Chips from the North

Semiconductor Strategy for Finland

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Cover photo: Okmetic

1 Foreword

In Helsinki, 26.4.2024

As we stand at the forefront of a new era in technological advancement and geopolitical shifts, it is my privilege to present Chips from the North – Semiconductor Strategy for Finland. This document is not just a blueprint for our future endeavors but a testament to the collective ideas and foresight of a remarkably wide group of individuals and organizations.

First and foremost, I extend my heartfelt gratitude to every member of the Semiconductor Branch Group of Technology Industries of Finland. Your commitment and expert insights have been the cornerstone of this strategy. To the numerous companies and institutions, both established and emerging, your practical experiences have been invaluable in shaping a realistic and forward-thinking approach.

Special thanks are due to our academic partners from Finland's leading universities and VTT. Your research and innovative spirit have not only guided our strategy but will also ensure that we continue to foster a culture of continuous learning and adaptation to the changing world.

I would be remiss not to acknowledge the crucial support of the Finnish government. Your policies and initiatives in fostering a conducive environment for technological growth have been instrumental in enabling us to dream bigger and aim higher.

A special note of appreciation goes to TT-säätiö, whose generous funding has been a catalyst in turning our vision into a tangible plan. Your belief in the potential of the semiconductor industry in Finland has been a source of encouragement and inspiration.

Equally, I wish to express our sincere gratitude to BCG for their strategic guidance, insights, and facilitation throughout the development of this report. Your expertise has been pivotal in ensuring that our strategy meets global standards and ambition for growth in the semiconductor industry.

This strategy report is just the beginning. I invite all stakeholders, from industry veterans to aspiring innovators, to join us in the journey of implementing this strategy. Your participation and collaboration are essential in turning these plans into actions that will shape the future of semiconductors and microelectronics in Finland and beyond.

Let us move forward together, with a shared vision and concerted effort, to establish Finland as a leader in the global semiconductor industry. The journey ahead is challenging but filled with opportunities. Together, we can create a future that is not only prosperous but also sustainable and inclusive.

With anticipation and optimism,

Tomy Runne

Chair, Semiconductor Branch Group,
Technology Industries of Finland

This report was commissioned by Technology Industries of Finland (TIF), conducted in collaboration with Boston Consulting Group (BCG), and enabled by support from TT-säätiö. The authors would like to thank the members of TIF and BCG for their contributions to the development and production of the report. In addition, the authors are extremely grateful to all survey, 1-on-1 discussion, and focus group discussion participants for their valuable contributions toward the enrichment of the report. Furthermore, the authors extend their sincere appreciation to *Joonas Mikkilä, Tomy Runne, Henrik Nisén, Juuso Soininen, Jan Hinnerk Mohr,* and *Ib Löfgren* for their contributions to the report.

About Technology Industries of Finland

Technology Industries of Finland (TIF) is the lobbying organization for technology industry companies. TIF promotes competitiveness and the operational preconditions for technology industry, the largest and most important export sector in Finland. A constantly developing technology industry creates the basis for the long-term prosperity of Finland. TIF has about 1,800 member companies.

Technology Industries of Finland

About Boston Consulting Group

Boston Consulting Group partners with leaders in business and society to tackle their most important challenges and capture their greatest opportunities. BCG was the pioneer in business strategy when it was founded in 1963. Today, we work closely with clients to embrace a transformational approach aimed at benefiting all stakeholders—empowering organizations to grow, build sustainable competitive advantage, and drive positive societal impact.

Our diverse, global teams bring deep industry and functional expertise and a range of perspectives that question the status quo and spark change. BCG delivers solutions through leading-edge management consulting, technology and design, and corporate and digital ventures. We work in a uniquely collaborative model across the firm and throughout all levels of the client organization, fueled by the goal of helping our clients thrive and enabling them to make the world a better place.

BCG

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2 Executive Summary

A persistent worldwide growth trajectory is expected during the next ten years, with the semiconductor market anticipated to grow from €570B to at least €1T by 2030. This creates an opportunity for Finland to boost its overall economy.

Finland's own export-heavy semiconductor industry reached an estimated €1,6B annual revenue in 2022 and employed 7.000 people. Although it is still a small part of the global semiconductor industry, Finland's sector has the potential to grow significantly. This is due to its existing strengths in specialized domains, to the hundreds of millions in industry investments already made, and to further public and private-sector investments expected in education, research, and development.

Around the world, national policies to support the semiconductor industry are moving forward (e.g., EU Chips Act, targeted subsidies, and tax breaks). These policies demonstrate the significance of semiconductors to economies and security.

Finland's semiconductor industry requires focused efforts – to benefit from global market growth and reinforce Finland's competitiveness in these critical future technologies. This strategy report for Finland identifies six must-win opportunities. Together, they could triple annual revenues to €5-6B by 2035, raise the directly employed workforce to 20.000, generate 15.000 or more ancillary jobs, and produce an estimated indirect value impact of €90B to €180B over ten years.

Finland's six growth opportunities are:

1. Chip design: Specialized mobile network, edge AI, and ultra-low power system-on-chips
2. MEMS and sensor innovation: Next-generation MEMS and sensor technologies for communications, healthcare, and automotive sectors
3. Photonics: Enhanced photonics value chain and system-in-package design leadership
4. Quantum technologies: Research, design, fabrication, and integration of quantum technologies
5. Advanced materials: Research, development and manufacturing of advanced materials
6. Process technologies: Sustainable thin-film deposition and flexible microelectronics technologies.

To maximize growth in the opportunities, Finland needs to aim for five outcomes for each opportunity: fostering closer collaboration between the industry and stakeholders, enabling a competitive R&D ecosystem, growing the workforce, attracting significant R&D and design site investments, and attracting investment in manufacturing sites. (Exhibit 1)

Finland's long-term success in semiconductors depends on actions taken now. To explore how Finland can seize the opportunity, TIF and BCG conducted independent and fact-based analysis and collaborated over the winter 2023-2024 with over 200 semiconductor professionals to help inform a national semiconductor strategy.

This report has several objectives: To inform national decision makers of the industry's ambition for growth, to gather industry views into a single statement, and to promote the strengths and potential of Finland's semiconductor industry to the public, including investors and future talent.

Exhibit 1 I Semiconductor Strategy for Finland: Six must-win opportunities to triple industry revenue.

2024 — Chips from the North: Semiconductor Strategy for Finland — 2035

2024

€1,6B industry revenues

90 companies across value chain

7.000 direct employees

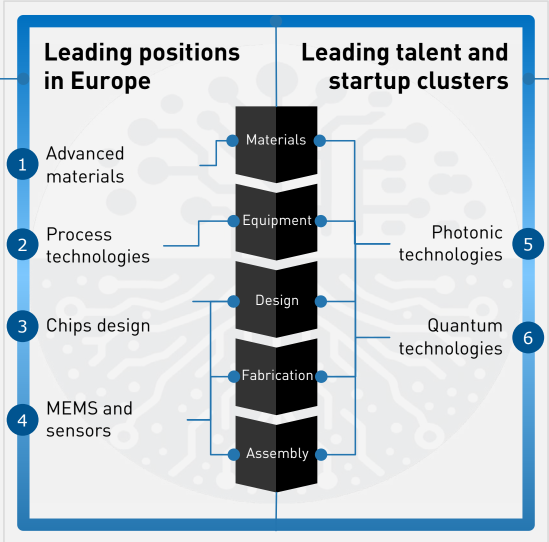
2035

€5B to €6B in industry revenue

€90B to €180B indirect value

20.000 direct employees

Finland's six growth opportunities



Competitive advantages

Societal predictability and infrastructure

Mobile network expertise

System chip design

Sensors and MEMS

Process and material technologies

Photonic technologies

Quantum technologies

Enabling outcomes

Industry-academia-public collaboration
Effective collaboration structures and resources

Competitive R&D ecosystem
Joint R&D funding of €5B over ten years

Over 15.000 new employees
Elevated education output and talent attraction

New established R&D and design centers
Promotion of talent, startup and technology clusters

Over €1B manufacturing site investments
Public-private collaboration and public instruments

Kuvaaja 2 I Puolijohdestrategia Suomelle: Kuusi mahdollisuutta kolminkertaistaa alan liikevaihtoa.

2024 — Siruja Pohjolasta: Puolijohdealan kasvustrategia Suomelle — 2035

2024

1,6 mrd. € toimialan liikevaihto

90 yritystä arvoketjun läpi

7 000 työpaikkaa ja osaajaa

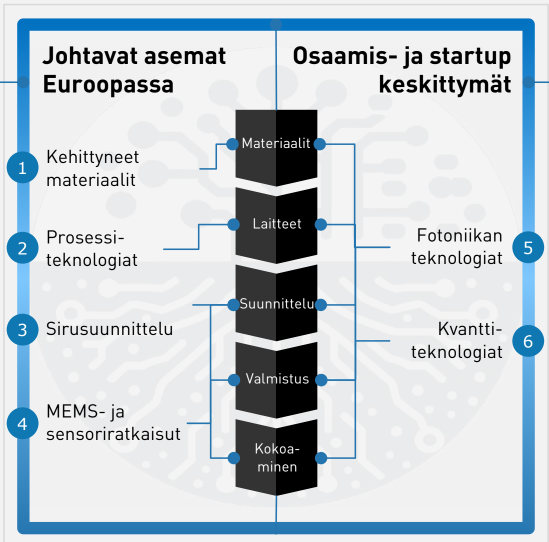
2035

5-6 mrd. € toimialan liikevaihto

90-180 mrd. € talousvaikutus

20 000 työpaikkaa ja osaajaa

Suomen kuusi kasvumahdollisuutta



Kilpailuedut

Yhteiskunnan ennakoitavuus ja infrastruktuuri

Mobiiliverkkoteknologiat

Systeemisirusuunnittelu

Sensori- ja MEMS-teknologiat

Prosessi- ja materiaaliteknologiat

Fotoniikka

Kvanttiteknologiat

Mahdollistavat tekijät

Toimialan ja julkisen sektorin yhteistyö
Tehokkaat yhteistyön rakenteet ja resursointi

Kilpailukykyinen T&K-ekosysteemi
5 mrd. € T&K-rahoitusta 10 vuodelle

Yli 15 000 uutta työpaikkaa
Koulutuksen lisääminen ja alan houkuttelevuus

Uudet T&K- ja suunnittelukeskittymät
Osaamis- ja yrityskeskittymien tunnettuus

Merkittävät valmistusinvestoinnit
Yksityisen ja julkisen sektorin yhteistyö ja tuki

Tiivistelmä

Maailmanlaajuinen puolijohdetoimiala kasvaa voimakkaasti – alan odotetaan lähes kaksinkertaistuvan 570 miljardista eurosta noin biljoonaan euroon vuoteen 2030 mennessä. Tämä luo Suomelle mahdollisuuden merkittävään talouskasvuun.

Suomen vientipainotteisen puolijohdealan liikevaihto oli 1,6 miljardia euroa vuonna 2022 ja se työllisti noin 7 000 ihmistä. Suomen puolijohdeala on pieni globaalisti, mutta sillä on merkittävää kasvupotentiaalia. Kasvupotentiaalia tukevat Suomen vahvuudet, satojen miljoonien tehdyt investoinnit sekä julkisen ja yksityisen sektorin panostukset koulutukseen, tutkimukseen ja kehitystoimintaan.

Valtiot maailmanlaajuisesti tukevat kansallisesti puolijohdeteollisuutta (esim. EU:n sirusäädöksen rahoitus, kohdennetut tuet ja veronkevennykset), sillä se nähdään merkityksellisenä kansalliselle menestykselle ja turvallisuudelle.

Suomen puolijohdetoimiala tarvitsee kohdennettuja toimia hyötyäkseen globaalista kysynnän kasvusta ja vahvistaakseen kilpailukykyä kriittisissä tulevaisuuden teknologioissa. Tässä strategiaraportissa on tunnistettu Suomelle kuusi kasvumahdollisuutta, joihin keskittymällä Suomen toimialan arvioidaan kolminkertaistavan liikevaihdon 5–6 miljardiin euroon ja kasvattavan alan työpaikat 20 000:een vuoteen 2035 mennessä. Muille toimialoille arvioidaan välillisten vaikutusten myötä syntyvän 15 000 uutta työpaikkaa ja jopa 90–180 miljardin euron talousvaikutus.

Suomen kuusi kasvumahdollisuutta ovat:

1. Sirusuunnittelu: Markkinajohtajuus erikoistuneissa mobiiliverkko-, reunatekoäly- ja alhaisen tehonkulutuksen liitännäisissä järjestelmäpiireissä
2. Mikroelektromekaaniset järjestelmät (MEMS) ja anturi-innovaatiot: Seuraavan sukupolven MEMS- ja anturiteknologiat viestintä-, terveydenhuolto- ja autoteollisuudelle
3. Fotoniikka: Vahvennettu fotoniikan arvoketju ja paketointi- ja integraatio-osaaminen
4. Kvanttiteknologiat: Kvanttiteknologioiden suunnittelu, valmistus ja järjestelmätason integraatio
5. Kehittyneet materiaalit: Uusien, kehittyneiden puolijohdemateriaalien tutkimus ja valmistus, keskittyen erikoistuneisiin piikiekkoihin ja korkean suorituskyvyn puolijohdemateriaaleihin
6. Prosessiteknologiat: Ohutkalvoprosessit ja joustavan mikroelektroniikan kestävien valmistusprosessien kehitys, hyödyntäen olemassa olevaa pitkäaikaista alan tutkimusta.

Suomen on panostettava viiteen tukipilariin tukeakseen kasvua jokaisessa kasvumahdollisuudessa: yhteistyön tiivistämiseen toimialan ja sidosryhmien välillä, tutkimus- ja tuotekehitystoiminnan kilpailukyvyn vahvistamiseen, työvoiman määrän ja laadun kasvattamiseen sekä tutkimus- ja suunnittelukeskusten ja puolijohdevalmistuksen houkuttelemiseen Suomeen.

Suomen pitkän aikavälin menestys puolijohdetoimialalla riippuu nyt tehdyistä toimenpiteistä. Teknologiateollisuus ry ja Boston Consulting Group laativat talven 2023-2024 aikana kansallisen puolijohdestrategian yhteistyössä yli 200 puolijohdealan ammattilaisen kanssa.

Tällä strategiaraportilla on useita tavoitteita: kertoa kansallisille päättäjille toimialan tavoitteesta ja mahdollisuudesta kasvaa, koota yhteen toimialan näkemykset ja kertoa Suomen vahvuuksista ja mahdollisuuksista laajasti kotimaiselle ja kansainväliselle yleisölle.

3 Introduction: An Opportunity for Finland to Seize

Semiconductors enable all modern technologies, products, and services that our societies rely on globally. Without them, we would not have computers, mobile phones, Internet, or the modern healthcare. They are vital for defense, cybersecurity, and critical infrastructure resilience. Achieving the European Union's Green Deal and strategic technology development objectives would be impossible without advanced semiconductor technologies. There are no substitutes to semiconductors for enabling the modern life as we know it. Given their importance to the economy and national security, as well as their susceptibility to supply chain vulnerabilities, governments are taking actions to strengthen their national semiconductor industries.

Our increasing dependence on semiconductors is reflected in the high performance of the industry compared to the general economy during the past decade. There has been a six-fold increase in the PHLX Semiconductor Index since 2013 until 2024, while the S&P 500 Index merely doubled[2]. The industry is estimated to grow at 7-9% CAGR, from €570B in 2022 to €1T by 2030.

Finland is well-positioned to benefit significantly from the global market's tailwinds while supporting the European Union's strategic technology autonomy and competitiveness agenda. The semiconductor industry's growth hinges on having a skilled workforce in place. In Finland, this would require initiatives in education, talent attraction, and reskilling. There is a great opportunity to enhance collaboration with European value chains, necessitating focused efforts on targeted funding and innovation as well.

What are semiconductors?

Semiconductors are materials with electrical properties between conductors and insulators. These materials form the foundation of microelectronics products (such as chips and sensors), which are used extensively in electronic systems like smartphones, computers, and advanced automotive systems.

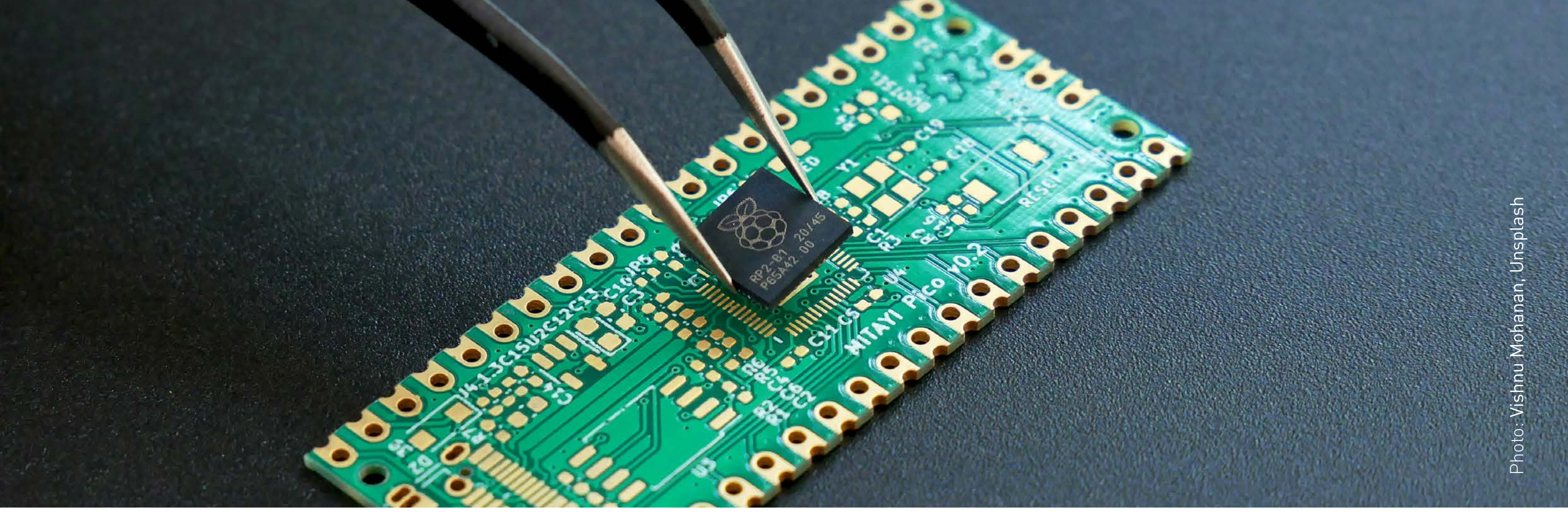
Semiconductor devices range from microelectromechanical components (such as sensors) to advanced system chips (like those used in mobile devices and mobile networks) and components used in power systems or other machines and appliances. Semiconductors are generally categorized into general-purpose (such as memory or generic processing chips) and application-specific devices (such as 5G baseband chips and image signal processors).

Why is the semiconductor industry important?

Semiconductors are crucial for nearly all electronic devices of modern human life, including smartphones, computers, and communications networks. They enhance vehicle safety, entertainment, and enable autonomous driving, while also being vital for IoT devices, sensors, artificial intelligence (e.g., enabling generative AI applications such as ChatGPT), military applications, and cybersecurity.

Each euro spent in semiconductor R&D indirectly creates approximately €15 to €90 in end market value, according to the EU Investment Scoreboard[3] and Gartner[1]. Just in four European Union industrial sectors (automotive, industrial, healthcare, and networks), BCG estimates that the semiconductor industry will generate €3,1T in value and create 8,2M jobs by 2030.

The global semiconductor value chain is complex and susceptible to vulnerabilities, such as geopolitical tensions, natural disasters and epidemics affecting supply. Dependence on single supply sources can limit national technological sovereignty and undermine economic security. Many nations are currently focusing on developing their domestic semiconductor capabilities.



3.1 Growing demand for semiconductors

Globally, most of semiconductor demand growth is driven by data processing and communications. Three types of applications are expected to drive around 85% of the growth in EMEA and North America[1]: 1) automation, AI, and robotics, 2) connectivity and edge computing, 3) and electrification. For example, European mobile data traffic is expected to triple in next five years[4].

The automotive sector is the fastest-growing segment, projected to maintain a 12% global CAGR until 2030. The industrial sector is expected to grow by 9% CAGR. These two sectors are projected to drive European demand for semiconductors.

General semiconductor devices will remain important, but demand for specialized high-performance semiconductors, such as ASICs, generates new opportunities (See Exhibit 2). Optimized performance, power efficiency, and compact design will be increasingly important features. These advanced, custom devices may also combine general components and advanced packaging methods (such as 3D stacking, system-in-package (SiP) and system-on-chip (SoC) designs).

The need for data storage and computation increases constantly. Rising requirements for higher bandwidths and lower latencies in data transmission accelerates a shift from electrical to optical signals. Increasing demand for computing power will require new device architectures and materials. The rise of purpose-built devices necessitates smaller die sizes and advanced packaging methods. The widespread use of Internet-of-Things (IoT) devices will expand the market for low-cost/low-power sensors, hardware-specific human-machine interfaces, and connectivity. Artificial intelligence and extended reality (XR) technologies will raise demand for decentralized computing.

Exhibit 3 I Global semiconductor market opportunities[1] (Revenue, annual growth rate 2022-30)

Circle size = 2022 revenue; CAGR, 2022-30: + 1-5% / + 5-10% / + 10%

End-users	Devices: Logic €210B 6% CAGR		Devices: Memory €135B 7% CAGR		Devices: Discrete, analog and other €215B 7% CAGR	
Data processing €185B 6% CAGR	€90B	Datacenters, edge computing; SoCs, advanced packaging	65	High-performance computing; New memory technologies	30	Energy, sensoring; Sensors, power, quantum
Communications €180B 5% CAGR	50	Smartphones, networks; SoCs, low power solutions, photonics technologies	45	Smartphones, networks; Advanced materials, low power solutions	85	IoT, infrastructure; RF, analog, power, mixers
Automotive €65B 12% CAGR	20	Electric vehicles, autonomy; Chiplets and SoCs	5	Infotainment, control units; High-performance memory	35	Electric vehicles, autonomy; Imaging and sensors, power
Industrial €70B 9% CAGR	20	Robotics, automation, security; Low power solutions, advanced packaging	5	Control systems, defense; High-endurance memory	45	Automation, healthcare; Analog, discrete, power, MEMS and sensors
Consumer €60B 4% CAGR	25	Personal devices, XR/AR; Integrated connectivity, advanced packaging	15	Personal devices, gaming; High-performance memory	25	Personal devices, XR/AR; Sensors, photonics

Note: OSAT = Outsourced assembly and testing; IDM = Integrated device manufacturer; EDA & IP = Electronic Design Automation and intellectual property
Source: Gartner[1], BCG analysis

Significant evolutions are required in semiconductor devices and manufacturing processes

Advances in logic chips are facilitated by extreme ultraviolet lithography (EUV), AI-driven chip design, and photonics in integrated circuits. Optoelectronic and photonic devices are increasingly required in sensing, displays, and silicon photonics. Heterogenous integration and chiplet technologies (modular design of chips) are driving changes in manufacturing and process technologies.

Digital memory is moving towards 3D designs, and new integration and packaging technologies. In- and near-memory technologies, in which memory and processing circuits are placed close to each other, improve computing performance and drive innovation in memory materials and architectures.

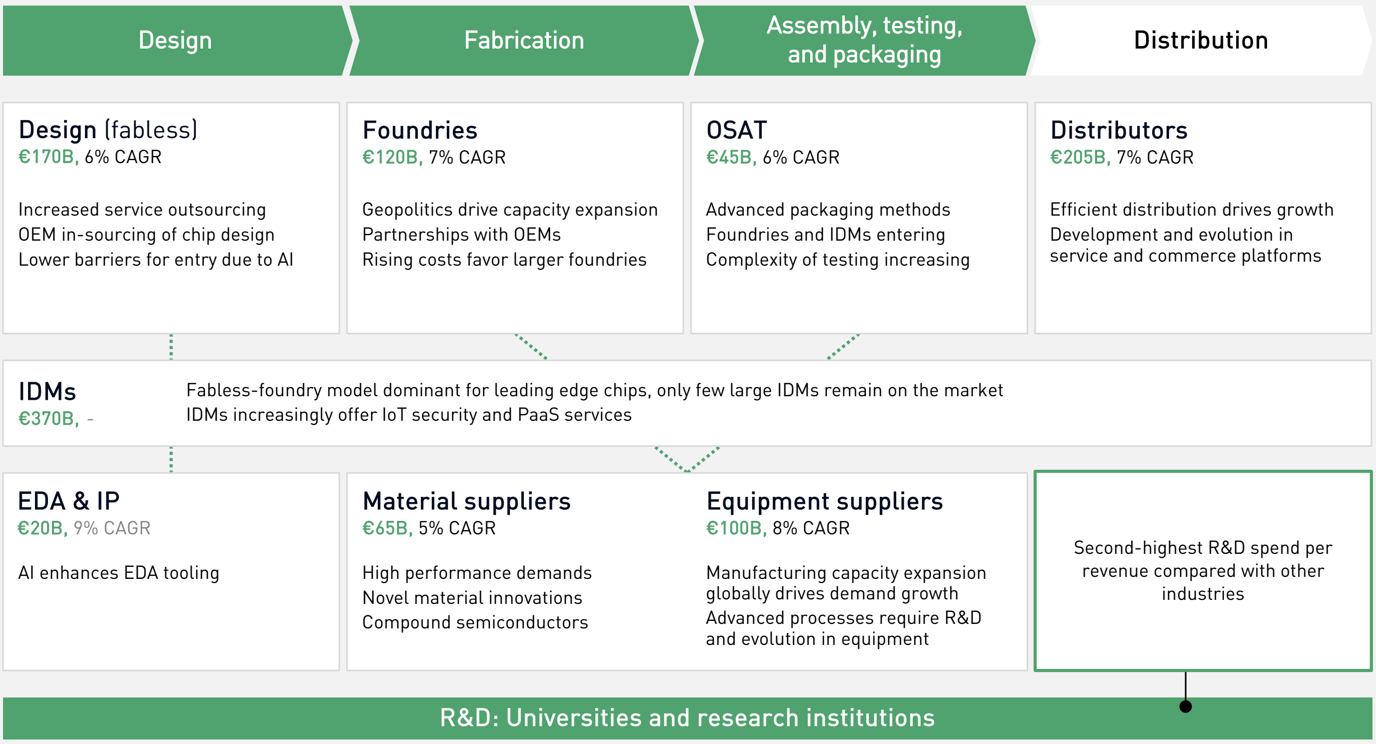
Discrete components like diodes, transistors, and thyristors are required for IoT, electrification, healthcare innovation and industrial automation. Changes in analog components are spurred by electrification and network advancements. RF and digital baseband components are evolving with expansion of wireless networks like 5G and 6G. Demand for micro-electro-mechanical systems (MEMS) and sensor components is driven by industrial automation, healthcare, IoT, and XR/VR/AR technologies. Miniaturization, advanced packaging and other process technologies will be required.

Over the next decade, innovations expand the limits of today's semiconductors. This may include optimizing data movement, increasing memory bandwidth, advancing optical computing, creating neuromorphic computing systems that mimic the human brain, and developing practical fault-tolerant quantum computing systems.

For integrated device manufacturers (IDMs), there are opportunities in advanced nodes for players with substantial volume and access to capital. The IDM model is suitable also for smaller players in device categories such as sensors, which do not require large volumes to be profitable. The fabless model enables smaller, specialized players to capitalize on market demand and market changes without substantial manufacturing investments. Fabless manufacturing has been observed to generate high cumulative profits. Some existing foundries are seeking new locations for expansion, driving demand for equipment and process technologies that semiconductor manufacturing requires.

For smaller countries like Finland, specialized opportunities exist in design, manufacturing, material, and equipment. Finland can carve a niche in designing advanced chips and devices in lower-volume categories dependent on specialized expertise. There are opportunities for faster-than-average industry growth in emerging fields such as photonics, quantum technologies, new material R&D, and selected process technology niches for smaller countries to play an outsized role.

Exhibit 4 I Semiconductor value chain trends (Revenue, annual growth rate 2022-30)



Note: OSAT = Outsourced assembly and testing; IDM = Integrated device manufacturer; EDA & IP = Electronic Design Automation and intellectual property
Source: Gartner[1], Capital IQ[2], BCG analysis

3.2 Semiconductors as a national strategic interest

Governments around the world are enhancing strategic autonomy in semiconductors. Their goals include economic growth and stronger national security. Strategic R&D investments and the attraction of semiconductor manufacturing sites are on top of their agendas, with national funding directed to technologies and workforce development. Examples of targeted initiatives include the US CHIPS and Science Act (2022) and the EU's Chips Act (2023).

Geopolitical developments in the US-China trade conflict are leading to a technology separation that disrupts the global value chains of the semiconductor industry. According to this report's benchmarking analysis, national policies increasingly focus on semiconductor-related national security, supply chain stabilization, strategic manufacturing, and economic growth. This strategic focus drives increased global and regional competition in semiconductor design, manufacturing, talent acquisition, and investments.

Strategic agendas support critical national interests, including defense, cybersecurity, and domestic industries. Benchmarking reveals that smaller economies concentrate on seizing growth opportunities, while larger agendas, like those in the US and China, also include mitigating security risks and addressing supply chain vulnerabilities.

Governments are investing heavily in design and production, while incentivizing the private sector. The US CHIPS and Science Act dedicates about €47B to semiconductor R&D and manufacturing, in addition to €22B in tax credits, aiming to strengthen domestic production and reduce reliance on Asia[5]. China's Five-Year Plan (2021-2025) mentions semiconductors as a strategic interest to build an independent, controllable semiconductor supply chain[6]. The EU's Chips Act mobilizes more than €43B in investments, targeting to double its global semiconductor market share by 2030, with a focus on research, manufacturing, innovation, and workforce development[7].

Governments are selective in funding specific technologies. Concerted national efforts take place through multi-year R&D programs. For example, UK programs emphasize chip design, compound semiconductors, and quantum technologies[8], while Spain focuses on advanced chip design (RISC-V) and integrated photonics[9]. Governments are also involved in establishing semiconductor design and manufacturing sites. Europe has seen over €70B in new fab investments announced in the past few years. Germany has granted €10B for Intel's new Magdeburg facility (complementing Intel's investment of €33B)[10] and €5B to TSMC, NXP, Infineon, and Bosch for a wafer fab facility in Dresden[11]. Poland has provided substantial subsidies for Intel's €4,6B facility and leveraged quality of life, family facilities, schools, sports infrastructure, and economic factors to attract investments[12].

Governments are actively supporting the development of a skilled workforce. Talent is recognized as a crucial factor for enabling growth and attracting investment. The semiconductor industry relies on highly educated professionals, especially those with hands-on experience in chip design, incl. MSc and DSc degrees and post-doc experience. There is currently a significant talent shortage[6]. The EU aims to triple the semiconductor workforce by 2030 to achieve a 20% market share. The UK is investing €880M over three years to enhance the talent pipeline by supporting higher education in disciplines such as engineering and physics[7]. Some governments offer incentives to attract and retain skilled workers. For example, Spain has a lower base tax rate for foreign talent, the Netherlands provides a 30% tax-free salary benefit[13], and Germany permits foreign students to stay for 18 months post-graduation[14]. Countries like Spain and Belgium have reskilling initiatives, while others, including the UK, France, and Denmark, are increasing funding for doctoral students.

3.3 An opportunity Finland cannot miss

Finland needs to ensure it plays a pivotal role in the semiconductor industry, aligning itself with the European Union's agenda for strategic technological autonomy and competitiveness. By leveraging its unique strengths, Finland can become a key player in specific niches and can lead in the development of future technologies. This effort can generate a substantial economic impact, creating an estimated 15.000 new jobs by 2035.

Finland must take immediate action to unleash its full potential in the semiconductor industry and make a significant contribution to both global and European value chains. Its main objectives, according to an industry survey conducted for this report, should include strategic differentiation in specialized domains, upgrading facilities for innovation, leveraging EU funding for facility improvements, and research and development in advanced technologies. Finland should also aspire to become a global leader in microelectronics education and to attract international investors and talent.

Finland's future success in semiconductors hinges on the decisions made today. This report identifies several potential levers to capitalize on the opportunity and fully realize the industry's potential.

Photo: Tapio Haaja, Unsplash

4 Semiconductors in Finland: Industry and its competitive advantages

The Finnish semiconductor industry is ready to play a more significant role in the expanding global market and grow at a faster pace than the global average. Finland is neither particularly large nor small in semiconductors; the Finnish semiconductor industry contributes 0,5% to Finland's GDP, which is in line with a global average. Finnish companies, already strong in selected niches, are well-integrated into global markets, and their businesses closely align with the EU's strategic goals. The industry benefits from Finnish education and research that has led to pioneering innovations in key semiconductor technologies such as atomic layer deposition and carbon nanotube pellicles. To fully realize its potential, Finland must address the talent gap, concentrate on specialized semiconductor fields, effectively utilize both EU and national funding, and attract both investors and skilled professionals.

4.1 The Finnish industry outpaces global growth

The Finnish semiconductor industry generated about €1,6B in revenues in 2022, and currently consists of around 90 registered companies, employing roughly 7.000 people (excluding Nokia and Microsoft)[15]. According to the survey conducted for this report, the industry is expected to grow at a CAGR of 10-11%, doubling its total annual revenue to €3,2B by 2030 and tripling it to €5-6B by 2035, assuming crucial enablers are in place. The rate of growth will depend primarily on the supply of skilled resources, R&D funding and collaboration, and the attraction of site investments. Industry survey respondents emphasize the importance of workforce supply, noting that growth would require expanding the current workforce almost threefold by 2035.

Semiconductor companies in Finland hold significant market share in specialized areas and are well-positioned to capitalize on global growth opportunities in the high-growth segments. They primarily include integrated device manufacturers (IDMs), pure-play design firms ('fabless' producers), and suppliers of specialized equipment or materials such as wafers and membranes. Of the semiconductor turnover in Finland, approximately 45% (€690M), comes from application-specific solutions, including RF, 5G, logic, and quantum chips. About 30% (€515M) is attributed to MEMS and sensors, and around 25%, (€365M), is generated by optoelectronics and photonics, including lasers, imaging technologies, and extended reality. (Exhibit 5)

In recent years, foreign companies have actively established their presence in Finland, either by opening offices in Finland, as Huawei and MediaTek did, or through acquisitions. Murata acquired VTI Technologies in 2012, Applied Materials acquired Picosun, and Bosch acquired Minima. Finland is seen as an attractive destination for semiconductor design and manufacturing sites because of its societal stability, high level of education, comparatively low white-collar labor costs, clean and affordable energy, and abundance of water – all critical inputs for the industry.

Finland's semiconductor industry, which exports almost all its production, primarily serves end-users in the telecommunications, industrial automation, healthcare, and automotive sectors. The industry is globally connected, with 74% of survey respondents having reported direct connections to the US, 68% to Germany, 58% to France, 54% to Japan, 44% to Taiwan, and 40% to Mainland China. Such extensive global linkages, while exposing the industry to ongoing trade tensions between the US and China, also provide opportunities to reinforce ties with the EU's strategic objectives for technological autonomy and competitiveness.

Finland is home to many universities and research centers dedicated to advancing semiconductor technology and education. These include Aalto University, the University of Oulu, Tampere University, the University of Turku, Åbo Akademi, the University of Eastern Finland, the University of Helsinki, and VTT (Technical Research Center of Finland). Driven by investments into high-quality research, education and supporting infrastructure (such as Micronova's cleanroom facilities and equipment for semiconductor and microelectromechanical systems processing) Finland has become a pioneer in many critical semiconductor innovations, including mobile network solutions, sensors, and process technologies (such as atomic layer deposition). Current research focuses especially on semiconductor lasers, quantum technologies, process technologies, materials, and photonics.

At least 30 large semiconductor initiatives have taken place within Finland since 2018, with over 1.000 projects involving approximately 900 participating organizations[16 17]. These range from industry-wide initiatives (such as Chips from Finland and Chip Zero) to more specialized efforts like quantum computing – for example, The Finnish Quantum Flagship.

Exhibit 5 I The Finnish semiconductor industry, revenue per player and device type

Value chain / Devices (Circle size = 2022 revenue)	Logic €85M €210B, 6% CAGR	MEMS & sensors €515M €230B, 8% CAGR	Optoelectronics €375M €34B, 8% CAGR	RF and baseband €425M €19B, 7% CAGR	Other €180M €170B, 5% CAGR	Opportunities
Fabless €360M €170B 6% CAGR	€15M SoC design			325 Chips, components	20 Analog, power comp.	SoC design, Edge AI chips, Ultra-low power, Power management, RF MEMS components
IDMs €665M €370B		410 MEMS, sensors	240 Imaging, optics, detectors	5	10 Quantum technologies	
OSAT €55M €45B 6% CAGR		5	50 Testing			
Equipment €320M €100B 8% CAGR	55 ALD, equipment	20 ALD, equipment	75 ALD, equipment, lasers	20	150 Quantum technologies	Thin film deposition, Additive manufacturing, Sustainability
Materials €180M €100B 5% CAGR	15 Photonics, nanomaterials	80 Specialized wafers	10 Photonic materials	75 Specialized wafers		Specialized wafers, Advanced materials
Opportunities	Communication, healthcare, automotive; RF MEMS components; Multifunctional and quantum sensors		Photonic solutions; Systems-in-package; Photonic-quantum systems		Quantum tech research, design, and fabrication	

Note: Excluding large global companies such as Nokia and Microsoft. Global market sizes and CAGRS included below Finnish figures.
Source: Gartner[1], Capital IQ[2], Orbis[15], BCG

4.2 Finland builds on its competitive advantages

The Finnish semiconductor industry, with its unique blend of societal and technological strengths, is well-positioned to excel in the global market to produce semiconductor innovations.

Finland's societal advantages make it an attractive destination for semiconductor design and manufacturing sites. Finland's strengths in critical technologies, relevant to future demand, have been built with long-term investments into education, research, and development activities, sustained over the last decades. The Finnish government plans to significantly increase R&D funding between 2024 and 2027 (for example, additional €92M per year for Business Finland, €45-55M per year for Academy of Finland, €262M for doctoral pilot program over 2024-2027), which is expected to benefit the semiconductor industry[18].

To ensure the growth of the Finnish semiconductor industry, Finland needs to continue to reinforce its competitive advantages, so that they do not erode. Finland is advantageous and has notable strenghts in ten areas supporting the semiconductor industry:

Finland's societal strengths:

Societal stability and predictability: Finland consistently ranks among the three most stable[19] countries and top 10 business environments[20] in the world. Finland has low bureaucracy, efficient services and high predictability supporting long-term investment time frames. Finland's English language skills are on a high level. Finland currently ranks number one among the world's countries in progress toward the UN's 2030 Sustainable Development Goals.

Well-functioning infrastructure: Finland benefits from a relative lack of natural disasters and a moderate climate supporting for example stable electricity production. Finland has reached autonomy in electricity production. In 2022, almost 90 % of the electricity produced was already emission-free, with renewables accounting for 54 % of electricity production, including Finland's growing wind power capacity[21].

Natural resources: Finland is the water-richest country in the world[22], which is crucial for the water-intensive semiconductor sector. Water security will become an increasingly important factor in semiconductor manufacturers' credit profiles and could lead to rising chip prices[23]. Finland has an abundance of space for larger factories and facilities. Combined with affordable energy, Finland is an attractive target destination for semiconductor fabrication.

Low cost of innovation: According to the conducted survey for this report, one of Finland's most significant competitive strengths is relatively low cost of innovation; Finland has been a pioneer in many semiconductor innovations in the past (such as atomic layer deposition and mobile networks) with internationally relatively competitive labor costs.

Photo: Murata

Finland's technology-specific strengths:

Mobile network expertise: Finland is a European leader in research and design of 5G and 6G mobile network system circuits. When surveyed, a high proportion of the semiconductor industry stakeholders identify this as a critical technological strength.

Chip design: Finland has strong competencies in semiconductor chip and specifically system-on-chips (SoC) design, enhanced by the presence of global firms such as Nokia and Microsoft along with university research. Finland holds the second-highest number of SoC patents per capita in Europe.

MEMS and sensors: Finland already has a significant market share in EMEA for inertial and environmental sensors, supported by large companies such as Vaisala and Murata, and university-led MEMS-specific research and education.

Photonics and optoelectronics: Finland is home to one of the most important clusters of photonics expertise in Europe (with 300 companies, 6000 employees, €2B revenue in 2023), attracting global technology giants like Microsoft. The Finnish photonics sector excels in optical sensing, detectors, and imaging. It is projected to grow annually +30% in revenue and 18% workforce . When surveyed, a high proportion of industry leaders mention strong competencies in photonics as a competitive strength.

Process and material technologies: Finland stands out in advanced material and process technology, particularly in atomic layer deposition (ALD). Finland has the world-leading cluster of ALD reactors (approximately 90 in 2023), more than 500 R&D experts and notable professors in the field, and the presence of all leading firms. It also has strong sectors in carbon nanotube solutions and printable flexible electronics. The Printocent industry cluster, with more than 500 experts and pilot manufacturing lines and laboratories, is centered in Oulu. Finland ranks among the top-5 European nations in patents and citations for advanced materials research per capita[22]. When surveyed, industry leaders identify strong competencies in material and process technologies as one of Finland's strengths.

Quantum technologies: Finland has one of the densest cluster of expertise in quantum technologies, formed by leading companies, Aalto University, and VTT, placing Finland at the forefront the field in Europe. Finland attracts significant venture capital investments in the field and holds a leading position in quantum computing-related patents[22]. Industry leaders mention strong competencies in quantum technologies as a competitive strength.

Finland's main constraints limiting industry growth:

Supply of talent from Finnish universities is insufficient to support industry growth, especially from doctoral-level education required by the industry. The constraint is driven by the industry's limited appeal to students and the low student intake in relevant fields. As a result, the industry is challenged by limited workforce growth which is required to attract and support large-scale investments to Finland. According to the survey, the national employee supply is ranked as Finland's second major challenge.

Attraction of international workforce is also perceived as a contributing major challenge by the industry, when surveyed. Attracting foreign experts to Finland at the current salary levels is considered challenging. Other factors include geographical location and restrictive or bureaucratic immigration policies.

Lack of large domestic end use markets for semiconductor components leads Finnish companies to exporting most products globally. Survey results indicate the limited domestic market for semiconductors as key challenge. There is a perceived lack of large OEMs driving local demand and value chains. Limited collaboration exists today as Finnish industries' digitalization efforts benefit from e.g., private mobile networks based on SoCs utilizing Nokia's fabless design. Identified opportunities for working more closely with domestic OEMs exist for example in power semiconductors.

Lack of large semiconductor manufacturing facilities, necessitating less competitive smaller production volumes. Only selected applications can command higher prices at lower volumes. The survey ranks manufacturing volume as the fifth major challenge. It notes the global industry's reliance on economies of scale, particularly for leading-edge devices. Attracting investments in manufacturing sites, globally often in the tens of billions of euros, is observed to require substantial government subsidies which Finland struggles to match compared to larger nations.

Raising later-stage larger growth funding is challenging in Finland. The capital expenditure needed to scale up semiconductor start-ups to commercial production volumes are high. According to TESI, the number of deep tech investors in Finland decreased from 105 in 2022 to less than 50 in 2023[26]. Later-stage funding relies heavily on international capital, currently slowed by the market environment. Surveyed opinions suggest that the national funding system lacks the long-term perspective necessary for sustained semiconductor and microelectronics R&D and innovation.

All these factors combined make it difficult to scale and commercialize semiconductor products in Finland. Scalability ranks as the third major challenge according to survey results. This is mostly linked to the low domestic demand and international investments. Current manufacturing capacity investments have been almost fully funded by the companies, based on the benchmarking.

Photo: Canatu

5 The Finnish Semiconductor Vision: Six growth opportunities

Finland has a significant opportunity to capitalize on semiconductor demand by focusing on high demand categories and catalyzing strategic long-term R&D collaboration and education development. Finland should aim at opportunities 5 to 10 years ahead of commercial production. Due to the long development and productization cycles in the industry, Finland should build on its existing strengths in the semiconductor industry to benefit from the global market growth.

Three guiding principles were leveraged to identify growth opportunities:

1. An opportunity should build on Finland's current strengths and advantages:
    - Opportunity leverages existing companies, products, and services for faster scalability.
    - Opportunity is built on expertise clusters to attract investments and maintain competitiveness.
    - Opportunity benefits from collaborations between government and industry for R&D funding.
    - Industry recognizes this as an opportunity, as indicated in surveys.

2. An opportunity should be supported by existing research and education:
    - Opportunity utilizes research from Finnish universities to remain at the forefront.
    - Opportunity is built on or develops partnerships and infrastructure with academic and research institutions to foster technology innovation and talent development.

3. An opportunity should be backed up by high demand growth:
    - Opportunity focuses initially on areas adjacent to existing products and services or strengths as new opportunities take longer to leverage.
    - Opportunity is built on strong market growth fundamentals, including product and end-use market size and growth projections.
    - Opportunity aligns with European strategic objectives and views on critical technologies to benefit from EU funding and support strategic autonomy and competitiveness goals.

Based on the industry views and conducted analysis, this report identifies six opportunities for Finland to capitalize on market growth in the next decade:

1. Chip design: Specialized mobile network, edge AI, and ultra-low power system-on-chips
2. MEMS and sensor innovation: Next-generation MEMS and sensor technologies for communications, healthcare, and automotive sectors
3. Photonics: Enhanced photonics value chain and system-in-package design leadership
4. Quantum technologies: Research, design, fabrication, and integration of quantum technologies
5. Advanced materials: Research, development, and manufacturing of advanced materials
6. Process technologies: Sustainable thin-film deposition and flexible microelectronics technologies.

The six identified opportunities fulfill the principles for selection introduced in this report: they lean on Finland's strengths, research focus, and projected market potential. They position Finland as a significant contributor to the global semiconductor industry. They are poised to make a significant leap in terms of impact to adjacent industries, Finland's exports, and workforce growth.

5.1 Opportunity 1: Chip design

Vision

Finland has a position in design of advanced SoCs for 6G and application-specific AI solutions

Finland is integrated deeply with Europe's industrial demand for automation, AI, and robotics

Finland breaks new grounds with energy-efficient, ultra-low power chips

Finland designs leading next-generation mobile network chips

Finland has the potential to enhance its leadership in chip design for wireless and edge AI SoC chips. By leveraging its existing large companies, like Nokia, and research institutions, Finland is well-positioned in the global market that is projected to reach €200B by 2035[1]. This market demand includes wireless chipsets for 5G and 6G, expected to grow annually at rates of 20-35%[27 28]. Advanced 5G is expected to enable connectivity for Industry 4.0 automation solutions and has strong links to the Finnish technology industry and other fields. The European Union's focus on strategic autonomy in network technologies boosts demand for Finland's regional integration and expertise. Finland's established role in mobile networks provides a solid foundation for expanding into edge AI chips and power management solutions. There is potential for cross-industry R&D opportunities particularly on design and manufacturing of RF MEMS components, novel high-frequency materials, and advanced process technologies for next-generation networks. Over the next 10-15 years, Finland should explore new fields in quantum key distribution, beyond-6G network solutions, energy-efficient network technologies, and ultra-low power chip consumption. AI capabilities will need to be built-in to connectivity solutions.

Finland designs world-leading edge AI chips

Finland has the potential to become a key player in Europe's industrial automation by leveraging its SoC chip design capabilities to develop innovative application-specific AI solutions and accelerators. Utilizing strengths in SoC and chip design with existing experience in edge AI solutions, Finland can meet the growing demands of Europe's industrial automation sector. The AI chip market is experiencing significant growth, with an expected increase to €120B by 2027 and an annual growth rate of over 20%[29]. In the next 10-15 years, Finland could lead in developing application-specific AI-at-edge solutions, high performance energy efficient connected AI chips, and explore neuromorphic and analog computing approaches. This development will be bolstered by existing ongoing research, although the market demand and timing for these technologies are currently uncertain.

Finland designs world-leading energy-efficient, low-power chips

Finland has the potential to significantly contribute to Europe's electrification efforts through design of ultra-low power chips and power management solutions. Increasing demand for energy-efficient chips, particularly SoCs, can be observed across various sectors and includes battery-operated devices like mobiles and wearables, as well as high-performance applications in computing, AI, and automotive. The energy usage of chips is a key factor affecting battery life, device size, cooling needs, performance, and carbon footprint of final products. Leveraging expertise in chip and SoC design, along with novel material R&D, Finland can address growing demand for energy-efficient and sustainable semiconductor solutions. Over the next 10-15 years, additional novel growth areas potentially emerge in energy-harvesting power management integrated circuits (PMICs), embedding these in MEMS/NEMS nodes, with low to zero-power components and further embedding sensors into energy source components. The continued evolution of Internet, industrial Internet-of-Things, and large-scale introduction of a connected metaverse/extended reality into society requires energy-efficient connectivity coupled with advanced mobile communication technologies and built-in AI capabilities.

Finland has multiple advantages in focusing on fabless chip design

With world-class expertise and a substantial number of SoC-related patents[22], Finland is home to approximately 20 fabless design companies that collectively employ over a thousand individuals (excluding large global companies). The Tampere SoC hub is noteworthy for developing SoCs that enhance edge computing and communication performance. Universities such as Aalto, Oulu, Tampere, and Turku, in collaboration with VTT, are deeply engaged in research and development in chip, SoC, and RF design, with a focus on wireless communication and AI. From this position, Finland has the potential to become a home to an EU Design Center of Excellence for 6G and Edge AI chips. Fabless companies require less capital, are more scalable, respond flexibly to market changes and new innovations, and provide significant value addition. By focusing on advanced chip design, Finland supports the EU's strategy for self-reliance in the semiconductor value chain, benefiting critical industries such as automotive and telecommunications and contributing to electrification and sustainability efforts.

Photo: Okmetic

5.2 Opportunity 2: MEMS and sensor innovation

Vision

Finland leads in MEMS solutions for communications, industrial, automotive, and healthcare sectors

Finland leads in next generation advanced sensor solutions innovation

Finland designs and manufactures next-generation MEMS and sensor solutions

Finland has potential to lead in the MEMS and sensor technology domain by leveraging its established market presence and expertise. Valued around €13B in 2022, the MEMS market is expected to grow annually by 8-11%[30], while the larger global sensor market is projected to surpass €400B by 2030 [31]. A growing need for sensors is driven by e.g., need to supply data for AI systems with most devices collecting external data using MEMS/NEMS sensors. Although these sensors constitute a small part of the overall semiconductor demand, they are crucial for linking real-world data to computation. Finland could concentrate on innovations in healthcare sensors, automotive sensors, and intelligent, automated industrial products. In sensors, Finland advances toward multifunctional and self-adaptive sensor systems, with efforts potentially directed to developing e.g., selective detection, fluidics, IR and hyperspectral imaging and quantum sensor capabilities. In MEMS technologies, Finland has potential to growth through cross-industry R&D, particularly in the design and manufacture of RF MEMS components for next-generation networks.

Over the next 10-15 years, Finland could be at the forefront of integrating multifunctional sensors and actuators, enhancing wearable technology, and advancing the integration of quantum sensors. Prospective growth areas include the development of multifunctional sensors and actuators using micro/nano-electromechanical (MEMS/NEMS) and micro-opto-electromechanical systems (MOEMS), self-monitoring MEMS/NEMS solutions, and highly integrated sensors for context recognition. Furthermore, Finland could aspire to create sensor and actuator systems that can withstand harsh environments. The convergence of various semiconductor components will necessitate the hybrid integration process technologies for diverse systems ranging from biological to photonics and electronics.

Finland has multiple advantages in focusing on MEMS and sensor innovation

Finland, with companies like Vaisala, Murata, Bosch, and Okmetic, holds strong European market positions in MEMS and sensor technologies, commanding a significant market shares in EMEA. Finland is already established favorably in terms of design and manufacturing capabilities. The Finnish industry benefits from world-class research in MEMS and sensors, including VTT's applied research and the specialized focus of Aalto University and the University of Oulu on sensor materials and design. Robust research foundation bolsters Finland's potential to lead in the sector.

5.3 Opportunity 3: Photonics

Vision

Finland has a reinforced domestic photonics value chain from design to materials and equipment

Finland leads globally in photonics-microelectronic SiP design capabilities

Finland breaks new grounds in healthcare, silicon-photonics, and quantum integration

Finland designs and manufactures world-leading photonic solutions

Finland has the potential to become a leader in the photonics sector by leveraging its extensive expertise and infrastructure. Finland can capitalize on its strong photonics research and infrastructure by attracting global tech companies and fostering the growth of new deep-tech ventures. The Finnish photonics industry, which is currently diversified into smaller domains, boasts solid market fundamentals. By bolstering competencies in areas such as optical imaging, micro- and nano-photonics, and laser and XR technologies, Finland can tap into the growing market demand.

The sector is projected to experience over 25% growth rates in main markets and a 30% increase in company turnover[23]. Finland can leverage its photonics expertise at the rapidly evolving intersection of photonics and medicine in applications like medical imaging, laser surgery, and wearable photonic devices.

There are additional opportunities in developing photonic-silicon integration and photonic-quantum systems. Over the next 10-15 years, Finland could take the lead in developing new wavelength materials, integrating electro-optical components, combining photonic devices with RF solutions, and advancing quantum-photonic integrated circuits (PICs). There could be further opportunities in analog and neuromorphic photonic computing.

Finland has multiple advantages in focusing on photonics

Finland holds a unique place in European photonics sector with a dense expertise cluster and comprehensive research infrastructure. This ecosystem encompasses IDMs, material, and equipment suppliers and robust research groups in photonics and optoelectronics. Notable initiatives include PREIN, the Photonics Research and Innovation Flagship, the Center for Photonics Sciences at the University of Eastern Finland and the Optoelectronics Research Center at Tampere University, establishing Finland as a leading hub in photonics research and development in Europe. Photonic technologies are essential in consumer electronics, advanced manufacturing, healthcare, and environmental monitoring. Recognized by the European Commission as one of Europe's six key enabling technologies[32], photonics drives innovation across multiple industries and is showing significant growth.

Photo: Okmetic

5.4 Opportunity 4: Quantum technologies

Vision

Finland has technological and export superiority in Europe in quantum technologies

Finland has an end-to-end quantum value chain with state-of-the-art quantum infrastructure

Finland has Europe's leading quantum ecosystem of academic-industry collaboration

Finland designs and manufactures leading quantum technologies

Finland has the potential become a leader in the quantum technology market by capitalizing on its robust quantum ecosystem. Finland should aim to foster growth in quantum technology companies, attract significant investments, and develop state-of-the-art infrastructure. By leveraging its expertise in RF electronics, photonics, cryogenic CMOS, and ultra-low temperature physics and engineering, Finland can enhance its role in quantum technologies. This expertise is critical for example in developing quantum sensors and imaging systems, for example, through collaboration with the Turku medical imaging cluster. Additionally, Finland could focus on integrating quantum technology at the system-level, for example by developing turn-key solutions, to seize a share of the market at the higher steps of the value chain.

The global quantum technology market is projected to reach €20B to €40B by 2030, encompassing quantum computing and services, sensors, and communication. The coming decade is anticipated to witness the emergence of enterprise-grade quantum computing and the next generation of quantum-sensing technologies, potentially revolutionizing sensing solutions across various sectors.

Early opportunities for collaboration could arise within the medical/drug development cluster in Turku. Over the next 10-15 years, Finland has the potential to become a leader in the integration of quantum systems, the development of superconducting photonic-silicon technologies, and the exploration of quantum SiPs for room-temperature applications, or with integrated cooling solutions.

Finland has multiple advantages in focusing on quantum technologies

Leadership in quantum technology could become crucial for economic power and growth, and the European Union views quantum technology sovereignty as essential for future economic development. Recognized as having one of Europe's top three densest quantum ecosystems, Finland possesses leading expertise in quantum technologies, RF electronics, cryogenic CMOS, and ultra-low temperature physics and engineering. This expertise positions Finland as an ideal hub for fostering new quantum technology companies. Finland hosts more than 10 leading quantum technology companies, such as IQM and SemiQon, and receives significant investments in the sector. Finland has already attracted 10% of the top 20 investments in quantum technology within Europe[33]. Institutions like Aalto University, the University of Helsinki, and VTT boast extensive experience in quantum science and technology research and commercialization. InstituteQ, which unites national research groups, is focused on enhancing the skilled workforce in quantum technology. Furthermore, Finland leads in quantum-related patents and citations per capita across Europe, cementing its role as a key player in the quantum technology landscape[22].

5.5 Opportunity 5: Advanced materials

Vision

Finland has reinforced specialized high-quality wafer production capabilities

Finland leads design and manufacturing of high-performance semiconductor materials

Finland manufactures world-leading specialized wafers

Finland can enhance its role in specialized silicon wafer manufacturing. Finland could boost its manufacturing of high-quality silicon wafers aligning with future demand. Global production capacity is increasing by 6,5% per year, with over 25% expected to be in 300mm wafer size by 2024. Major applications transition towards this size[45 35]. Finland should aim to address the growing need for 300mm technologies and attract R&D and design customers globally. Compatibility with leading European research institutions such as IMEC, CEA-Leti, and Fraunhofer enhances Finland's potential to attract major customers. Finland's R&D and innovation infrastructure, including plans for pilot lines like Kvanttinova, is being developed to support this transition and entice global clientele. The shift to advanced manufacturing, requiring significant investment in equipment and skilled talent, presents challenges in the short to medium term and necessitates further technical and economic evaluation.

Finland develops and manufactures novel semiconductor materials

Finland should explore opportunities in novel semiconductor materials through R&D collaboration, aligning with other identified growth opportunities. The overall demand for semiconductor materials is growing at an annual rate of 5%[36] with novel materials experiencing faster growth rates of 20-30%[37]. Significant opportunities exist for innovation in materials supporting future nodes and architectures.
Finland should continue to focus on developing new nanomaterials in thin films, carbon nanotubes, silicon nanostructures and potentially for high-frequency materials for the terahertz range, high-voltage materials for applications over 800V, and advanced photonic and quantum materials. Over the next 10-15 years, Finland could anticipate growth in areas like flexible non-fossil materials, organic biocompatible materials, and sensor metamaterials.

Finland has multiple advantages in focusing on advanced semiconductor materials

Finland is well-positioned to develop novel materials, with a strong emphasis on research and production capabilities in wafers, carbon nanotubes, nanomaterials, and optical/photonic materials. Finnish universities, including Aalto University, Åbo Akademi University, and the Universities of Turku and Helsinki, boast a long history in materials science research. For instance, the University of Helsinki and ASM are focusing R&D efforts on discovering novel materials such as hafnium dioxide (HfO2) and new silicon nitride (SiNx) for future nodes in logic and memory. Finland is highly ranked in Europe for patents and citations related to advanced materials[22], which are recognized by the European Commission as one of the six key enabling technologies[30]. These materials are crucial for enhancing performance across various applications. European countries, increasingly investing in electrification, need materials that are currently sourced from China[38]. Further investment in material expertise is essential for de-risking global supply chains.

Photo: Applied Materials

5.6 Opportunity 6: Process technologies

Vision

Finland leads in development of thin films for novel applications

Finland leads in printed flexible and biodegradable manufacturing and process technologies

Finland designs and develops sustainable thin-film materials, deposition processes and equipment

Finland is globally recognized as a leader in atomic layer deposition technology (ALD) and advantageously positioned in the growing thin-film deposition market, which is experiencing annual growth rates of 9-13%[39]. ALD technology is expanding its role and is among fastest-growing segments in the wafer fabrication equipment market distinguishing itself from competing technologies[40]. Leadership position enhances Finland's capability to leverage ALD technologies in creating novel thin-film processes. These advancements have potential applications in the growing categories within logic, memory, optoelectronics, power semiconductor devices, and quantum technologies.

Finland develops process and manufacturing technologies for flexible microelectronics

There are opportunities in developing novel sustainable process technologies in collaboration with the other growth opportunities., For instance, the convergence of RF MEMS components with leading-edge SoC chips, as well as the integration of sensing devices in wearables and implants into SiPs, necessitates potentially novel integration and packaging technologies for hybrid electronic, photonic, and biomaterial components. Over the next decade, Finland could explore the potential in developing flexible and stretchable systems integrating biochemical and physical sensing, such as large flexible sensors and organic biocompatible materials.

Furthermore, Finland could prioritize the enhancement of additive manufacturing technologies. Additional competitive opportunities could include focusing on management of replacement of parts, recyclable materials and incorporating condition monitoring and predictive maintenance. The aim should be to achieve full recycling, material recovery, and repair processes in manufacturing processes with the goal of achieving CO2 neutrality and zero waste.

Finland has multiple advantages in focusing on process and manufacturing technologies

Finland has the world's largest cluster of ALD reactors, with approximately 90 units in 2023, and over 500 R&D experts, researchers, and professors. Finland is a leading hub together with firms such as Applied Materials, ASM, and Beneq in ALD thin-film deposition development for ultra-thin materials. Finnish universities like Aalto and University of Helsinki have dedicated research groups and world-leading professors in ALD technologies. The University of Oulu and the University of Turku contribute to surface science research, while VTT specializes in hybrid integration techniques and is involved in the Pack4EU advanced packaging initiative. Finnish companies are well-positioned to collaborate with European companies like ST Microelectronics and Infineon, leveraging the existing Chip Zero ecosystem established by Applied Materials, to become leaders in sustainable semiconductor manufacturing equipment and process technologies.

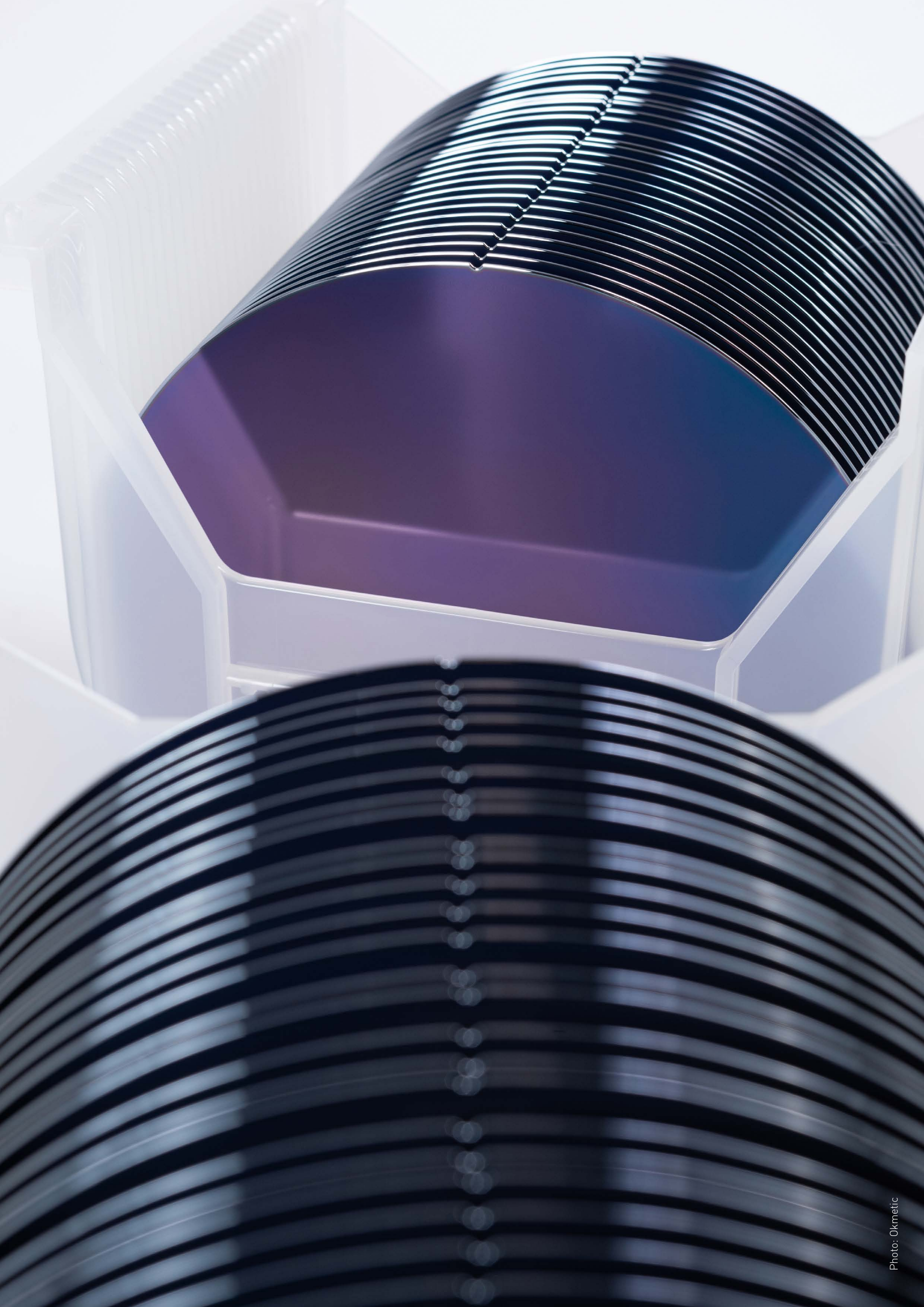


Photo: Okmetic

6 The Finnish Semiconductor Roadmap: Clear actions to accelerate growth

Finland has significant economic and technological potential in the semiconductor industry. This potential can lead to high-value job creation and economic benefits to Finland. However, many countries like the UK, Denmark, Germany, Spain, and France are also seeking similar growth, have launched long-term semiconductor strategies, and are making substantial national investments. Finland should ensure a level playing field for its industry in the current geopolitical climate by supporting for the industry. Part of this support should be channeled toward the most critical enabler of growth: education and research to create an adequate talent pipeline and robust clusters of expertise.

Since 2018, Finland has launched over 30 large initiatives involving 1.000 projects and 900 organizations, positively impacting the semiconductor industry[14, 15]. Notable initiatives include Kvanttinova, Chip Zero, Finnish Research Council's roadmap (including Finnish quantum computing infrastructure FIQCI, and Nokia's 'Unlocking Industrial 5G' consortium which increased R&D investments by over €200M[41].)

To maximize the industry's growth potential, Finland needs a strategic, long-term view for its semiconductor industry with clear, measurable targets. The overall strategic goal of industry growth and job creation is supported by five outcomes for each of the six opportunities (Exhibit 6):

1. **Competitive R&D ecosystem:** Finland must secure international R&D collaborations, and rapidly commercialize innovations. Key measures include leading in patent applications and doubling the number of deep tech companies founded per year. Proposed actions include public and private investment in R&D and building pilot lines for collaboration.
2. **Workforce growth:** Workforce supply is critical for industry competitiveness. Key measures include increasing the semiconductor industry workforce to 20.000 by 2035. Actions include academia-industry collaboration, improving international talent pipelines, and strengthening the government commitment to education resources.
3. **R&D and design site investments:** Attracting R&D and design sites is crucial for global competition. Key measures include securing new site investments and increasing the share of Finland's R&D investment by foreign companies. Proposed actions include establishing an EU-labeled Design Center of Excellence and raising Finland's influence in EU policies and funding.
4. **Manufacturing site investments:** Semiconductor manufacturing has clear economic benefits. Key measures include securing major manufacturing investments by 2035. Actions include public-private cooperation and attracting manufacturing investments.
5. **Collaborative ecosystem:** Finnish industry has a structure for closer and sustainable collaboration among companies and key stakeholders for implementing the strategy. A focus on this outcome would solidify, expand, and make continued use of that ecosystem.

Achieving the outcomes places Finland at the forefront of semiconductor innovation, meets workforce demands, and establishes Finland as a preferred location for specialized research and manufacturing in Europe and globally. Actions along outcomes are required from the government, industry, and academia.

Exhibit 6 I Enabling outcomes and actions

Chips from the North: What can the government and industry do?

1 Competitive R&D ecosystem

Increase R&D investments, international collaborations and R&D infrastructure

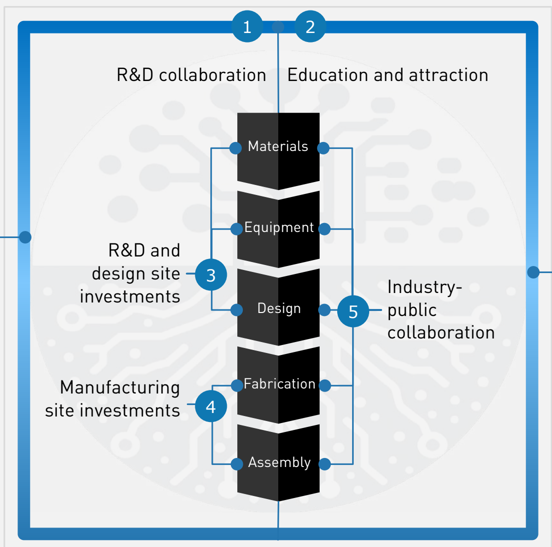
- Pilot lines operating model
- Joint R&D funding of €5B over ten years
- Coordinated EU funding tracking
- Multi-year flagship research program
- Closer non-EU bilateral relationships

3/4 Investment attraction

Attract significant R&D, design and manufacturing site investments

- Promotion of talent and startup clusters
- 6G EU Design Center of Excellence
- Broad range of public instruments
- Public-private collaboration

Five enabling outcomes



Workforce growth 2

Alleviate industry talent gap by educating and attracting 15.000 new employees

- Investments in education quantity and quality
- Funding mechanisms and tenure tracks
- Scalable programs for upskilling and reskilling
- Campaigns to promote industry attractiveness
- Coordinated international talent pipelines

Industry-public collaboration 5

Enable long-term collaboration among industry, academia, and government

- Effective industry collaboration structure
- Geopolitical monitoring and coordinated response
- EU policy and funding influence

6.1 Outcome 1: Competitive R&D ecosystem

Finland should increase R&D investments, secure international R&D collaborations and build infrastructure to rapidly commercialize innovations. Finland should aim for top-3 position in semiconductor patent applications in Europe. Finland currently ranks sixth in Europe for patent applications for semiconductors, and first in patent applications per capita[22]. Finland should aim to double number of founded semiconductor companies per year to 30. Between 2010 and 2023, an average of 16 deep tech and semiconductor companies were launched annually in Finland, according to TESI[24].

Actions

- **Finland needs a total funding of €5B for semiconductor R&D** over the next ten years, focused on the six opportunity areas. The majority of this will be carried out by the industry, with the government providing significant leverage through increased funding. (Industry, Government)
- **Finland needs to create an operating model for pilot lines** that builds and operates them, funds necessary equipment, attracts customers, and interacts with leading European research and technology organizations. The government should also pledge matching funds for these pilot lines and associated projects under the EU Chips Act and similar initiatives. (Government, Industry, Academia)
- **Finland should establish and track a plan to gain the most benefit from semiconductor-related EU funding programs.** The plan should include building networks to European research and technology organizations and global companies, enabling participation in multi-party funding calls and helping to attract international customers. (Industry, Government)
- **Finland should launch a new multi-year flagship research program** in microelectronics to complement the ongoing 6G, photonics and quantum flagships and industry-driven innovation initiatives. (Government)
- **Finland should establish closer bilateral relationships** on semiconductor technologies and related trade and R&D initiatives with partners beyond the EU: in particular the US, the UK, Canada, Japan, South Korea, India, and Taiwan. (Government)

6.2 Outcome 2: Workforce growth

Finland should aim to alleviate the talent gap to support growth and industry competitiveness. Finland should aim for 20.000 employees in the semiconductor industry by 2035. Finland currently has 7.000 employees in the semiconductor industry. The industry needs at least 15.000 new employees over the next ten years, considering also the workforce that will retire. More hands-on design experience is required from the workforce. Currently, PhDs and DScs in the workforce needs to triple and the number of MScs to at least double. Education focus should be on enabling MScs with practical, hands-on experience. Demand for clean room operators and technicians is expected to grow. Surveyed industry leaders say that complex and stringent immigration policies are a major issue, and these should be addressed.

Actions

- **Finland should commit to raising the quality and quantity of microelectronics higher education.** This means significantly increased student intake and adequate output of MSc and DSc graduates. Industry and academia should co-create degree programs that funnel new talent into the field. (Government, Academia, Industry)
- **Postdocs and professors should be attracted through innovative research funding mechanisms and world-class tenure tracks** and campaigns. Additionally, research and industry should collaborate on further developing leading semiconductor publications, aiming to gain international visibility and attract top talent. (Academia, Industry, Government)
- **Finland should foster vocational education and training in microelectronics** through degree programs and short courses with appropriate use of on-the-job learning and apprenticeships to meet the growing demand for manufacturing staff. (Government, Industry)
- **Scalable programs for upskilling and reskilling** the current workforce should be put in place, enabling smooth career transitions within the semiconductor industry and building a talent pipeline from declining industries. (Government, Industry, Academia)
- **Finland should launch campaigns** to promote the attractiveness of semiconductor-related studies and careers among students. There should be internships and other efforts to provide practical work-related engagements during studies and communicate clear paths towards industry employment. (Industry, Academia)
- **Finland should establish coordinated international talent pipelines** to Finland from abroad, ease immigration policies with targeted measures for critical talent, support pathways to industry jobs, and define joint actions to retain foreign students and talent in Finland. (Government, Industry, Academia)

6.3 Outcome 3: R&D and design site investments

Finland should aim to attract significant semiconductor R&D and design sites from foreign companies. Design, which accounts for roughly half of all industry R&D investment and value add[42], is a key strategic priority for reinforcing the EU's chip design ecosystem. Important site selection criteria include the workforce (access to university and startup talent), the existing ecosystem (proximity to research communities, startup ecosystems and design clusters) and affordability of facilities, cost of living and taxes. Finland should aim to increase the share of Finland's R&D covered by foreign-owned companies from 26,5% in 2020, to 35% by 2035. Peers like Sweden and Norway had 42% and 32% shares in 2020 respectively. According to OECD data, the foreign-owned companies' share of Finnish R&D has remained stagnant[43].

Actions

- **Finland must prioritize long-term initiatives to promote its design-related talent, startup, and technology clusters.** This involves enhancing research-industry collaboration through forums, showcasing innovations at international trade shows, executing targeted marketing campaigns, and leveraging diplomatic channels to bolster visibility among large design companies. (Government, Industry, Academia)
- **A comprehensive set of public instruments** should be developed and put forth, tailored to attracting specific design sites. (Government)
- **Finland should establish an EU-labeled 6G and Edge AI Design Center of Excellence** under the EU Chips Act. (Industry, Government, Academia)

6.4 Outcome 4: Manufacturing investments

Finland should set a target of >€1B in specialized manufacturing site investments by 2035 as a significant step-change to support the industry in Finland. No large-scale (>€1B) international semiconductor manufacturing investments have been made in Finland so far. Important site selection criteria include net production costs (site development, power and water, machinery, and taxes), power infrastructure, proximity to other fabrication sites, customers, services, and the availability of tax breaks and other incentives.

Actions

- **Public-private partnerships should be established to jointly attract manufacturing site investments**. These partnerships should consistently promote Finland's manufacturing capabilities at research-industry forums, international trade shows, and through diplomatic channels. (Government, Industry)
- **Finland should establish and employ a comprehensive set of public instruments** specifically designed to appeal to and secure specific manufacturing sites. (Government)

6.5 Outcome 5: Ecosystem between industry and stakeholders

Finland should enable long-term collaboration among industry, academia, and government to support the execution of the semiconductor strategy, and to maintain situational awareness on geopolitical, technological, and economic developments that would affect the execution.

Actions

- **Finland should establish an effective collaboration structure** for the implementation of the national semiconductor strategy that enables tracking of key outcomes and actions. (Government, Industry, Academia)
- **There should be an active process for sharing key developments in geopolitics and industrial and trade policies.** The industry and government should define and support proactive industry activities that would address key challenges in the operating environment. (Industry, Government)
- **Finland should bolster the cooperation and resources** needed to influence EU semiconductor-related policies, objectives, and funding instruments. (Industry, Government)

Conclusion

The global semiconductor industry is a significant growth opportunity for Finland, with the potential to yield long-term economic growth and enhance Finland's competitiveness for years to come. The Finnish semiconductor industry is equipped with unique competitive advantages and has identified six growth opportunities to establish itself as a leader in.

The outlined strategy in this report is just the beginning. Strong collaboration is essential for realizing the opportunities. The industry is committed to acting together through decisive actions that will shape the future of semiconductors and microelectronics in Finland.

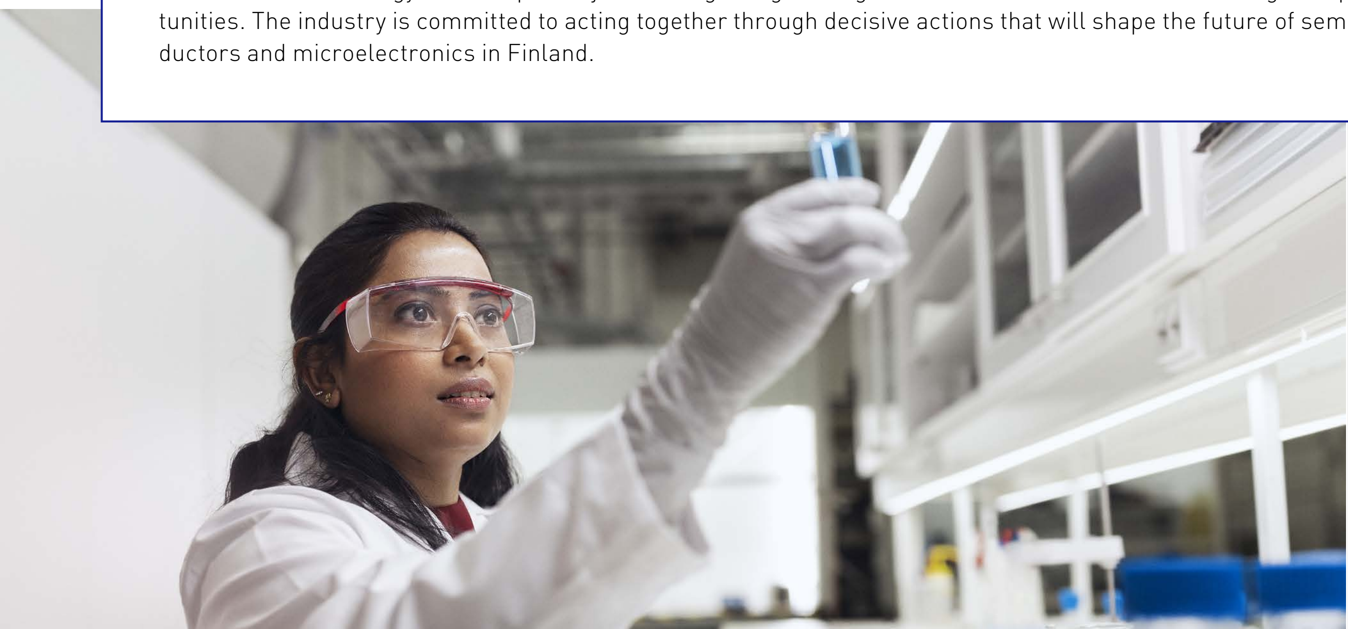


Photo: Canatu

7 Supporting Materials

7.1 Introduction to semiconductors

7.1.1 What are semiconductors?

Semiconductors are materials with electrical conductivity properties between conductors and insulators. These chips and sensors form the foundation of microelectronics products. They are combined extensively in electronic systems like smartphones, computers, and advanced automotive systems.

Silicon is the most widely used semiconductor material due to its availability and electronic properties. Other materials (such as germanium) and compound semiconductors (combining two or more elements, like gallium arsenide) are used for specific applications, such as high voltages in power electronics or high frequencies in communication. Basic sciences, including physics and materials sciences, play important role in industry.

Semiconductor devices range from microelectromechanical components (such as sensors) to advanced system chips (like those used in mobile devices and mobile networks) and components used in power systems or other machines and appliances. Semiconductors are generally categorized into general-purpose (such as memory or generic processing chips) and application-specific devices (such as 5G baseband chips and image signal processors).

Transistors are the foundational functional unit of typical complex chips. A logic or a memory chip in a smartphone can consist of billions of transistors acting as switches or amplifiers. Exponential growth in computing power per Euro over the past decades stems from continued innovation in chip design. Thus far, the number of transistors on a chip has doubled approximately every two years, while the cost of devices has halved. This principle, known as "Moore's Law", has been a guiding forecast and a target for the industry, driving research and innovation in related technologies.

The industry is evolving towards smaller node sizes in leading-edge chips (currently under 3 nm). However, larger node sizes, known as 'trailing edge' or 'mature,' remain important for many applications.

Maintaining the pace of Moore's Law is becoming more difficult due to physical and size limitations. The industry is addressing challenges like quantum tunneling and heat dissipation in dense chips, by innovating with new materials, 3D transistor architectures, and advanced lithography techniques.

Two complementary technological development paths have also emerged. "Beyond Moore" refers to technologies that go beyond traditional transistor scaling: enhancing computational capabilities through innovations like quantum technologies, neuromorphic computation, and materials like graphene. "More Than Moore" refers to diversifying integrated functionalities: with features like sensors, radio frequency components, and power management built into chips. This evolution broadens applications in IoT, smart systems, and sectors like healthcare and automotive.

Semiconductor research and development (R&D) is the process by which innovative ideas are transformed into technological advancements and capabilities to enable creation of more advanced semiconductors. Semiconductor R&D is critical part of a virtuous cycle of research and innovation that supports national technological leadership. Faster and more pervasive computation with increasing power efficiency of devices benefits the public and equally provides a strategic edge both in business and national security.

7.1.2 Why semiconductor industry matters?

The global semiconductor industry is critical for national economies, while its highly globalized supply chain is subject to geopolitical and supply vulnerabilities. Semiconductor components are vital for military, cybersecurity, and infrastructure resilience. The European Union's renewable energy and energy-efficiency goals rely heavily on semiconductor innovations. Semiconductors are also essential in everyday devices such as smartphones, computers, and communication networks. They play a significant role in vehicles for safety, entertainment, and autonomous driving, and are key components in IoT devices, sensors, and AI systems.[44]

The global semiconductor industry significantly impacts economies. The industry is a large part of the global technology industry. It represents 10% of technology revenue, 26% of operating income, and 27% of R&D spending, according to Gartner and Capital IQ figures. The global semiconductor market size is projected to grow annually at a rate of 7-8%, reaching almost €1T by 2030[1].

Some companies in the field have grown dramatically and are expected to continue at a similar pace. For example, the market capitalization for Nvidia, a GPU designer and manufacturer, has seen 1800% growth in the last five years (based on stock price 22.2.2024). The industry creates significant direct economic impact due to its size, but also has an outsized impact on adjacent industries and economy due to the integration of semiconductors in end products. In 2022, global semiconductor R&D spend was approximately €100B, supporting a global semiconductor market of €570B and an estimated end use market of approximately €9T. A euro spent in semiconductor R&D indirectly creates approximately €15 to €90 in end market value[1,3]. BCG estimates that in EU countries, the semiconductor industry will enable €3,1T in market growth across automotive, industrial, healthcare and network sectors by 2030, creating 8,2M jobs.

The globalized semiconductor supply chain is vulnerable to disruptions. Disruptions might include geopolitical tensions, natural disasters and epidemics affecting supply. There are more than 50 'choke points' across the supply chain where a single region holds over 65% of the global market share[45]. Advanced semiconductor technologies are a strategic asset, with nations implementing export and investment controls. Dependence on single foreign semiconductor sources can limit national technological sovereignty and undermine economic security. These factors are prompting countries to develop domestic semiconductor capabilities, to maintain technological sovereignty and strategic control. Protecting sensitive intellectual property in semiconductor R&D is vital for global technology leadership and competitiveness.

Semiconductors are integral to military systems and cybersecurity, with critical national infrastructure relying heavily on these technologies. For example, quantum sensors and radar could increase precision and stealth capabilities, creating advantages in surveillance and defense operations. Modern infrastructure, including power grids and communication networks, relies on semiconductors, making their security and resilience critical. Semiconductors are central in cybersecurity. Vulnerabilities in these components increase the risk of espionage and data theft. Secure supply chains are crucial for national security.

The EU's Green Deal depends heavily on semiconductor innovations for renewable energy and energy-efficient industrial processes. For example, photonics technologies are key in developing renewable energy sources and improving energy efficiency. Semiconductors enhance solar panel efficiency, optimize wind turbine controls, manage smart grid electricity flow, and improve energy storage systems. In industrial processes, semiconductors are used to boost energy efficiency, reduce waste, integrate energy sources, and manage environmentally friendly practices through sensors. At the same time, the semiconductor industry's environmental impact, particularly in terms of water usage and carbon footprint, has become a topic of concern.

Semiconductors are crucial in devices like smartphones, mobile networks and computers, accounting for a significant portion of device manufacturing costs and enabling functionalities like data processing and sensing. Wireless networks are also critical for national safety and security – and key enablers for societal transitions. 25% of revenue from semiconductor applications comes from wireless communications, and an additional 25% comes from computation[1]. Proprietary chip design offers competitive advantages for manufacturers. By designing their own 'chips', OEMs can optimize battery life, processing power and functionalities with tighter integration of hardware and software.

Semiconductors enable automotive features like safety and autonomous driving. Automotive industry generates 10-15% of the industry's revenue[1]. Semiconductors play a key role in automotive sensing, electric-vehicle batteries, energy efficiency and advanced driver-assistance systems. The automotive sector is estimated to be the fastest-growing semiconductor application segment, with an annual growth rate of 12% for the next five years according to Gartner[1]. In 2020 as global pandemic induced a global shortage of critical semiconductor components, grinding the industry to a halt.

Industry and defense sectors heavily rely on semiconductors for functions like navigation and surveillance. 10-15% of revenue from semiconductor applications is generated by the industrial, security, healthcare, agriculture, and military/civil aerospace sectors[1]. Nearly all products we use in the daily life are manufactured in facilities and production processes relying on enabling technologies like robotics, which in turn are built with semiconductors. Photonics plays a crucial role in medical technologies such as imaging and diagnostic tools. Quantum technologies will contribute to the development of new pharmaceuticals and personalized medicine through simulations of molecular and chemical interactions.

Semiconductors are key to IoT devices, sensors, and AI systems, driving advances in efficient, sustainable societies. Demand for edge computing, where data processing occurs close to the data source, is growing rapidly. By 2030, 80% of data processing is expected to happen at the edge (in proximity to local needs)[46], a significant shift from the current dominance of cloud services. ARM predicts that by 2035, there will be 1T edge devices in use[47]. Simultaneously, the development and operation of Artificial Intelligence (AI) demands substantial computational resources. AI systems process vast volumes of data at high speeds, enabled by technologies like photonics. The growing reliance on AI necessitates increased cloud computing capacity and data storage, which depend on servers equipped with semiconductor chips. The energy demands of AI solutions are rising, reinforcing the need for low-power designs.

7.2 Finland as part of the semiconductor industry

7.2.1 Finland in the global semiconductor industry

Finland's semiconductor industry generated about €1,6B in revenues in 2022 excluding large global technology companies (Nokia, Microsoft). This industry group consists of approximately 90 companies registered in Finland, of which around 60% are SMEs. Together, they employ roughly 7.000 people.

The Finnish semiconductor industry is relatively small, compared to the global semiconductor market. Finland's semiconductor industry total revenue contributes 0,2% to the global semiconductor industry revenue, in line with Finland's overall contribution to global GDP. The Finnish semiconductor industry contributes 0,5% to Finland's GDP, which is in line with similar global averages. Finland is not comparably large or small in semiconductors – but right to its size.

The Finnish semiconductor industry does not have a sizeable domestic end use market but is globally connected and exports almost all its output. In the survey conducted for this report, 74% of industry leaders said they have direct connections to the US, 68% to Germany, 58% to France, 54% to Japan, 44% to Taiwan, and 40% to Mainland China. These linkages expose the industry to ongoing trade tensions between the US and China and provide further incentives to deepen ties with the European Union's strategic technology autonomy goals. (Exhibit 7)

Exhibit 7 I Finland's industry's direct geographical connections. Share of 'direct connections' by country or region (Q: Which geographies is your organization directly connected to?)

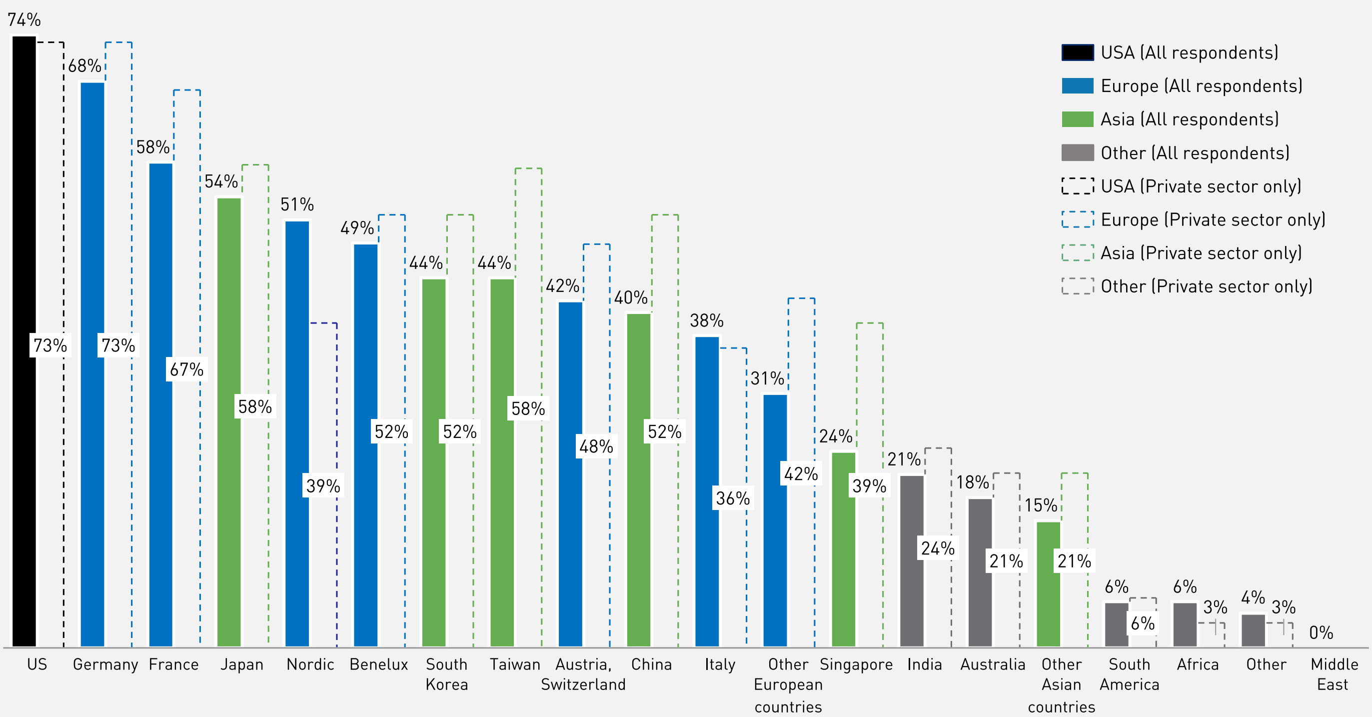



Photo: Julius Jansson, Unspash

7.2.2 Significant market shares in specialized domains

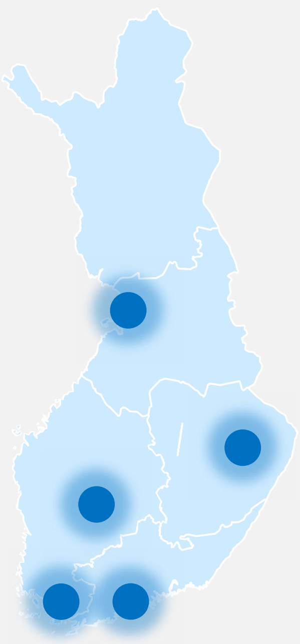
The Finnish semiconductor industry is spread out across Finland, with the largest hubs in the capital region (Helsinki, Vantaa, Espoo), the Oulu region, and the Tampere region, all having spearheads (Exhibit 8). Finnish companies are mostly integrated design-manufacturers, pure-play ('fab-less') design firms and suppliers of advanced equipment or materials. Their products include specialized wafers, membranes, MEMS technologies (including sensors and RF devices), ASICs (5G chips), and optoelectronics devices used in lasers, imaging, and extended reality. The industry primarily serves B2B customers in the telecommunications, industrial automation, healthcare, and automotive sectors. The Finnish semiconductor industry is positioned well to meet global growth opportunities and serve current high-growth semiconductor segments.

Approximately 30% of the semiconductor annual revenue in Finland (€515M) is related to **MEMS and sensors** (Exhibit 5 in chapter 3). Notable IDMs who both design and manufacture components include Vaisala and Murata. Vaisala, with 10-20% global market share for its advanced environmental and industrial measurement technologies, primarily serves sectors such as meteorology, environmental sciences, and industrial measurement. Murata specializes in high-performance MEMS components used in the consumer electronics, automotive, and healthcare sectors. Other key players include Okmetic, which is the world's seventh-largest specialized silicon wafer manufacturer.

Approximately 45% (€690M) is related to **application-specific solutions** (including RF and logic chips), primarily on semiconductor R&D and fabless design. Companies in this group include Nokia, Huawei, Nordic Semiconductor, and Applied Materials, along with smaller startups such as IQM. Nokia (not included in total revenue) has close to 20% share in the €50B market for 4G/5G mobile networks. In Finland, Nokia conducts fabless custom design of System-on-Chip solutions. Huawei in Finland focuses on the development of advanced communication technologies and solutions tailored to specific applications. Nordic Semiconductor Finland specializes in the design of low-power wireless chips, catering to a range of applications such as consumer electronics and medical devices. Applied Materials, the world's largest semiconductor equipment manufacturer, develops thin film coatings, a critical element in the fabrication of logic and memory chips. Smaller deep technology companies like IQM are at the forefront of developing full-stack quantum computing solutions.

Approximately 25%, or €375M, is driven by **optoelectronics and photonics** with IDMs like Detection Technology and Senop. Detection Technology specializes in advanced X-ray imaging systems, crucial for applications ranging from industrial automation to security and surveillance. Senop focuses on high-performance imaging systems for defense, security, industrial and scientific applications. OptoFidelity provides advanced metrology systems for AR/VR/MR.

Exhibit 8 I Guided tour through Finland's semiconductor industry, €1600m
(Companies' turnover in region 2022, Number of companies and employees in region 2022)



Oulu region — Wireless and sensor cluster
€260M
14 companies
1400 employees

Joensuu region — Photonics cluster
€10M
5 companies
90 employees

Tampere region — Chip R&D and design hub
€130M
17 companies
550 employees

Capital region (Helsinki, Espoo, Vantaa) — Broad research and expertise cluster
€1130M
43 companies
4400 employees

Turku region — Medical cluster
€45M
9 companies
200 employees

Example companies in Finland

Nokia	Networks	Bosch	Sensors
Microsoft	R&D and design	Intel	SW, RF circuits
Vaisala	Sensors and MEMS	SemiQon	Quantum processors
Murata	MEMS	Silicon Labs	Wireless connectivity
Huawei	Networks	Nvidia	SoC software
Bluefors	Cryogenic equipment	modulight	Lasers and optics
Okmetic	Silicon wafers	Danfoss	Power, climate and drives
Detection Technology	X-ray detectors	dispelix	XR waveguides
Beneq	ALD	Aspocomp	PCBs
Nordic	Wireless connectivity	ASM	ALD
OptoFidelity	Testing equipment	Texas Instruments	Analog, power and wireless
Applied Materials	ALD	IQM	Quantum computers
Senop	Optronic solutions	Canatu	Nanomaterials
CoreHW	IC design	PiBond	Nanomaterials

Note: Oulu region covers North Ostrobothnia and Kainuu region. Joensuu region covers North Karelia and North Savo regions. Tampere region covers Pirkanmaa and Kanta-Häme region. Capital region covers Uusimaa region. Turku region covers Southwest Finland region. Source: Orbis[15], BCG.

7.2.3 Above-market growth projections and talent requirementss

According to the industry survey conducted for this report, semiconductor companies operating in Finland are expected to **grow at an annual rate of 10-11%**, doubling the total industry annual revenue to €3,2B by 2030, and tripling to €5-6B by 2035. This growth rate will be influenced by the supply of skilled resources, along with R&D funding and collaboration, and the attraction of growth and site investments.

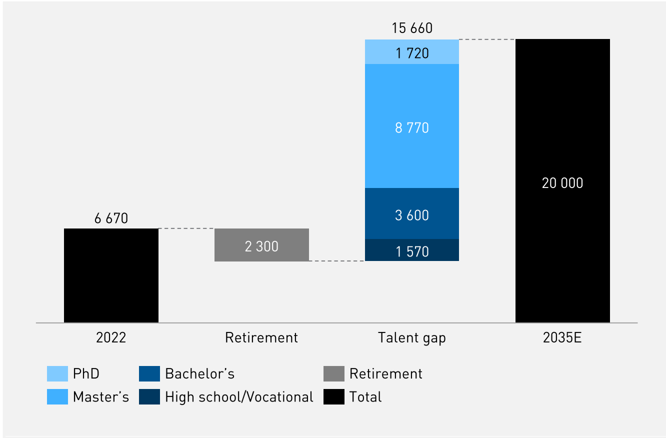
Survey respondents emphasized the importance of the available workforce. The anticipated growth of the industry is estimated to require at least 2 to 3 times the current workforce (at least 15.000 additional employees). The number of relevant PhDs in the workforce needs to triple and the number of MSc degree holders to double. Moreover, the industry needs to replace 2.000 to 2.500 employees to maintain the 2022 workforce level, due to retirements or leave. (Exhibit 9).

Imperatives for increasing the supply of talent include raising the number of higher education graduates in microelectronics design and manufacturing across all universities and improving Finland's appeal to foreign companies and experts.

Government policies and funding play a critical role in attaining expertise – for example, increasing intake in universities and implementing easier immigration policies. Surveyed industry stakeholders report complex and stringent immigration policies as a major issue to attracting international workforce.

Furthermore, without government incentives, scaling semiconductor businesses in Finland is comparatively expensive. Based on benchmarking, successful other countries subsidize their semiconductor industries, improving investment business cases and returns.

Exhibit 9 I Finnish Semiconductor Industry Talent Gap



Note: Based on estimates without productivity growth assumptions, i.e., static revenue per employee. Education data based on estimates from Norwegian semiconductor industry report. Retirement estimates based on EU data.
Source: Gartner[1], Orbis[15], Industry reports , BCG analysis

Photo: Applied Materials

7.2.4 The value of world-class education and research

Finland is home to multiple universities and research centers dedicated to advancing semiconductor technology and education. These include Aalto University, the University of Oulu, Tampere University, the University of Turku, Åbo Akademi, the University of Eastern Finland, the University of Helsinki and VTT.

This microelectronics and semiconductor research and development ecosystem was built over the last decades, with focused, long-term investments into education, research, and development. These activities succeeded in their goal: to help develop Finland's national telecommunications and specialized electronics industries. The resulting technological capabilities already existing in Finland – for designing semiconductor chips, radio frequency, analog, mixed-mode components, and other functions, and combining these in complex application-specific solutions – have been key enablers of the global success of Finnish end use industries.

With its investments in high-quality research and education and the supporting infrastructure (such as Micronova, a central facility for micro- and nanotechnology research), Finland has become a pioneer in many critical semiconductor innovations. It has gained a reputation for distinctive offerings in mobile networks, sensors, and process technologies such as atomic layer deposition (ALD).

A recent survey conducted at Aalto summarizes current semiconductor research focus in Finland on semiconductor lasers, quantum technologies (such as quantum wells and nanocrystals/dots), process technologies (such as doping, molecular beam epitaxy and thin films), materials (such as compound semiconductors like GaN and GaNi) and photonics (such as photoluminescence).

VTT Technical Research Centre of Finland, one of Europe's leading research institutions, plays a significant role linking academic institutions and industries through its applied research and commercialization efforts. It offers research and development services, small-volume production, a launch incubator, and access to cleanroom and process equipment. VTT fosters deep tech spinouts – such as SemiQon, launched in 2023, which designs and produces quantum processors.

OtaNano is a national research infrastructure supporting research in quantum technologies and micro- and nanoelectronics. It provides access to advanced fabrication and characterization facilities. Micronova is part of OtaNano. It offers cleanroom facilities and equipment for semiconductor and microelectromechanical systems processing.

Kvanttinova is a recent, significant Finnish R&D investment initiative, with strong backing from VTT and the government. It deploys €300M to build a piloting and development facility for microelectronics and quantum technology. This new infrastructure supports pre-commercial startups and tech firms with a pilot line for small-volume manufacturing and scale-up. Kvanttinova will contain the latest equipment for shared use, as well as company-specific labs and cleanrooms. It will enable capabilities and integration options for MEMS sensors, RF technologies, integrated photonics, compound semiconductors, quantum technologies, post-and-beyond-CMOS integration and the packaging of electronics and integrated photonics to applications.

Just as Micronova successfully supported industry leaders like Vaisala, VTI and Okmetic, the Kvanttinova initiative aims to strengthen Finland's position as one of Europe's most important microelectronics and quantum technology hubs. This is expected to increase the sector's RDI activities in Finland, boost product and service exports, and attract new international experts, companies, and investments. Another planned pilot environment for system-in-package chips (SIPFAB) in Tampere is intended to provide equipment to enable the assembly, packaging, testing, and verification of the functionality of complex hybrid microelectronic and photonic components and circuits.

7.2.5 How Finnish industryIndustry drives active R&D collaboration

At least 30 large semiconductor initiatives have taken place within Finland since 2018, with more than 1.000 projects and about 900 participating organizations[14 15]. This makes Finland an active hub for collaboration around emerging technologies.

The Chips from Finland initiative is focused on creating a European semiconductor and quantum industry ecosystem for local companies and researchers. It is establishing a nationally networked chip competence center and boosting growth of the industry through investments in joint-use infrastructure, such as pilot lines. There could be further potential in elevating initiatives like these into formal Finnish semiconductor technology flagship projects for further funding and momentum.

SoC HuB is a joint initiative supported by Tampere University and the industry. It supports the design of new system-on-chip solutions for 6G, artificial intelligence, imaging, and security applications. The initiative gathers stakeholders and fosters research, development and innovation in applications such as intelligent machines and edge computing. It helps boost SoC design competencies and complements existing expertise in embedded systems and microelectronics in Finland. There is further potential for expanding SoC capabilities more broadly in Finland.

Chip Zero, led by Applied Materials, aims to create the first sustainability-oriented semiconductor ecosystem into Finland. It is the first semiconductor 'Veturi' program of Business Finland. Its goal is to enable development of chips with zero lifetime emissions. It has set targets to lower the carbon emissions of semiconductor manufacturing by 50% and increase the handprint of chips by double digit percentages by 2030. There were 39 active companies participating in 2023, with already €60M in R&D investments into Finland.

The 6G Flagship initiative at Oulu University is the world's first 6G research program, a global leader in 5G adoption, and a preferred research partner in 6G development. The initiative focuses on high-quality 6G research, knowledge development and sustainable solutions for society's needs in the 2030s.

InstituteQ is an umbrella organization established by Aalto University, the University of Helsinki, and VTT to collaborate on quantum science and technologies, including the strengthening of quantum-related education.

The Finnish Quantum Flagship brings together leading quantum experts to consolidate and expand Finland's national ecosystem for quantum technology. The Flagship will merge research in quantum materials, devices, and information with leading expertise in applications and technology transfer. Through cutting-edge research, the Flagship aims to boost the emergence of new businesses and secure Finland's position as a leading quantum-enabled society.

7.2.6 Attractiveness to global technology firms and investments

Finland is an attractive destination for semiconductor design and manufacturing sites. Its advantages include societal stability, a high level of education, comparatively low white-collar labor costs, comparatively clean and affordable energy, and an abundance of water: all critical inputs for semiconductor industry. Foreign companies have actively established a presence in Finland during the last years, either through acquisitions or by locating facilities in the country.

ASM acquired Microchemistry Oy in 1999, recognizing the potential of Atomic Layer Deposition (ALD) in semiconductors, and facilitated its mainstream adoption in the industry. It played a key role in the development of HfO2 for Intel's transistors. Today, ASM has the largest state-of-the-art 300mm semiconductor manufacturing tools installation in Finland. Since 2000, ASM Finland has grown into a major R&D center, driving advanced material and process research, and close collaboration with the University of Helsinki. The Helsinki ALD group and the newly created ALD Center of Excellence have strengthened this long-term collaboration, contributing to fundamental research on the manufacturing of future semiconductors.

Murata expanded its MEMS sensor manufacturing in 2018 by building a new factory in Vantaa and increasing sensor production capacity. MEMS sensors manufactured by Murata in Finland are used in applications such as car safety systems and pacemakers. With the factory expansion, Murata strengthened its R&D and manufacturing operations and took a long-term perspective on increased utilization of this facility.

Vaisala opened a new R&D and innovation center in 2021. The new center houses 300 experts, representing 67% of Vaisala's R&D personnel, with 37 custom laboratories. These include environmental chambers, rain towers, and facilities for electromagnetic compliance, vibration and free fall, and system testing.

IQM opened Europe's first manufacturing facility dedicated to the fabrication of superconducting quantum processors in 2021. With an initial investment of €20M, the facility located in Espoo includes state-of-the-art equipment to manufacture multi-layer quantum chips as well as infrastructure for cryogenic characterization. The opening of the facility has strengthened IQM's position as a full-stack quantum computing company, attracting a highly educated workforce and further investments.

Applied Materials acquired Picosun in 2022, an innovator in atomic layer deposition (ALD) technology. Applied Materials targeted Picosun because of its leadership position, its deep R&D capabilities, its expertise and its strong relationships with leading research institutions and universities. Applied Materials has invested hundreds of millions of euros into Finland so far and continues investing a significant share of its €3,1B annual R&D spend here. Applied Materials has a 25% share of the €110B equipment market – highlighting significance and the potential to Finland.

Okmetic invested nearly €400M in 2022 into a new production facility in Finland, doubling the company's production capacity and creating more than 500 new jobs. The recent 2022 investment is a subsequent investment in a growing and developing industry. During the previous 5 years, Okmetic had invested over €100M in increasing the production capacity of its Vantaa fab.

Bosch Sensortec, a part of the Germany-based Bosch organization, is a leading provider of microelectromechanical (MEMS) sensors for consumer electronics. The company maintains a design center in Finland with office locations in Espoo and Oulu. The initial focus for Finland operations was to strengthen the company's capabilities in designing digital programmable sensors. A key factor for the entry was IC (ASIC/SoC) design and embedded software development capabilities, along with the built-up know-how of techniques required for low power, battery powered products. New positions around sensing and MEMS, such as for MEMS sensor and audio experts, have recently been opened due to existing expertise in Finland. All MEMS elements are manufactured in Germany, using proprietary processes developed in-house.

Nokia is a global leader in telecommunication and information technologies, with head office and major R&D sites in Finland. Nokia operates globally in 130 countries, has annual revenues of €22,3B (2023) and is committed to innovation and technology leadership across mobile, fixed and cloud networks. Nokia creates value with intellectual property and long-term research, led by the Nokia Bell Labs, with over 3,500 patent families essential to 5G networks. Nokia is one of the European manufactures that dominate in global mobile communications networks. Nokia's Radio Access Business relies on availability of high-performance leading-edge microelectronics as a key source of innovation. Nokia has built up chip design expertise to develop system-on-chip (SoC) solutions for leading-edge mobile technologies (5G) and has technology development ongoing for 6G networks. Nokia is using most advanced silicon node technologies in their SoCs and is committed to lead in custom silicon with Finland-based SoC expertise to ensure innovativeness in 5G-Advanced, 6G networks and edge AI solutions. As of early 2024, SoC innovation was a significant share of Nokia's R&D in Finland. Nokia has three major Technology Centers in Finland for 5G/6G and edge SoC design work. Tampere TC focuses on tooling and processes, machine learning inference, IP, and SoC research. Oulu TC is home to Nokia's radio products, and Espoo TC focuses on baseband solutions, virtualization, cloud and Bell Labs research. All three TCs have local ecosystems and value chain partners including universities and companies working with connectivity related semiconductor research and development. These include projects funded in part by Business Finland Veturi programs. Nokia is also well networked with EU semiconductor experts such as IPCEI's microelectronics and communications technology programs. It is also partnering with leading Asian and US based semiconductor giants.

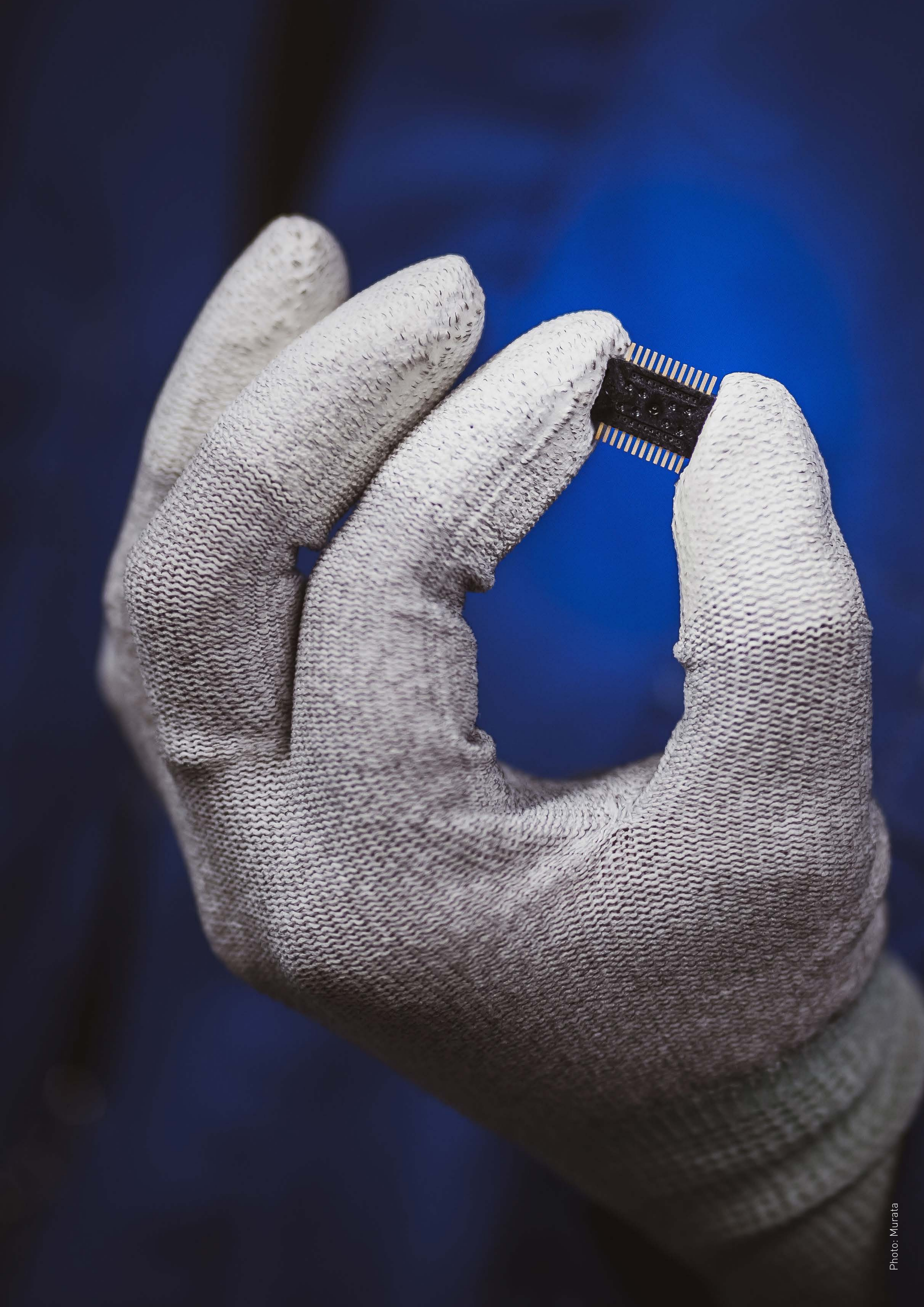


Photo: Murata

7.3 Benchmarking of initiatives and investments

As part of the research for this report, Finland's semiconductor industry was benchmarked against 15 peer economies. Through benchmarking, a more robust understanding of Finland's position was built within the broader European and global contexts.

The 15 peer economies selected were Austria, Belgium, Denmark, France, Germany, the Netherlands, Norway, Poland, Spain, Sweden, Switzerland, the UK, South Korea, Japan, and the US. Other economies were also investigated but were excluded from the benchmarking. The selection was based on geographical proximity, economic similarities, and strong positions in the semiconductor market. The benchmarking analysis covered more than 50 documents and reports on government actions, funding, talent-related efforts, and existing ecosystems, all linked to semiconductor industry and related sectors. Supporting information was sourced from public databases and indexes such as ESCAPE and EU Cordis.

The benchmarking results illustrate the varying approaches and priorities that nations take towards the semiconductor industry, balancing security concerns against economic ambitions. Finland, with its unique strengths and initiatives, is positioned to contribute significantly to this evolving global landscape.

7.3.1 National semiconductor strategies and priorities

National strategies and priorities were found to focus on national security, supply chain stabilization, strategic manufacturing, and economic growth. (Table 1)

All countries recognize the semiconductor industry's role in driving economic growth, particularly in areas like artificial intelligence, green transition, and electrification. National strategic objectives typically include efforts to secure semiconductor investments and improve R&D infrastructure access to improve general economic vitality of the sector.

Larger economies emphasize semiconductor industry's importance for national security and supply chain resilience. The US highlights the security risks of depending on foreign semiconductor production50. The UK prioritizes risks from hostile states and cybersecurity. Both countries emphasize the need for resilient semiconductor supply chains to mitigate fragility and disruptions, impact business growth and manage costs. They champion domestic manufacturing, particularly of advanced chips, while acknowledging that not all components can be produced domestically.

Table 1| Comparison of national semiconductor strategy objectives

Non-exhaustive

Themes \ Country	UK	Germany	Sweden	Korea	Japan	US	US
	National Semiconductor Strategy	Semiconductor Strategy for Germany and Europe[1]	Sweden in the semiconductor world[1]	K-Semiconductor Strategy	Strategy for Semiconductors and the Digital Industry	Strategy for the Chips for the America Fund	The National Semiconductor Economic Roadmap
National security	Security against acquisitions and cyberattacks	Maintain global value chains, identify and secure control points		Protect the domestic industrial ecosystem with crisis response	Become strategically independent through economic security	Secure and sustain supply of leading edge and mature chips for national security and critical industries	
Supply chain stabilization	Mitigate risk of supply chain disruptions			Reduce reliance on Chinese supply chains	Ease choke points through joint ventures with foreign players		Gain access to global supply chain
Strategic manufacturing		Gain competitiveness through innovation and attractive economic conditions		Emerge as the center of semiconductor manufacturing beyond memory	Strengthen domestic capacity in mature nodes	Manufacture strategically important chips domestically	Reduce manufacturing emissions Modernize utility infrastructure
Economic growth Innovation, workforce and partnerships	Grow domestic sector, through R&D and supporting infrastructure	Increase attractiveness of school, vocational and academic training Proposed ecosystem via European Semiconductor Alliance Enhance and expand funding mechanisms at national and EU levels	Strengthen innovation ecosystem for semiconductors Attain investments for R&D infrastructure Secure and maintain representation in the bodies for future EU investments	Secure talent Global 10% market share Multiple technology-specific objectives	Develop and design next-generation technologies in communications and green innovation Partnership with the United States	Strengthen R&D leadership to capture the next set of technologies, applications, and industries Enable diverse semiconductor workforce and build strong communities	Increase financial attractiveness of US Train workforce to meet demand for talent Enhance R&D environment

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Note: Germany and Sweden's strategies were published by regional industry alliances
Source: Industry reports [8,49,50,51,52,53,54], BCG.

7.3.2 Government actions related to semiconductor technologies

Government initiatives were identified as crucial to shaping national semiconductor industries' success. Each country takes a unique approach based on its history, capabilities, national assets, and priorities. (Table 2)

Some governments, including those of larger European countries such as Spain and Germany, use state aid/subsidies to fund major semiconductor projects and to attract global companies. The success of these efforts suggests that there is value in governmental support and strategic involvement in semiconductor industry development. Finland, focusing on niche RDI and specialized manufacturing, has often relied solely on private funding and foreign investments and acquisitions.

Countries have broadly implemented talent programs to address the industry's talent gap, combining tax incentives for companies that attract or retain talent with broader STEM education efforts. Finland's approach includes a comprehensive national STEM strategy and initiatives for international talent attraction[86 87].

Peer economies leverage cohesive networks in the semiconductor sector. Finland has a more fragmented ecosystem. There is potential in Finland to enhance sector integration and collaboration.

Table 2 | Comparison of semiconductor industry actions and initiatives

Non-exhaustive

Themes and subgroups		Finland	Sweden	Denmark	Norway	Germany	France	UK	Austria	Spain	Poland	EU
Government actions	Semicon. strategy[1]						✓	✓		✓		✓
	Quantum strategy			✓		✓	✓	✓	✓	✓		✓
	RDI funding	✓	✓	✓		✓	✓	✓	✓	✓		✓
	Significant subsidies					✓	✓			✓	✓	✓
Investment	Manufacturing					✓	✓		✓	✓	✓	
	Design sites					✓				✓		
	R&D infrastructure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Talent and education	Re- and up-skilling	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Doctoral education	✓	✓	✓			✓	✓	✓	✓	✓	✓
	Education programs	✓	✓	✓		✓	✓	✓		✓	✓	✓
	International talent	✓		✓		✓		✓		✓		✓
Ecosystem and alliances	Targeted clusters[2]	✓	✓			✓	✓	✓	✓	✓	✓	✓
	Clean-room network	✓	✓		✓	✓	✓			✓		✓
	OEM cooperation		✓			✓	✓	✓				✓

Note: Semiconductor strategy refers to a strategy launched by the government. A semiconductor cluster is defined as an organized network of companies, RTOs, and academia within a geographical region specializing in semiconductors. Source: Industry report, press releases, and organization websites [7,55,56,57,58,59,60,8,61,62,9,10,11,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90] BCG.

7.3.3 National semiconductor technology priorities

Benchmarked countries focus on selected semiconductor technologies, with an aim to reinforce strengths within existing ecosystems. (Table 3)

Finland boasts a strong ecosystem in SoC design, particularly for 5G/RF chips, supported by Nokia's significant presence. Spain, with its PERTE Chip strategy, and the UK with its National Semiconductor Strategy, are heavily investing in chip design, especially in RISC-V architecture[7,8]. They provide support for essential design tools and IP.

Finland is home to major players in MEMS and sensors. Other European countries are emphasizing efforts in advanced packaging, which is crucial for the development of advanced MEMS and sensors. Germany, France, and Finland have significant MEMS and sensors hubs focusing on the automotive, healthcare, and environmental sensors.

Multiple European countries, including Spain and the Netherlands, have announced substantial investments in photonic integrated circuit (PIC) development – domain where Finland does not have a recognizable representation.

Finland's strong quantum technology ecosystem centers around notable universities, VTT and companies like IQM. Unlike peers, Finland lacks a comprehensive national strategy for quantum technologies. Several European countries have launched multi-year national programs to enhance research, development, and innovation in quantum technologies.

Several European countries can be observed to concentrate on compound semiconductor materials like GaN and SiC. Finland's strengths lie in niche materials and specialized silicon wafer manufacturing.

The Netherlands and the UK have strongholds in enabling equipment and advanced packaging initiatives, where Finland's expertise lies in Atomic Layer Deposition (ALD) technology.

Table 3 | Comparison of national semiconductor technology focus (illustrative)

Legend: Clusters, Domain focus[1], Investments[2]

Non-exhaustive

Domains	Finland	Sweden	Germany	France	NL	Belgium	UK	Austria	Spain
Chip design	Nokia cluster	Ericsson cluster	Auto, IoT clusters		Research clusters	Flanders cluster	ARM ecosystem		Barcelona cluster
MEMS and sensors	Murata and Vaisala	Manufacturing	Bosch cluster	Grenoble cluster	NXP ecosystem	Melexis cluster	Automotive hub	ams-OSRAM hub	
Photonics and optoelectronics	PREIN clusters R&D flagship	Stockholm cluster	Bavaria cluster PIC pilot line	Grenoble cluster PIC pilot line	Eindhoven cluster €1B fund	IMEC cluster PIC pilot line	Scotland cluster PIC pilot line	ams OSRAM hub	Barcelona cluster €150M ('22-'27)
Quantum technologies	Quantum cluster €200M ('20-'23)	Chalmers cluster €130M ('18-'29)	Munich cluster €3B ('22-'26)	Paris & Grenoble €2B ('21-'26)	Quantum Delta €615M ('21-'27)		Oxford cluster €2,9B ('23-'33)	Research cluster €100M ('21-'26)	Barcelona cluster €62M ('22-'27)
Materials and chemicals	Helsinki cluster	Linköping cluster	Silicon Saxony	Grenoble cluster	Eindhoven cluster	GaN Valley hub	CSConnected hub		
Processes and equipment	ALD R&D cluster		South Germany		Eindhoven cluster		Packaging focus	Equipment focus	

Note: Focus area is stated in a national strategy or industry alliance report. Investments refer to public/private investments between 2021 and January 2024. SiP = silicon photonics, and PIC = photonics integrated circuit. Source: Industry report, press releases, and organization websites [91,92,93,94,49,66,95,53,96,64,7,8,97,65,98,99,100,55,56,57,58,59,60,77,101,102], BCG.

7.3.4 Government support for design and manufacturing sites

Governments play a key role in advancing their national semiconductor industries, with larger economies like Spain and Germany offering significant state aid to develop large semiconductor design and manufacturing facilities. These efforts indicate a global trend for targeted public-sector investment in technology areas and R&D investment. (Table 4)

Some governments pay significant attention to manufacturing sites. Countries with substantial state aid, such as Spain's PERTE Chip strategy and Germany's subsidies for Intel's Magdeburg site, demonstrate an observable correlation between government support and the establishment of major facilities[8] [9]. Intel's €4,3B testing facility in Poland also received regional government support[11] and societal factors played a role in attracting the investment. Finland, while unable to match the multibillion-euro subsidies, provides other advantages and attractors for site investments, such as a cool climate, affordable and stable utilities, stable geology, and a skilled, relatively cost-effective workforce.

Governments with public semiconductor strategies, like the UK, Denmark, and France, have clear focuses backed by multi-year investment programs. The UK's strategy includes a €1,2B investment in R&D and compound semiconductors[7]. Denmark focuses on quantum technology RDI and commercialization, while France's Electronique 2030 program aims to boost manufacturing in electronics and sensors[52] [53]. Finnish initiatives like InstituteQ and the Chips from Finland are advocating for coordinated, long-term RDI funding efforts and focus on growing domains like SoC design and integrated photonics.

Table 4 | Comparison of government actions for semiconductor industry

Non-exhaustive

Subgroups	Selected initiatives					
Semiconductor strategy	**Chips Act** Launched in 2022, aims to reinforce EU technological leadership with cumulative budget of €43B	**PERTE Chip** National program to increase production capacity across the value chain by end of the decade	**Electronique '30** Investment plan for electronics industry, part of the France 2030 strategy	**National Strategy** Official national strategy launched in '23 with a budget of €1,2B; focus on R&D, design & IP, and compound semiconductors		
Quantum strategy	**Quantum Strategy** Official national quantum action plan, with €3B of funding, with Aim for 100 qubit quantum computer by '26	**Quantum Spain** National €22M program to create quantum ecosystem by financing and promoting quantum computing infrastructure	**Quantum Strategy** Official national strategy, with €130M allocated until 2030 to bridge gap between research and implementation	**Quantum Strategy** National strategy with €2,9B committed for quantum R&D until '34; focus on research hubs, accelerators etc.	**Quantum Fund** Part of the National Quantum Strategy, dedicated fund to ensure longer term financing for key initiatives	**Quantum Delta** €615M national program on quantum technologies launched in '21 with aim to strengthen key hubs Delft, AMS, Leiden etc.
RDI funding and incentives	**PERTE Chip** Program has allocated €600M to RDI efforts in chip design and integrated photonics	**Horizon & Digital** Main RDI funding arms of the EU, which has allocated €1,65B each for a total budget of €3,30B for Chips Act	**Center for Semicon** Led by Vinnova, Sweden has applied for funding via CJU to build pilot lines to enhance commercialization efforts	**Chips for Europe** First pillar of the Chips Act with a budget of €3,3B, with aims to deploying design, pilot lines and competence centers	**Quantum Strategy** National strategy with €1,8B investment plan focused on RDI efforts, and talent development of young researchers	**Quantum Austria** Funding initiative focused on quantum technology R&D infrastructure with €100M allocated
Significant public subsidies	**IPCEI ME/CT** Important Project of Common European Interest (IPCEI ME/CT) is EU approved state aid of approximately €8B	**PERTE Chip** Includes ~9B of funds to be allocated as subsidies for manufacturing sites among other related efforts	**Electronique '30** The investment plan includes €5B allocated funding for manufacturing, RDI, education efforts	**CJU** Chips Joint Undertaking (CJU) aims to facilitate commercialization by providing €1,67B in funding for pilot lines	**Silicon Photonics** Consortium of government and industry to invest €1B in photonics to expand manufacturing capacity	

Note: QT/QS/QC = Quantum technologies/sensing/computing; CUT = Chalmers University of Technology; CU = Copenhagen University
Source: Industry report, press releases, and organization websites [7,8,9,55,56,57,58,59,60,100,99,103] BCG.

7.3.5 Investment in the semiconductor industry

Investments in semiconductor industry can be observed to be influenced by public subsidies and attractiveness to private investments. Larger countries in Europe generally attract large semiconductor investments through state aid and government involvement in concerted public-private efforts to attract investments, while smaller countries gain resources through acquisitions and investment by foreign companies. (Table 5)

Large semiconductor facilities in Europe are often established by non-European companies in larger countries, leveraging substantial public subsidies. Examples include TSMC's >€10B facility in Germany with significant subsidies, STMicroelectronics, GlobalFoundries' €7.5B facility in France, and Intel's joint chip design center in Spain[10 62 96]. Smaller European countries focus on enhancing RDI infrastructure and ecosystems, often becoming targets for acquisitions by larger firms seeking R&D hubs.

Largest share of investments has taken place in or around Germany. Smaller countries, including the Nordic countries, have carved out niches in RDI and specialized manufacturing, often supported by foreign investments and acquisitions. Initiatives like the Finnish Quantum Computing Institute and Sweden's Semiconductor Competence Center represent regional efforts to bolster the industry.

Finland has participated in the EU's IPCEI ME/CT program and had access to pandemic relief funds. Nonetheless, most recent large-scale investments in Finland, like Okmetic's €400M facility, have been privately funded[93]. A significant portion of Finnish semiconductor companies with annual revenues above €10M are foreign-owned, reflecting the trend of deep-tech ventures in Nordic regions attracting substantial foreign investments.

Table 5 | Comparison of investments into semiconductor industry

Non-exhaustive

Subgroups	Selected initiatives				
Manufacturing	**TSMC** New €10B fab in Dresden as joint venture with Bosch, Infineon and NXP, 10% each, and 70% ownership of TSMC	**Wolfspeed** New €2,8B 200mm silicon carbide factory and a joint R&D facility - partnering with auto supplier ZF in Ensdorf	**GlobalFoundries** Expansion of wafer fab from 400k to 1M annual output, located in Dresden, Saxony	**Intel** New €4B assembly and testing facility in Wroclaw	**Infineon** New €1,6B 300mm power chips fab in Villach
Manufacturing	**Intel** Two chip-making fabs, with Intel investing over €30B, in Magdeburg, Saxony	**Bosch** New €1B 300mm wafer fab for auto chips and sensors located in Dresden, Saxony	**Infineon** New €6B 300mm Smart Power fabrication site in Dresden, Saxony	**asm Osram** €300M expansion of existing facilities in optoelectronics fab located in Regensburg	**Broadcom** New €1B large-scale back-end facilities
Design sites	**Apple** New €1B Apple European Silicon Design Center focused on 5G, and wireless technologies located in Munich	**Intel** New €400M chip design lab in collaboration with Barcelona Supercomputing Center. Focus on design chips for supercomputers on RISC-V	**Cisco** New €400M design center in Barcelona, focusing on new generation of chips such as Cisco Silicon One		
Research and development infrastructure	**Center of QT** New €130M research program led by CUT, with majority of funding from Wallenberg foundation	**Quantum Lab** Officially known as Deep Tech Lab – Quantum, the center consists of an accelerator and four test facilities at CU	**QC at CU** €200M project to build fully functional quantum computer by '34, with majority funding from Novo Nordisk foundation	**QC Center** National QC Center focused on bridging gap between research and innovation in QC	**IMEC** Belgium and the EU invest €1,5B into IMEC to expand clean-room test facility

Note: QT/QS/QC = Quantum technologies/computing; CUT = Chalmers University of Technology; CU = Copenhagen University;
Source: Industry report, press releases, and organization websites [10,11,12,59,65,66,68,95,96,104,105,106,107,108,109,110,111], BCG.

7.3.6 Semiconductor ecosystems and innovation hubs

Peer countries use industrial networks to enhance semiconductor industries, taking a more comprehensive approach than Finland. Several examples highlight the importance of cohesive, well-integrated networks and collaborations within the semiconductor industry for fostering innovation, research support, and industry growth. (Table 6)

Some countries have established industry-oriented networks in the form of international or national clusters, targeting specific sectors like defense. Examples include Semiconductors by Sweden Alliance, Denmark's CenSec, and Germany's regional clusters like Silicon Saxony. Finland has networks like Photonics Finland and Microelectronics Finland, but their efforts are more focused and less integrated. The Semiconductor Branch Group of Technology Industries of Finland, founded in 2022, brings together leading companies from the fields of microelectronics, photonics, and quantum technology and provides a platform for industry-driven cooperation. Business Finland also plays an important supportive role in the ecosystem through its services.

Collaboration in other countries leads to benefits like close R&D support between automotive, industrial, and other OEMs and domestic semiconductor sectors, as seen in Sweden and Germany. In Finland, semiconductor companies have established less R&D cooperation with domestic OEMs. Based on observations, there could be potential in improved collaboration. Finland could strengthen ties with wider European and Nordic networks and engage in European collaborations like the EU-funded PIC production line in Eindhoven. This approach could enhance access to facilities, reduce costs, and speed up pilot production, benefiting the entire ecosystem.

Table 6 | Comparison of semiconductor ecosystems and talent initiatives

Non-exhaustive

Subgroups	Selected initiatives					
Ecosystems and alliances	**Silicon Europe** (EU) An alliance of 13 regional clusters within Europe, totaling +200 companies	**Semicon from SE** (SE) Brings together +20 companies to identify synergies and opportunities in semiconductors globally	**DigitalLead** (DK) National cluster for digital technologies consisting of over 500 organizations both from supply and end-users	**Silicon Saxony** (DE) Large cluster of ~500 companies and RTOs located in Dresden, Saxony	**Optechnet** (DE) Umbrella organization for nine regional innovation networks in the field of optical technologies	**Silicon Alps** (AT) Founded in '16, regional microelectronics cluster of +120 companies and RTOs
	SECPHO (ES) Founded in '09, deep tech cluster around photonics, microelectronics and quantum computing with +180 members	**Techtank** (SE) Industrial cluster in southern Sweden, focused on skills, tech and business development support for +100 members	**CenSec** (DK) Founded in '10, the Center for Defense, Space & Security cluster consists of over 200 organizations	**Cluster Nanotech** (DE) Focused on supporting commercializing and co-op efforts in Bavaria, via €8M funding for +170 members	**EPoSS** (EU) Founded in '13, and is focused on smart systems integration	**High Tech NL** (NL) Industry association for high-tech Dutch companies, with a large base of semiconductor companies
Talent and education	**Pact for Skills** (EU) Launched in '20, aims to support public-private organizations to up/reskill for green and digital transitions	**Chips Skills Acad.** (EU) Follow-up to METIS, industry-academia network offering scholarships, access to labs etc.	**QT Program** (UK) Part of the national program, funds doctoral centers and other education efforts to increase talent pool	**Micro-credentials** (NL) Headed by KU Leuven, provides micro-credentials in IC design with aim to close talent gap in Flemish region	**Semicon strategy** (UK) Provides €880M of funding training teachers in primary, and secondary education in topics such as STEM	
	METIS (EU) Predecessor to Chips Skills Academy, and focused on increasing amount and level of talent	**Semicon Education** (UK) Alliance led by ARM, aims to create tailored frameworks, training pathways for regions to support talent pool	**Quantum Strategy** (DK) Funds new courses and international summer schools for foreign talents around universities and industry	**DIGITALIZA** (ES) Running since '19, co-op program with CISCO in reskill over 100k in digital technologies, and recently extended to '25	**Electronique '30** (FR) Allocated €50M for training and skills development projects, to increase visibility and attractiveness	

Note: QT/QC = Quantum technologies/computing; RTO = Research and technology organization; METIS = Microelectronic Training, Industry, and Skills; STEM = Science, technology, engineering, and math. Source: Industry reports, press releases, and organization website [8,56,67,69,70,71,72,75,76,77,79,112,113,114,115,116,117,118,120,121], BCG.

Finland's peers are implementing a range of activities to alleviate the industry talent gap, combining focused upskilling initiatives with broader STEM education efforts. These efforts reflect a global trend where countries are actively enhancing educational systems and seeking to cultivate and attract skilled expertise for the growing demands of the semiconductor industry.

Some countries are enhancing pre-university and postgraduate education nationally. The UK government has allocated €880M, while Finland's Ministry of Education and Culture launched a national STEM strategy with 31 measures[7 87]. Others are collaborating on semiconductor-specific talent development at the EU level. The European Chips Skills Academy, with partners like Okmetic, offers scholarships and training programs. Countries are also focusing on increasing long-term doctoral program funding.

Tax and immigration incentives are used in some countries. For attracting talent, Spain offers a Special Tax for Expatriates with lower rates for qualified individuals. Germany allows graduates to stay for 18 months post-graduation[72 73]. The UK provides special visas for talented foreign engineers, including High Potential Individual and Scale-up Visas[7].

Unlike other countries, Finland adopts a holistic approach to international talent attraction through initiatives like Business Finland's Talent Boost. Business Finland's Talent Boost promotes talent attraction but also supports talent retention and assists companies with immigration procedures[86].

Photo: Okmetic

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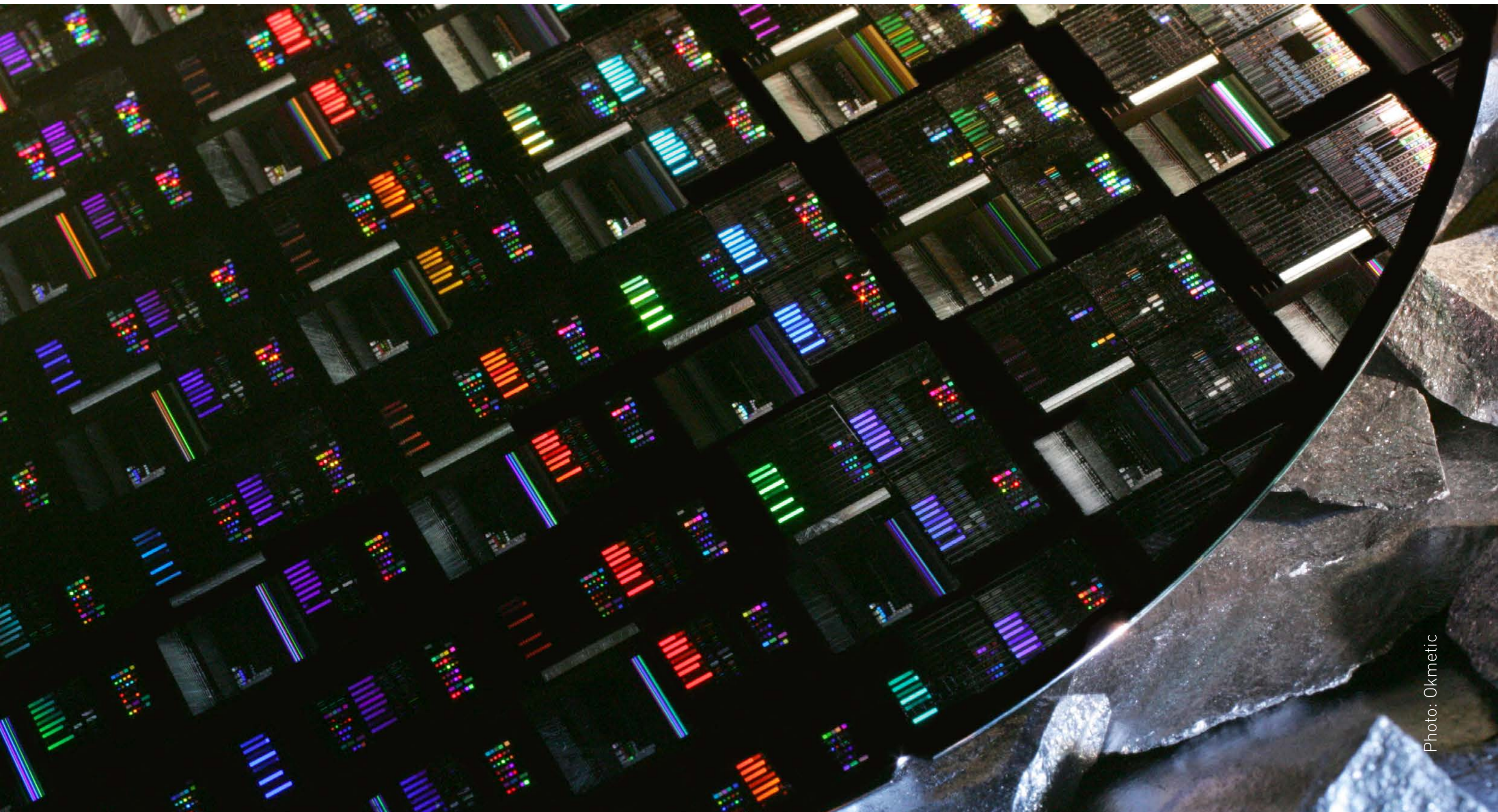

Photo: Okmetic

8 Abbreviations

Atomic Layer Deposition (ALD): A thin-film deposition technique based on the sequential use of a gas-phase chemical process, used in semiconductor manufacturing.

Compound Annual Growth Rate (CAGR): A measure of an investment's annual growth rate over time, with the effect of compounding considered.

Graphics Processing Unit (GPU): A specialized processor designed to accelerate graphics rendering.

Integrated Device Manufacturer (IDM): A company that designs and manufactures its own semiconductors.

Internet of Things (IoT): The network of physical objects embedded with sensors, software, and other technologies to connect and exchange data with other devices over the Internet.

Microelectromechanical Systems (MEMS): Technology that integrates mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology.

Micro-Opto-Electro-Mechanical Systems (MOEMS): Microsystems that combine mechanical, optical, and electrical components. They are used in a range of applications, including display technologies, optical switching, and bio-sensing.

Original Equipment Manufacturer (OEM): A company that produces parts or equipment that may be marketed by another manufacturer.

Photonic Integrated Circuit (PIC): A device that integrates multiple photonic functions, like an electronic integrated circuit, but using photons instead of electrons. PICs are used in applications such as optical data transmission, sensors, and quantum computing.

Radio Frequency (RF): A rate of oscillation within the range of about 3 kHz to 300 GHz, used in various types of communications signals.

System-in-Package (SiP): Integrating multiple integrated circuits into a single package, instead of on a single semiconductor die.

System-on-Chip (SoC): An integrated circuit that integrates all components of a computer or other electronic systems into a single chip.

Technical Research Centre of Finland (VTT): A Finnish state-owned research center that provides research and innovation services.

Extended Reality (XR): An umbrella term encompassing augmented reality (AR), virtual reality (VR), mixed reality (MR), and other immersive technologies.

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Technology Industries of Finland | Eteläranta 10, P.O. Box. 10, 00130 Helsinki | Tel. +358 9 19 231 | techind.fi