smart power technologies



Photonics Integrated circuits



Challenges for Photonics Ecosystems

- Low volume: need more applications
- Getting the best materials (Heterogeneous integration)
- Design and modelling (first-time-right capabilities)
- Rapid prototyping (bypass long chip iteration cycles)
- Packaging (optical, electrical, mechanical, thermal, RF)
- Combining photonics and electronics

Challenges & possible solutions: Advanced functionalities

- Innovation in **new, highly sensitive and more versatile sensors** requiring more advanced sustainable (bio)materials innovation and integration
- **For energy harvesters the improvement of the performance**/ efficiency is as important as the development of "**green" materials**
- **Wide band gap** (e.g. SiC, GaN) and **ultrawide band gap materials** (e.g. AlN, GaOx, diamond) for power devices
- **Heterogeneous integration** of best materials for target application
- Hybrid integration of various functional chips
- **Advanced design tools**, including multi-physics simulation for first-time-right modelling capabilities
- **Rapid prototyping** to bypass long chip iteration cycles (e.g. PDK, ADK availability)
- **Packaging that meets multiple design requirements** such as optical, electrical, mechanical, thermal, RF, (bio-)fouling etc.

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Challenges For Future Compute Systems

CMOS and DRAM PPAC

Memory Wall

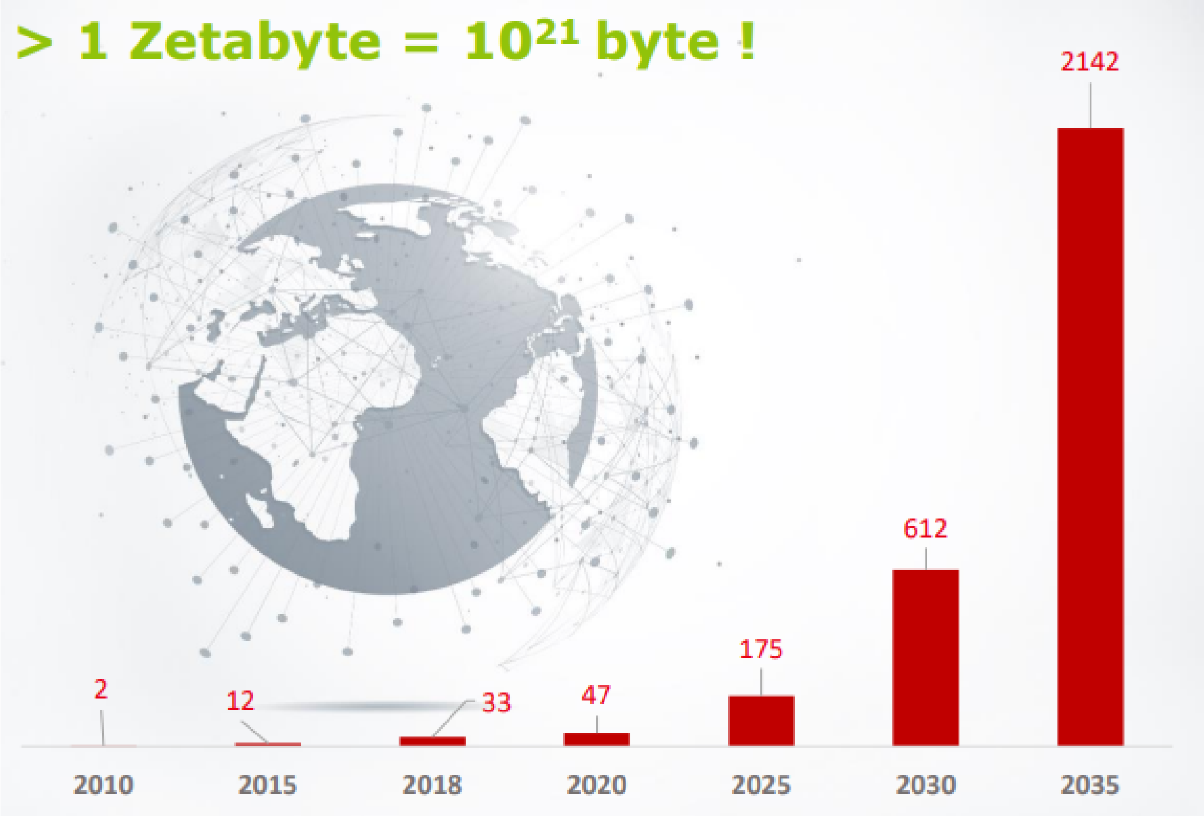
Power Wall

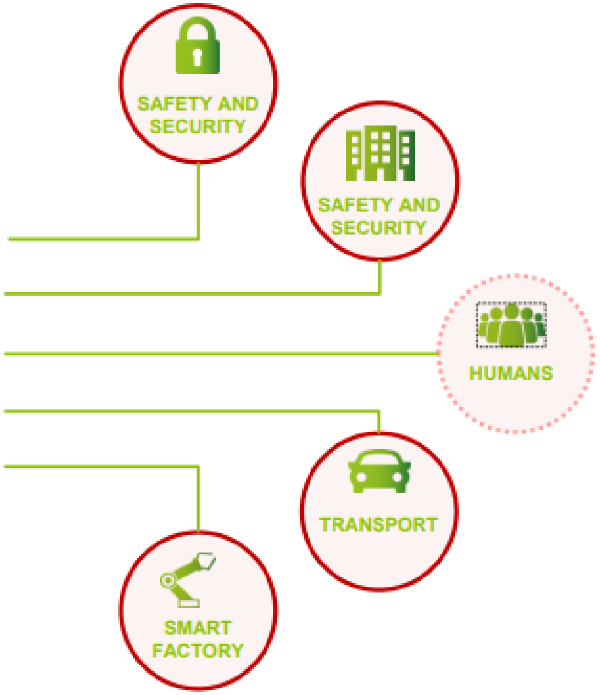
Sustainable Manufacturing

PPAC=Power-Performance-Area-Cost

Introduction

Global data generation (actual & forecast)

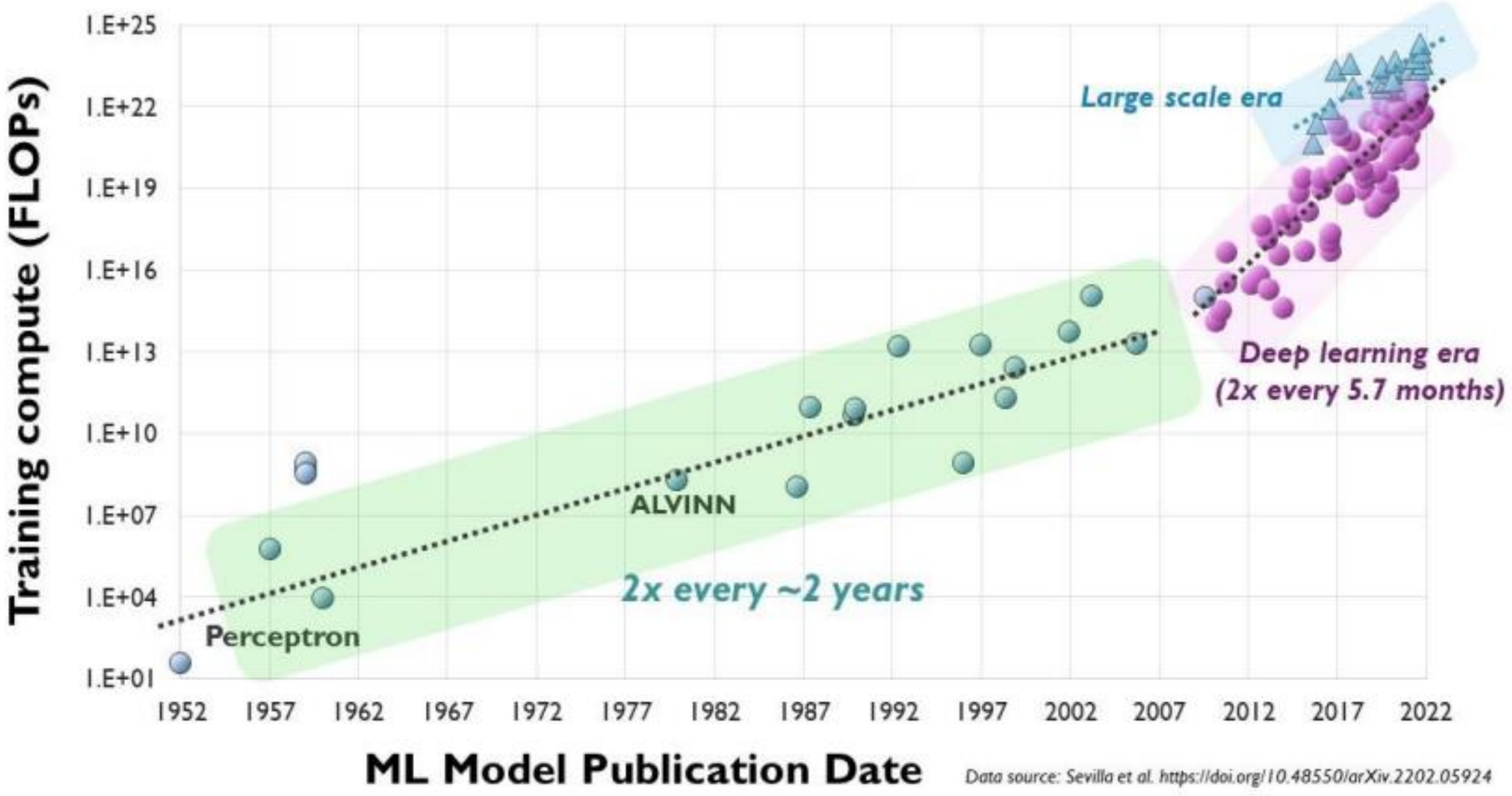




> A true data deluge, not only generated by humans!

Introduction

Compute needs for Machine Learning (ML) continue to grow



Data source: Sevilla et al. https://doi.org/10.48550/arXiv.2202.05924

The required gain in energy efficiency

>1000x
by
2030

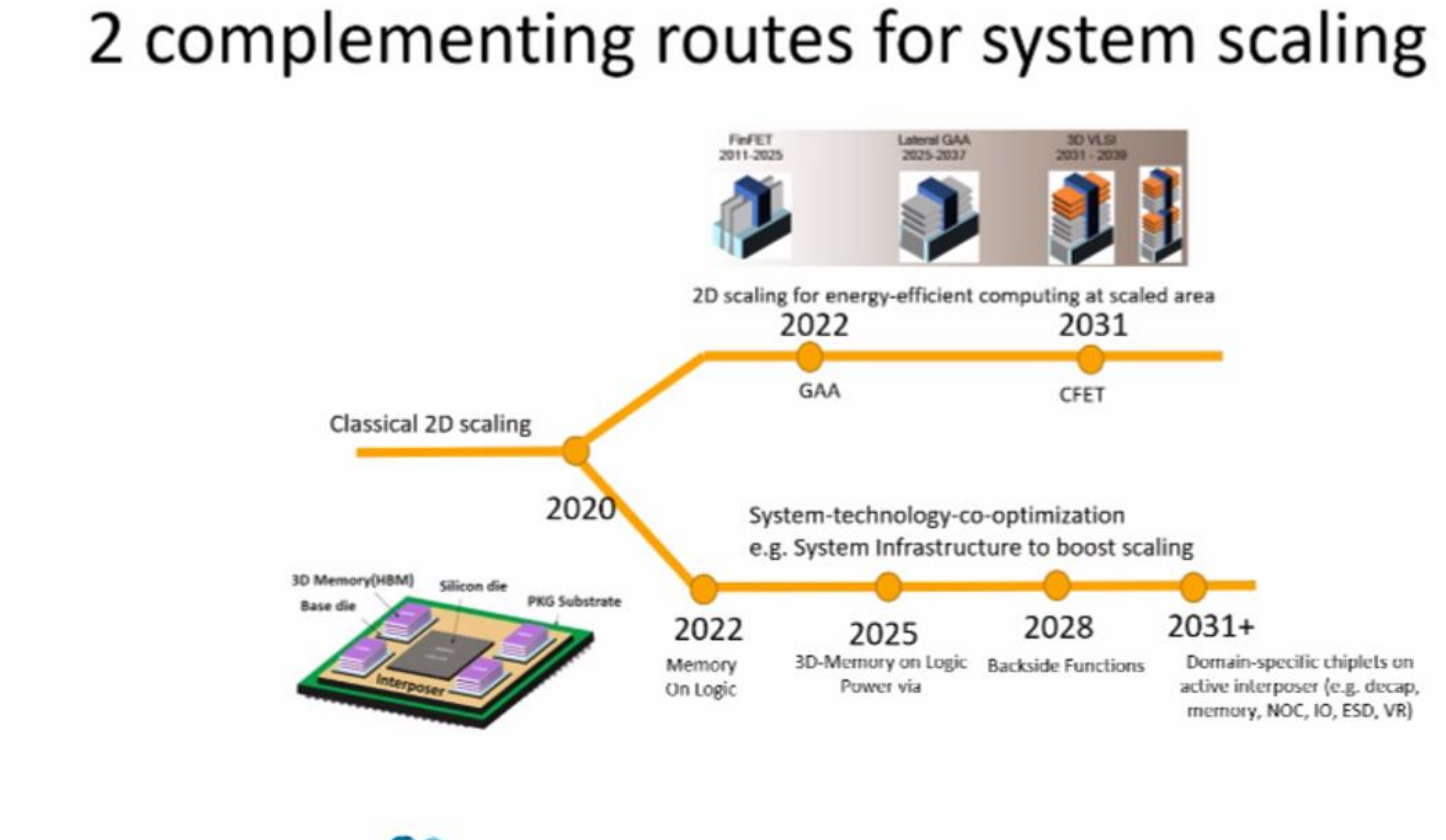
CMOS scaling

Memory technologies

Disruptive Computing

Chiplet & 3D System

More Moore Roadmap



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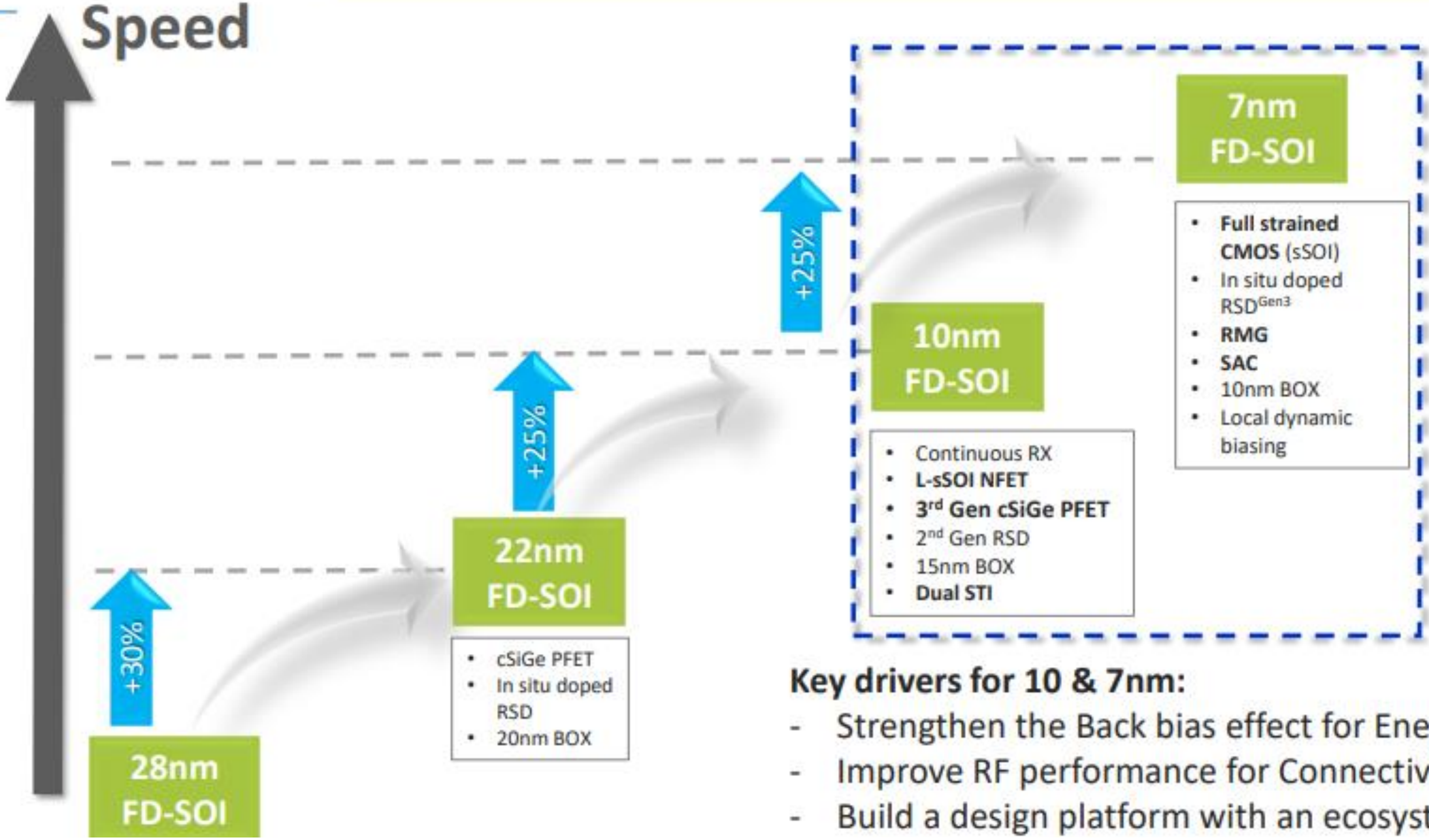
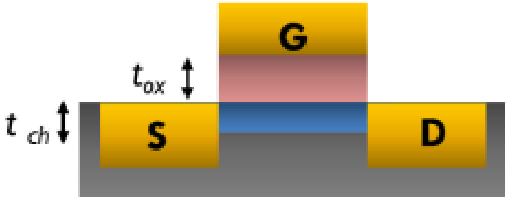
FD-SOI Technology Roadmap



Key drivers for 10 & 7nm:

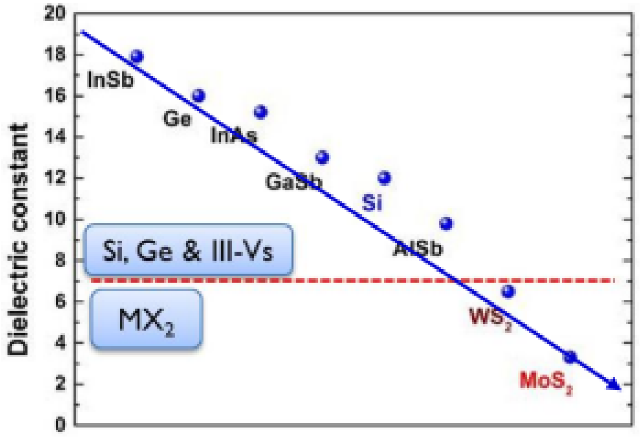
- Strengthen the Back bias effect for Energy saving
- Improve RF performance for Connectivity
- Build a design platform with an ecosystem

2D Atomic Channels: Next generation logic devices



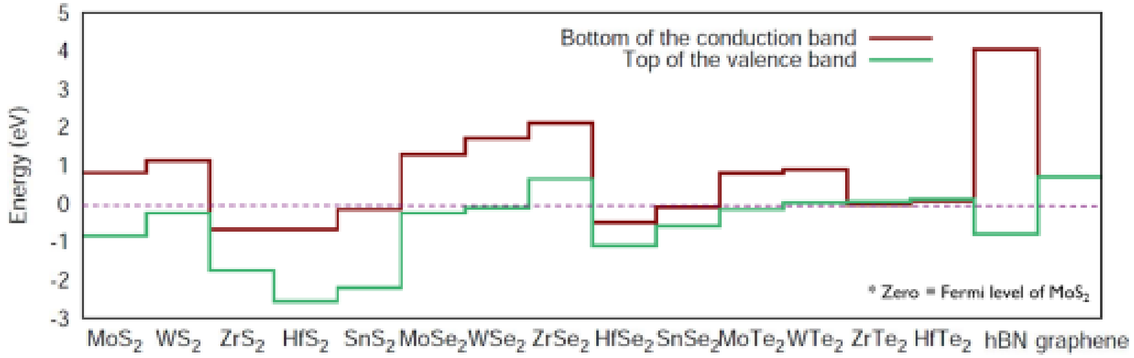
Characteristic length of short channel FETs:

$$\lambda = \sqrt{\frac{\epsilon_{ch}}{\epsilon_{ox}} t_{ch} . tox}$$



Expect reduced short channel effects in planar devices

Ultra-thin materials



Choice of bandgaps and band alignment

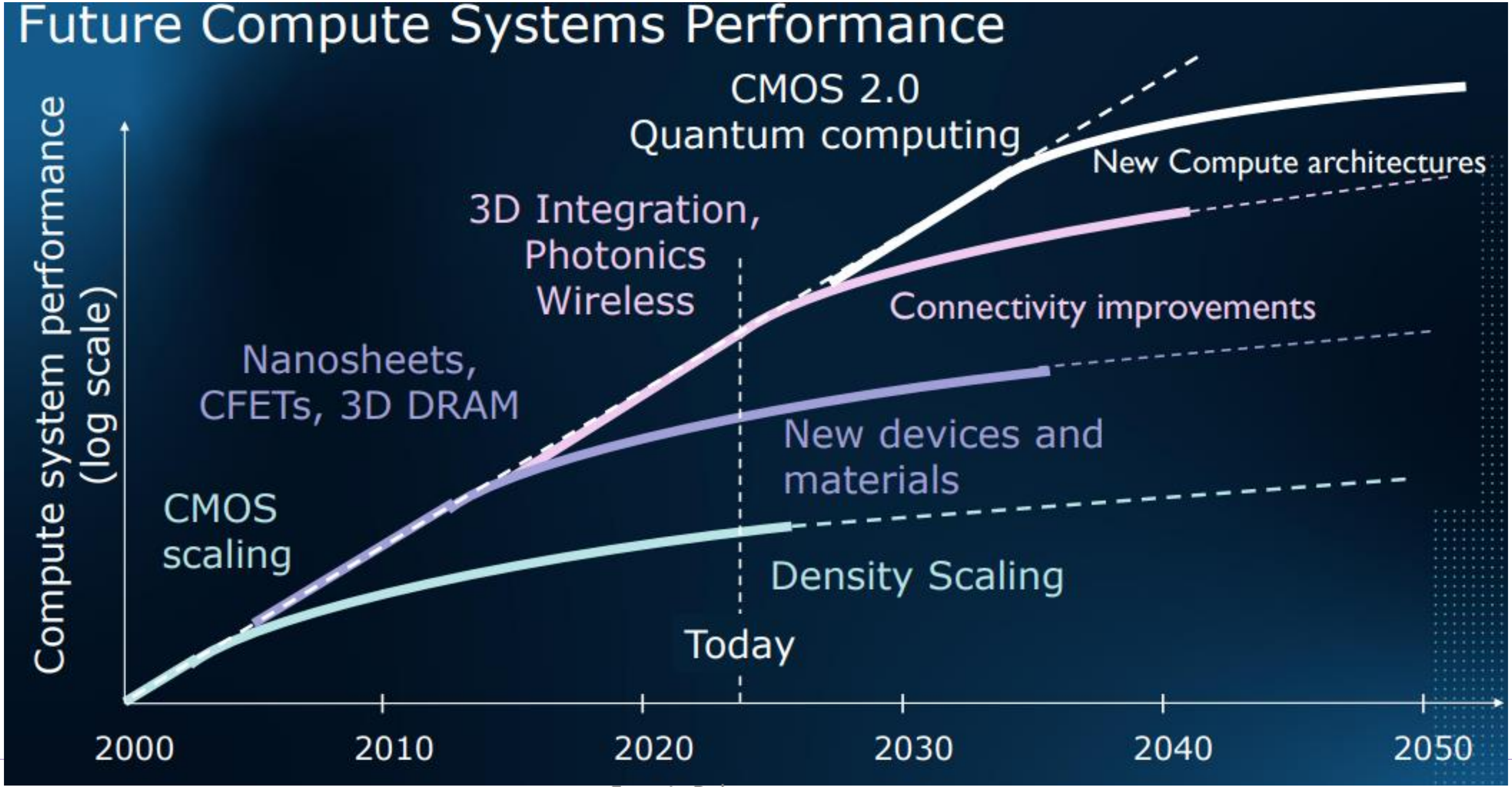
No/Few dangling bonds at interfaces

Emerging Non-Volatile Memories

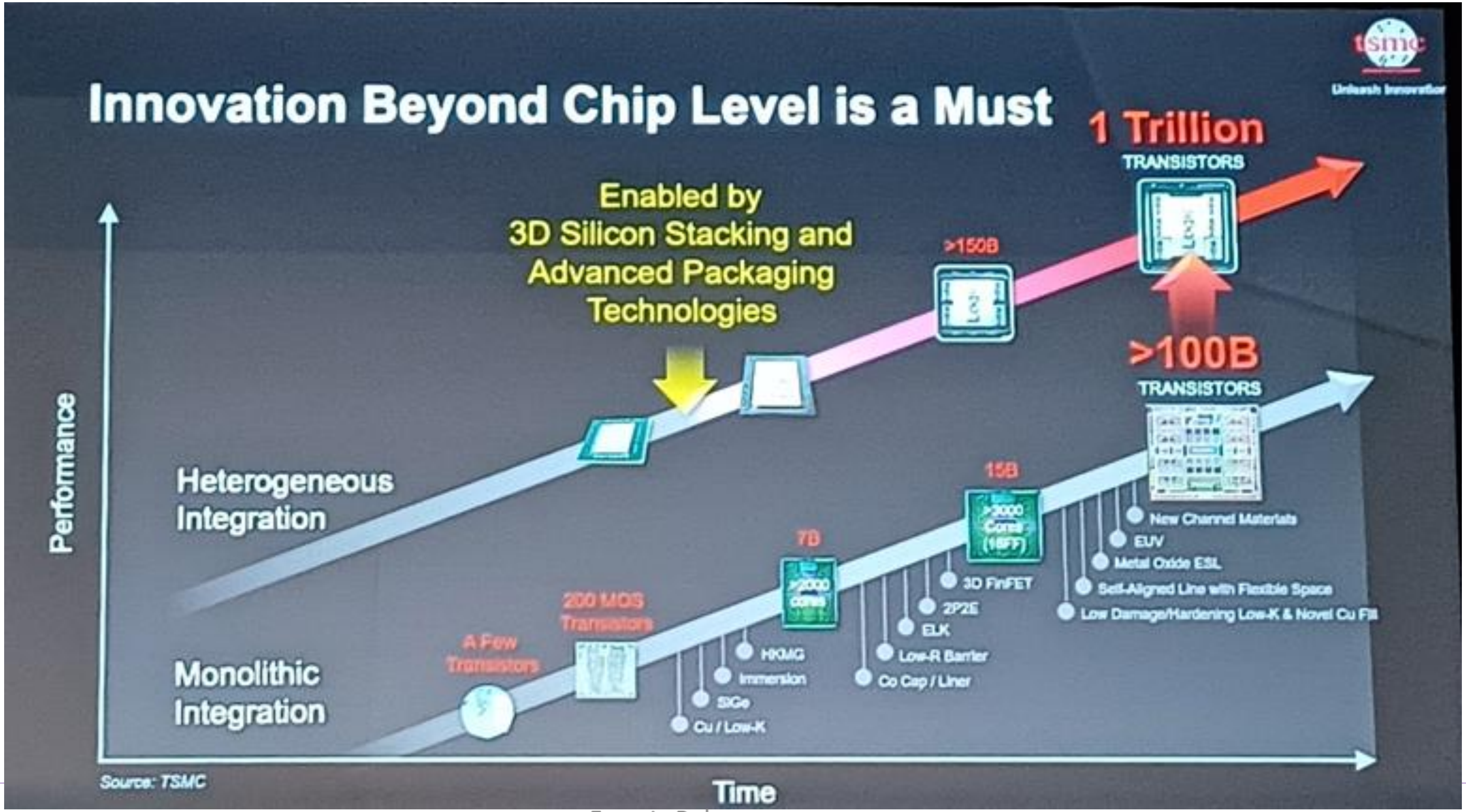
	NOR FLASH	MRAM	PCRAM	OxRAM	FeRAM (PZT)	FeRAM (HfO_2)
Programming power	~200pJ/bit	~20pJ/bit	~300pJ/bit	~100pJ/bit	**~10fJ/bit**	**~10fJ/bit**
Write speed	20 µs	**20 ns**	**10-100 ns**	**10-100 ns**	<100ns	**14ns @ 2.5V (SONY) 4ns @ 4.8V (LETI)**
Endurance	10^5 - 10^6	**10^6-10^{15}**	10^8	10^5 – 10^6 on 16 kbit	**> 10^{15}**	**> 10^{11} single device 10^6 – 10^7 on 16 kbit**
Retention	> 125°C	85°C - 165 °C	**165°C**	> 150°C	125°C	125°C
Extra masks	Very high (>10)	Limited (3-5)	Limited (3-5)	**Low (2)**	**Low (2)**	**Low (2)**
Process flow	Complex	Medium	Medium	**Simple**	**Simple**	**Simple**
Multi-Level Cell	Yes	No	**Yes**	**Yes**	No	No
Scalability	Bad	Medium	**High**	**High**	Medium	**Poor (2D) High (3D)**

Power Reduction by 10000!

Advanced computing



Monolithic and Heterogeneous integration



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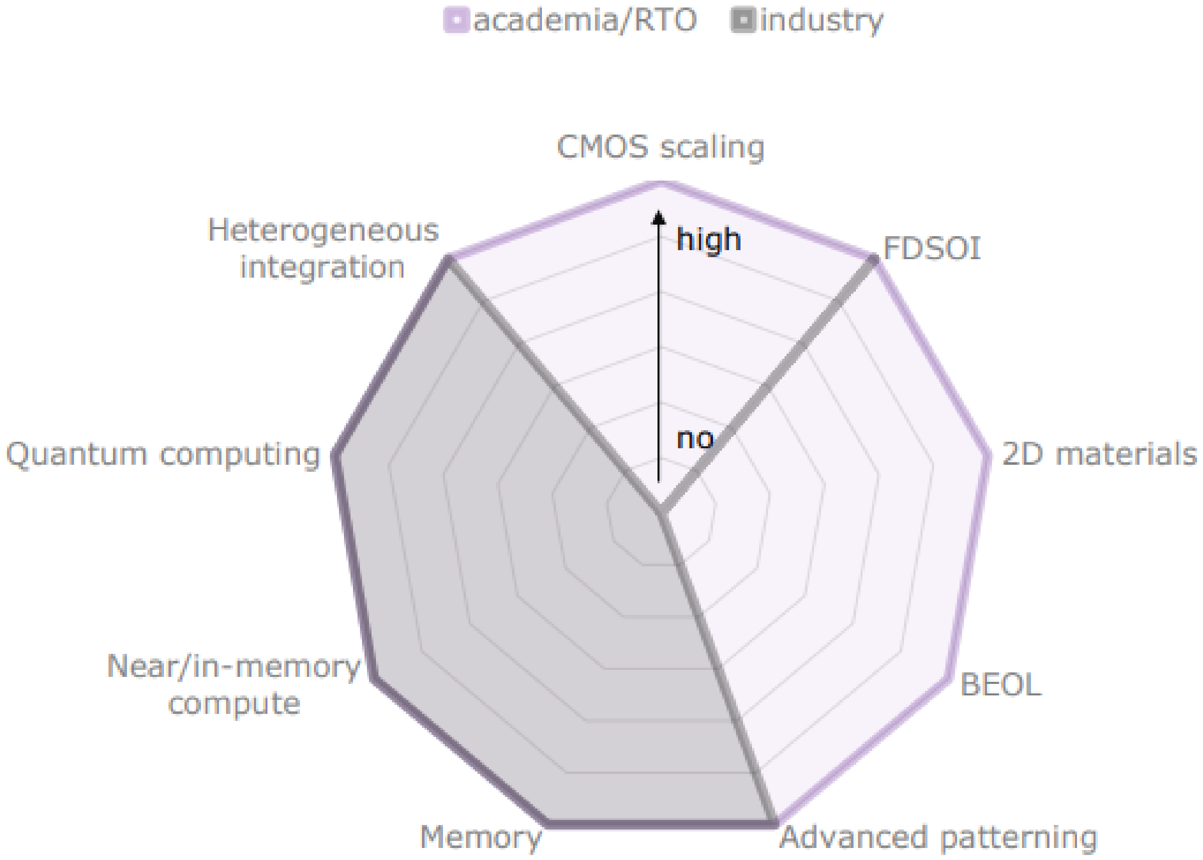
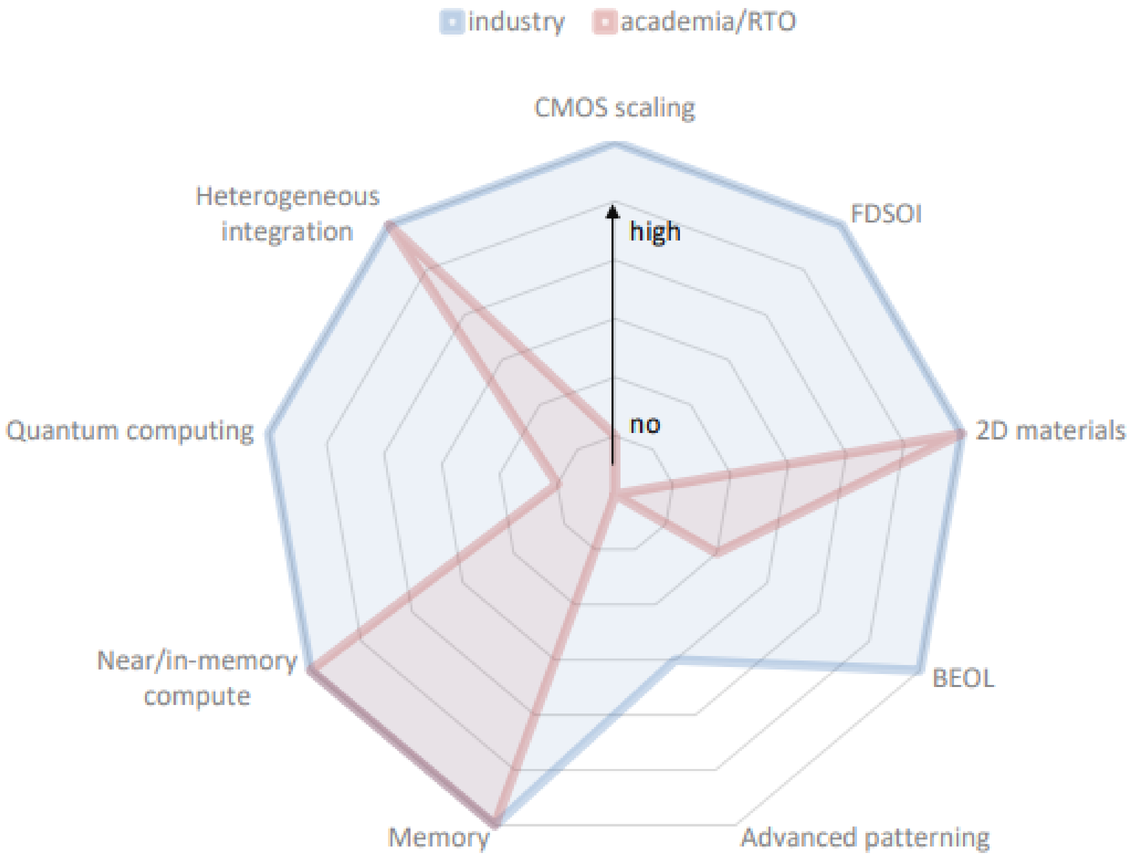
EU and non-EU actors - EU



- R&D very strong in all areas of compute
- Unique strong position in EUV lithography
- In general, industrial EU players lacking to take up R&D

EU and non-EU actors - US



- Strong industrial activity in most areas of compute
- Weaker academic activity on traditional logic scaling
- Strong R&D in new materials, heterogeneous integration and memory

Challenges & possible solutions: Advanced Computing

- Classical' Logic Scaling Roadmap beyond FinFET technology that extends devices structures through sub nm nodes (e.g., **GAA and CFET architectures**)
- Exploration of '**Fully Depleted SOI**' technology for Power Efficient Analog and RF applications
- Exploration of **alternative channel materials** (e.g., 2D materials)
- Extension of the **scaling of BEOL technologies**, through the use of Ru, Airgap or Graphene-based metallization, by reducing the associated RC network
- **Added BEOL functionality** through the introduction of new materials such as 2D, oxide semiconductors and ferroics
- Exploration of the use of BEOL **Non-Volatile Memories** (using for example resistive RAM such as FeRAM, MRAM, PCRAM) to supplement/replace charge-based memories, for in-memory computing (eNVM), and for Power Efficient Neuromorphic-based architectures
- **Photonic chips for optical interconnects and quantum information processing**
- Demonstration of the capability of the '**Buried Power Rail delivery'** to decongest the interconnection density that is becoming the most limiting factor for the scaling at 2nm and below
- Enablement of the **High-NA EUV lithography** for the patterning of 2nm nodes and beyond
- **Usage of 3D integration** to desegregate the classical large area chips into chiplets that will be much more power efficient when reconstruct using 3D integration design flow and associated toolbox

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Impact

In regards to:

- the complexity of the global value chains in the semiconductor area
- the high interdependencies between the different regions of the globe
- consortium partners representing the main European stakeholders and to their International Networks

ICOS is a central instrument to generate impact for the European ecosystems and to support the EC for international cooperation

=> **Provide advice to the European Commission** on joint research and other cooperation initiatives on specific topics with selected leading semiconductor countries

=> **Offer support in their implementation**, based on well documented analysis of value chains, important technologies and mutual advantages of potential collaboration

=> **Implement EU policy** by organizing joint international workshops on defined topics

=> **Strengthen European capacities** in key parts of digital and future supply and value chains

=> **Allow to invest in early discovery and industrial uptake** of new technologies

Thank you for your attention

Acknowledgements: *All ICOS Partners*

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