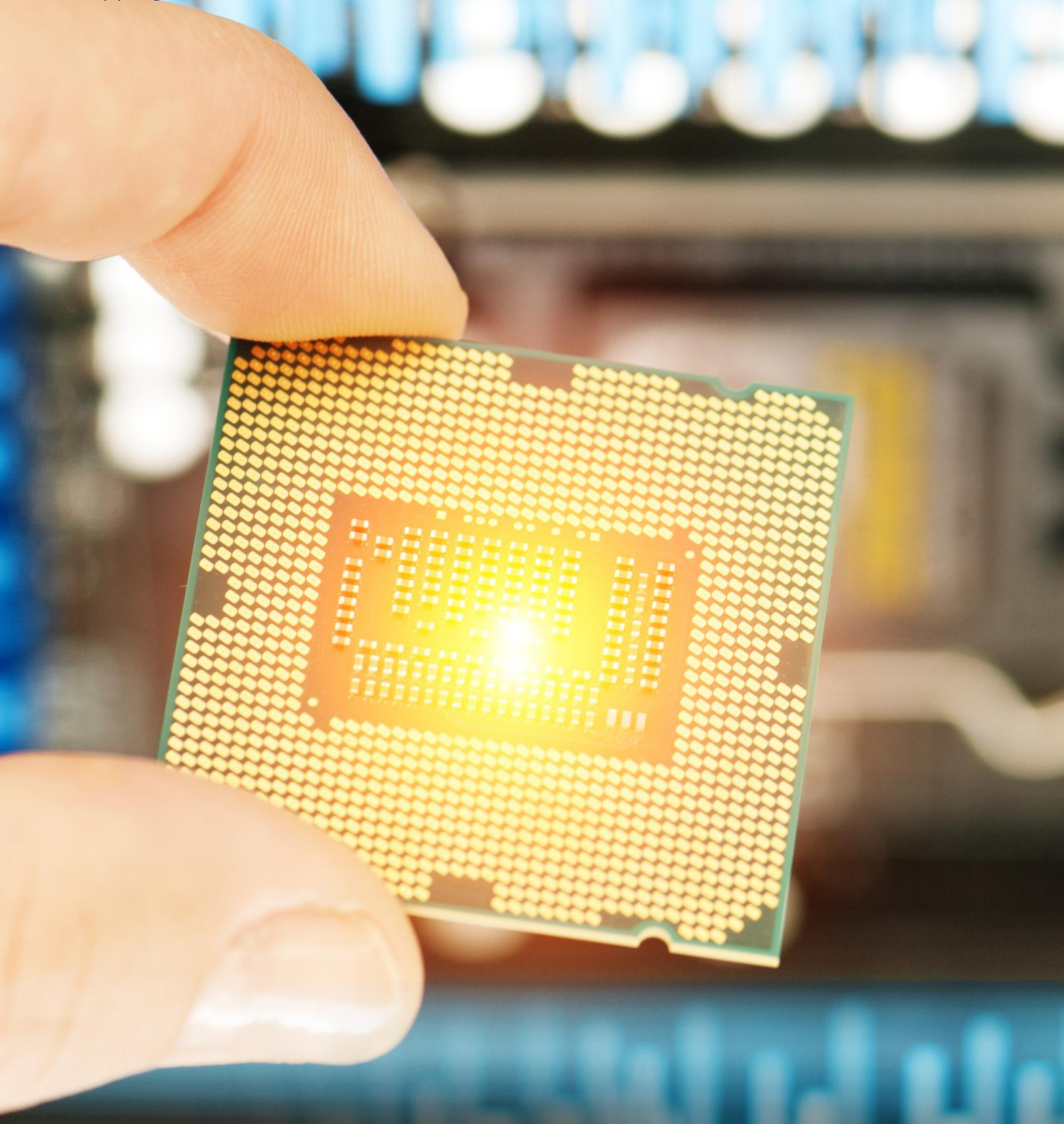
MENON ECONOMICS

REPORT

THE SEMICONDUCTOR INDUSTRY IN NORWAY

A mapping of the value chain



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Preface

Menon has been commissioned by Innovation Norway to map the Norwegian value chain for semiconductors.

As part of the analysis, we have both used various quantitative data sources, and had fruitful interviews with both industry actors and professors at universities. We thank all respondents for their valuable input.

Jonas Erraia has been the partner responsible for the project, with Øyvind Vennerød as project manager and Erlend Lund as team member. Leo Grünfeld has acted as the internal quality assurance manager.

Menon Economics is a research-based analysis and advisory firm at the intersection of economics and business and industry policy. We offer analysis and advisory services to businesses, organisations, municipalities, county authorities and ministries. Our main focus is on empirical analysis of economic policy, and our staff have economic expertise at a high scientific level.

We thank Innovation Norway for an exciting project.

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August 2023

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Executive summary

As the backbone of modern electronic devices, the semiconductor industry drives innovation and connectivity across economies worldwide. In response to the recent chip crisis, both the EU and US have taken steps to enhance their semiconductor value chains. However, there has so far been few attempts to understand and map out the Norwegian value chain. This report aims to fill that gap by analysing the semiconductor industry in Norway.

The global semiconductor value chain is complex, efficient, and specialised

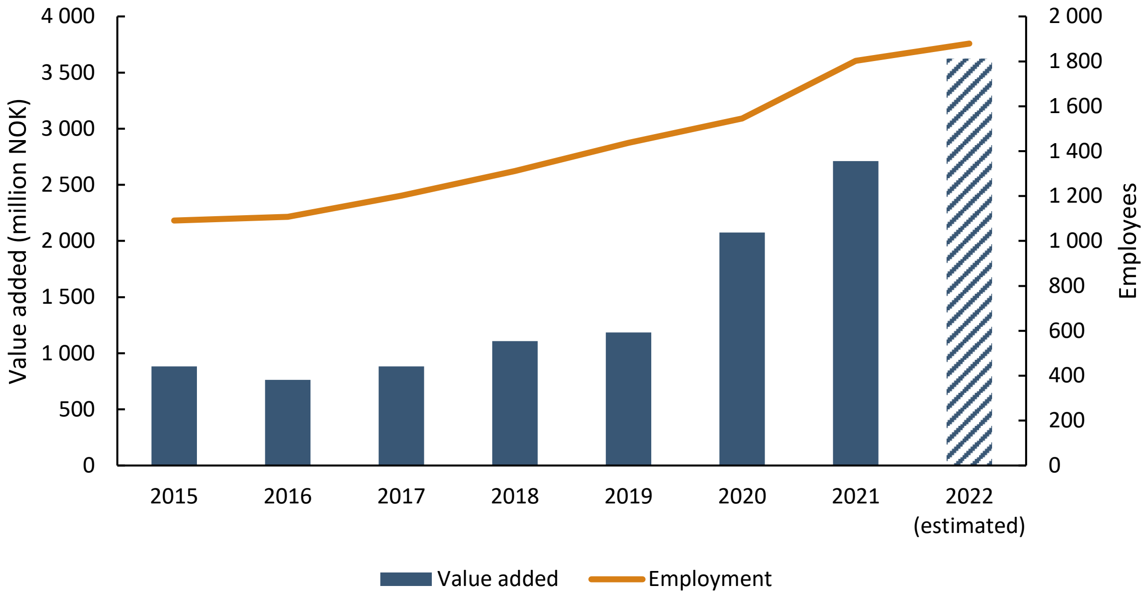
The global semiconductor value chain is designed to be highly efficient and is therefore very specialised. A key aspect of the value chain is that many semiconductor companies operate with a so-called "fabless" (fabrication-less, i.e., without a factory) model, where they focus on design and outsource the manufacturing to specialised manufacturers. Part of the reason for this split is that the manufacturing of semiconductors is technologically advanced and requires expensive machinery. Consequently. the manufacturing phase has grown highly concentrated and is dominated by a few companies globally. Today, more than 50 percent of all advanced chips are made in only two countries: South Korea and Taiwan.

The separation of manufacturing and chip design means that there are two relatively separate value chains. One centred around the chip designers, with inputs of research and software, and one centred around the manufacturing factories, with inputs of raw materials and machinery. Contrary to many other industries, the factories which manufacture the chips are usually also suppliers to the chip designers. As a general rule, the chip designer is the owner of the produced chips.

The Norwegian semiconductor value chain is growing rapidly

We have identified around 50 Norwegian companies which work primarily with chip design, chip manufacturing, or chip assembly and packaging. These companies employ around 2,000 people, have a value added of approximately 3.6 billion NOK, and revenues of just over 10 billion NOK. The industry is export-intensive, and the majority of customers are outside of Norway. The companies have grown rapidly, as shown in Figure 1.

Figure 1: Value added and employees in the semiconductor value chain from 2015 to 2022. Source: Menon Economics



In the past 8 years, the value added of the semiconductor industry has quadrupled, while the number of employees has grown by 70 percent. The largest growth has come in the past few years, with the value added more than doubling from 2019 to 2021, and by our estimates, continuing to grow equally rapidly in 2022.

The core Norwegian expertise is chip design and low-power communications

The core expertise in Norway is the design of semiconductors, especially for low-power wireless communications. The largest Norwegian company, Nordic Semiconductor, is the global leader in low-power Bluetooth communications, and several of the other large companies in Norway also focus on the fabless design of low-power wireless communications. The semiconductors these firms design are known as integrated circuits, and this is the largest category of semiconductors made in Norway.

The companies making integrated circuits are highly productive. Whereas the average value added per employee for companies in mainland Norway is slightly above over 1 million NOK, it was almost 2.5 million NOK per employee among companies making integrated circuits in 2021. Few major industries in Norway have such high labour productivity.

Norway has significant expertise in sensor semiconductors

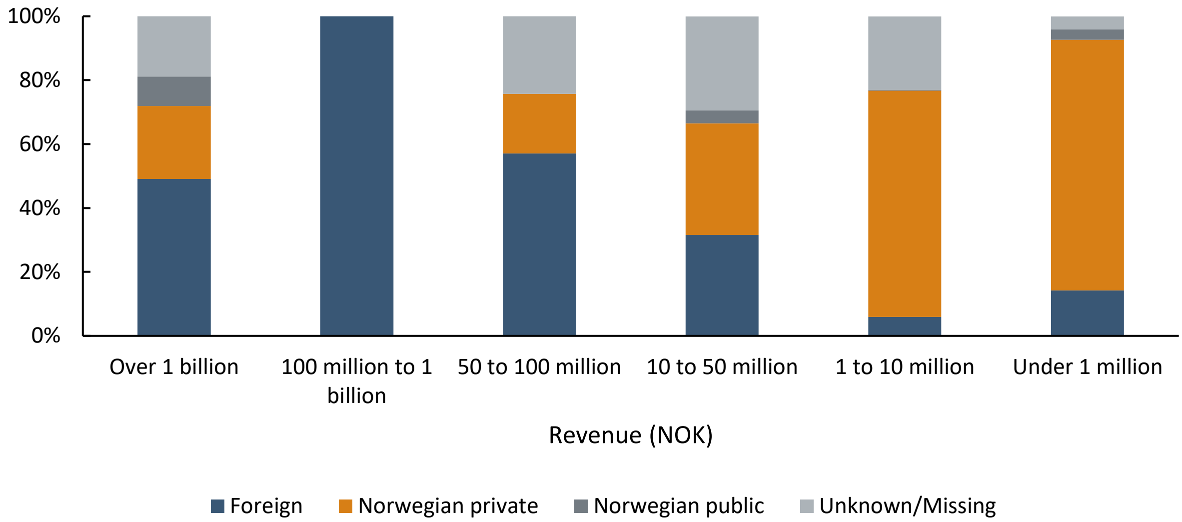
While the speciality in Norway is the design of semiconductors, some are also manufactured in Norway. These are primarily miniaturised sensors which can sense physical phenomena such as motion, pressure, temperature, and acceleration. Sensors made in Norway are used in a variety of applications, e.g., point-of-care medicine, subsea exploration, and sensors inside the Mars Rover. The majority of the chips made in Norway are manufactured at SINTEF MiNaLab, which is part of the Norwegian Infrastructure for Micro- and Nanofabrication, or at Safran Sensing Technologies. The rest of the Norwegian Infrastructure for Micro- and Nanofabrication is the Norwegian University of Science and Technology (NTNU), the University of Oslo (UiO), and the University of South-Eastern Norway (USN). Each of these have designated cleanrooms where academics, researchers and companies can come to test and study semiconductors.

Companies in the sensor industry tend to be young and growing. Being not yet fully commercialised, many of them are not profitable. In 2021, only around a third of the companies made an operating profit.

The large semiconductor firms in Norway are foreign-owned

The semiconductor industry is a global industry with many large actors, and substantial foreign ownership of large Norwegian companies. The figure below shows the ownership of Norwegian semiconductor firms.

Figure 2: Ownership of Norwegian semiconductor firms, by revenue intervals. Source: Menon Economics

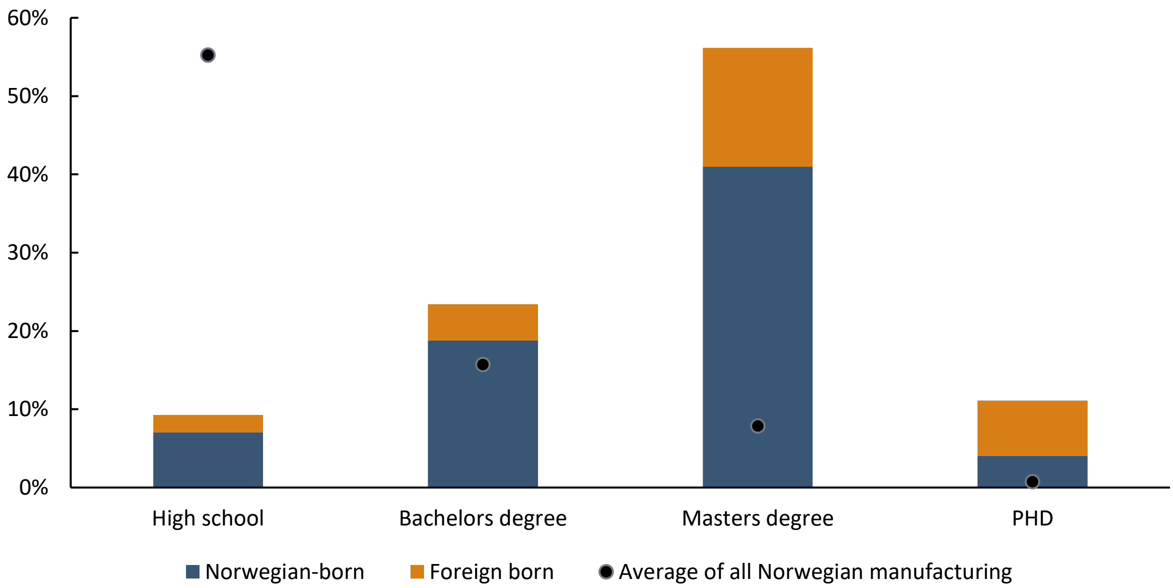


As can be seen from the figure, most of the smaller companies have Norwegian owners, while the larger ones tend to be foreign-owned. All of the firms with a revenue of over 100 million NOK are now foreign-owned, except for Nordic Semiconductor, which is listed at Oslo Stock Exchange.

The semiconductor workforce is highly educated

The semiconductor industry requires advanced skills and employs individuals highly educated employees. The figure below shows the level of education of employees in the semiconductor industry.

Figure 3: Level of education in the semiconductor industry. Source: Menon's estimates based on SSB's Microdata



We find that about 11 percent of the semiconductor workforce hold a PhD, and 56 percent a master's degree. This compares with less than 1 percent of the industrial workforce in Norway having a PhD, and around 8 percent having a master's degree. In addition, we find that around a quarter of the workforce is foreign born. For those with a PhD, almost two thirds were born outside of Norway.

An under-appreciated value chain with high potential

Though our analysis has mainly focused on mapping the existing microchip and semiconductor value chain in Norway, it has become clear that the sector has a significant growth potential in the next decade. With both the US and the EU wanting to develop home-grown manufacturing capabilities, there is reason to believe that the expertise and technology present in the Norwegian value chain set the stage for substantial growth potential.

Over the last decade or two, Norway's economy has struggled with three particular issues. Firstly, (mainland) export growth has been lacklustre, with the country being out-paced by almost all other European countries. Secondly, productivity growth has been sluggish, with much of the industrial workforce being bound up in relatively low-productivity jobs. Lastly, the Norwegian economy remains concentrated in industries that are based on natural resources. This concentration makes the country vulnerable to global price swings and leaves comparatively little room for technological development.

Further growth in the Norwegian semiconductor industry may contribute to ameliorating these ailments. With a vast growth potential, high productivity, and a clear possibility for diversifying the Norwegian economy, it seems surprising that not more focus has been put on the existing value chain, technological infrastructure and semiconductor expertise present in Norway.

Overall, we believe that the potential for the Norwegian semiconductor value chain has unfairly remained under the radar. Going forward, the reasons mentioned above suffice to include the semiconductor value chain as a priority industry. A possible first step would be to include the industry as a candidate for priority in the government's "*All of Norway Exports"*-programme. However, further analysis is needed. In particular, there is a need for a proper analysis of the market potential, the competitive advantages of the Norwegian industry, as well as a mapping of barriers to growth and necessary potential public policy instruments.

1. Introduction

In recent decades, electronics and technology have become an increasingly integral part of our daily lives. From mobile phones and computers to solar panels and cars, everything depends on the small yet powerful semiconductors. They are the heart of almost all modern technology and have revolutionised the way we communicate, work, and live. Today, a few major players dominate the global manufacturing of semiconductors, mainly located in the United States, South Korea, and Taiwan. However, behind the major manufacturers, you find a vast ecosystem and a broad value chain.

The strategic importance of semiconductors for key industrial value chains has been in the spotlight recently, especially with the chip shortage of the past few years. This caused delays in production and factory closures in a broad range of industries, such as automotive, energy, communications and health, as well as defence, security and space.[1]

Part of the reason why these shortages occur is the way the semiconductor value chain is organised. The value chain is global, with a few major players dominating certain parts of the value chain. Problems for these actors thus ripple through the value chain, causing shortages in a plethora of other industries. The EU and US have, following the chip shortage, added an emphasis on strengthening their positions in the value chain, passing legislation such as the CHIPS and FABS acts in the US and the European Chips Act in the EU.

These initiatives mean that the value chain is changing globally, with for instance new manufacturing plants coming to Europe, such as Intel's planned 17-30 billion euro factory[2] in Germany, its 5 billion euro assembling plant[3] in Poland, STMicroelectronics' 7.5 billion euro factory[4] in France, TSMC's proposed 10 billion euro factory[5] in Germany, and more.

There are several Norwegian companies in the industry, especially those working on designing the microchips. These companies interact primarily with international customers and suppliers and are part of the highly global value chain. Some of the major Norwegian companies are well known, but relatively little work has been done on mapping the Norwegian semiconductor industry. That is the main purpose of this report: to map out the semiconductor industry in Norway, with a focus both on the relevant companies and research institutions within the value chain.

The report is structured as follows: In chapter 2, we illustrate and explain the global value chain for semiconductors. In chapter 3, we examine the Norwegian value chain, and go through the important companies in the different sub-parts of the value chain. In chapter 4, we look at the universities and their interplay with each other and the industry, before we look at education and skills. Appendix A examines the broader applications of semiconductors, while appendix B contains a glossary of terms used in the report.

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[1] *EU Chips Act, see https://digital-strategy.ec.europa.eu/en/library/european-chips-act-staff-working-document*
[2] *https://www.intel.com/content/www/us/en/corporate-responsibility/intel-in-germany.html and https://www.ft.com/content/05045524-4ca2-4b82-9412-680c164d4531*
[3] *https://www.intel.com/content/www/us/en/newsroom/news/intel-plans-assembly-test-facility-poland.html*
[4] *https://www.reuters.com/markets/europe/france-provide-29-bln-euros-aid-new-stmicroglobalfoundries-factory-2023-06-05/*
[5] *https://www.bloomberg.com/news/articles/2023-05-03/tsmc-plans-for-first-german-chip-fab-with-cost-up-to-10-billion*

2. The global semiconductor value chain

The global semiconductor value chain is specialised and highly productive. It involves three main steps: chip design, chip manufacturing, and finally assembly and packaging.

The **chip design** phase of the value chain is dominated by the US, which has a market share of around 80 percent in pure chip design.[6] There is little design activity in the EU, and the largest fabless chip designer is in fact Norwegian. Only 0.17 percent of the fabless design revenue comes from EU27-owned companies.[7] Chip design is characterised by large investments in R&D and high profitability.[8]

The **manufacturing** phase of the value chain is dominated by a small number of factories worldwide. Samsung in Korea and TSMC in Taiwan each had just under 40 percent of the market share in manufacturing in 2020, together totalling over 75 percent of the market. For the most advanced chips, Samsung and TSMC have a market share of 100 percent.[9] Currently, there is sparse European presence in pure-play manufacturing, although this may change when the planned factories in Europe are built[10]. The manufacturing phase is the most capital-intensive phase, with manufacturing plants usually costing around 20 billion USD.[11]

The **assembly, testing, and packaging** phase of the semiconductor value chain involves putting together individual semiconductor components, testing their functionality, and carefully packaging them for use in electronic devices. This is the most labour-intensive phase and is usually done by firms located close to the manufacturers.[12]

A key aspect of the semiconductor value chain is that many semiconductor companies operate in a so-called fabless[13] model. In this model, specialised chip design companies focus solely on chip design, leaving the manufacturing process to specialised factories. The chip designers develop complex chips using advanced software, while the actual manufacturing of the chips takes place in large-scale factories.

The fabless designers are heavily reliant on global suppliers of software. Chip design is extremely complex, and modern semiconductor chips can have billions of components. A few companies globally produce highly specialised "Electronic Design Automation" tools, which are essential for chip designers. Similarly, some companies have patents and IP rights that are necessary to produce the chips.

The manufacturer has its own – mostly separate – value chain from the chip designer. Where the chip designer mainly uses software, the manufacturing is done in highly complex factories with extremely expensive and complex machinery. The manufacturers also have raw material suppliers, with silicon wafers as a specifically important input. After the manufacturer has produced the chip to the chip designer's specifications, it is assembled and packaged, and then sent to either the chip designer or its customers before it is integrated into

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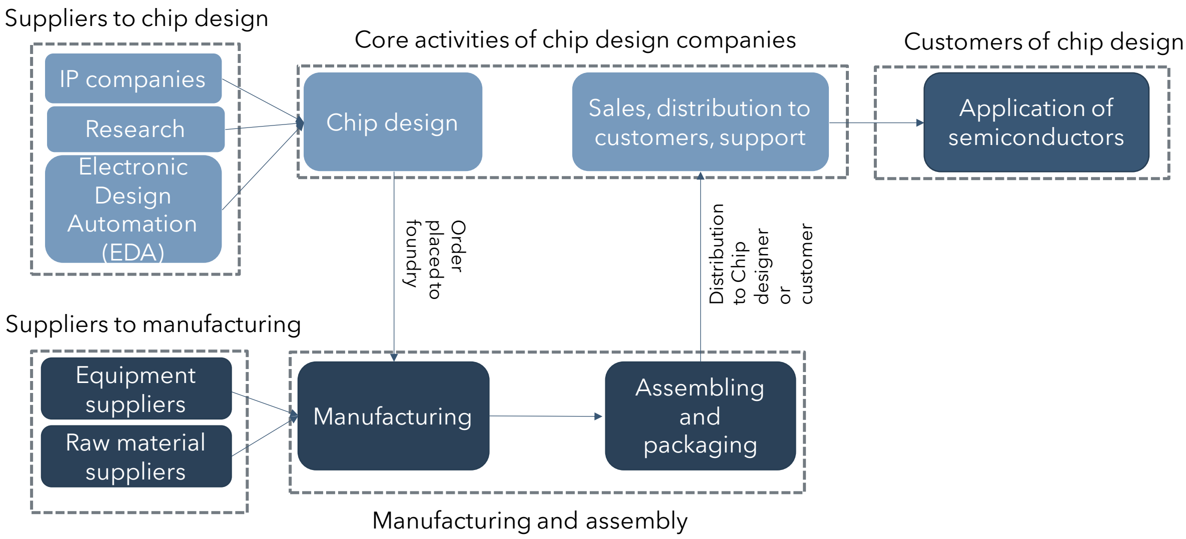
[6] https://www.accenture.com/content/dam/accenture/final/a-com-migration/r3-3/pdf/pdf-172/Accenture-Semiconductor-Value-Chain-Report.pdf#zoom=50
[7] https://joint-research-centre.ec.europa.eu/system/files/2022-04/JRC129035.pdf
[8] (Ciani & Nardo., 2022): https://joint-research-centre.ec.europa.eu/system/files/2022-04/JRC129035.pdf
[9] https://www.ft.com/content/d8bed732-e09c-4dca-859a-7075d47c2172
[10] Factbox: Chipmakers' plans for factories in Europe, US and Asia | Reuters
[11] https://www.europarl.europa.eu/RegData/etudes/IDAN/2022/698852/EPRS_IDA(2022)698852_EN.pdf
[12] https://joint-research-centre.ec.europa.eu/system/files/2022-04/JRC129035.pdf
[13] «Fabless» is short for fabrication-less, i.e., without a factory.

customers' products. The value chain is split up to make it as productive and efficient as possible. This is illustrated in the figure below.

Figure 4: Illustration of the semiconductor value chain. Source: Ciani & Nardo (2022), adapted by Menon[14]



Contrary to many other industries, the factories which manufacture the chips are usually also suppliers to the chip designers. As a general rule, the **chip designer is the owner of the produced chips**. The chip designer is – usually – not a subcontractor to the manufacturer, but rather the manufacturer is a subcontractor of the chip designer.[15]

[14] *We have taken the value chain of Ciani & Nardo (2022): The position of the EU in the semiconductor value chain: evidence on trade, foreign acquisitions, and ownership, and altered it slightly for readability with some inspiration from* *https://www.mckinsey.com/industries/semiconductors/our-insights/strategies-to-lead-in-the-semiconductor-world*

[15] *Since the chip designer is usually the owner of the produced chips, some argue that the term "chip designer" is misleading. They argue that using the term "designer" for a companies such as Nordic Semiconductor may be somewhat misleading, because the term "design" is often perceived as a service only. Some therefore use the term "chip supplier" for these firms, as they are often the ultimate supplier of the chips. In this report, we have opted for using the term "chip designer", as the term "chip supplier" is not easy to distinguish against the chip manufacturers.*

3. The Norwegian semiconductor value chain

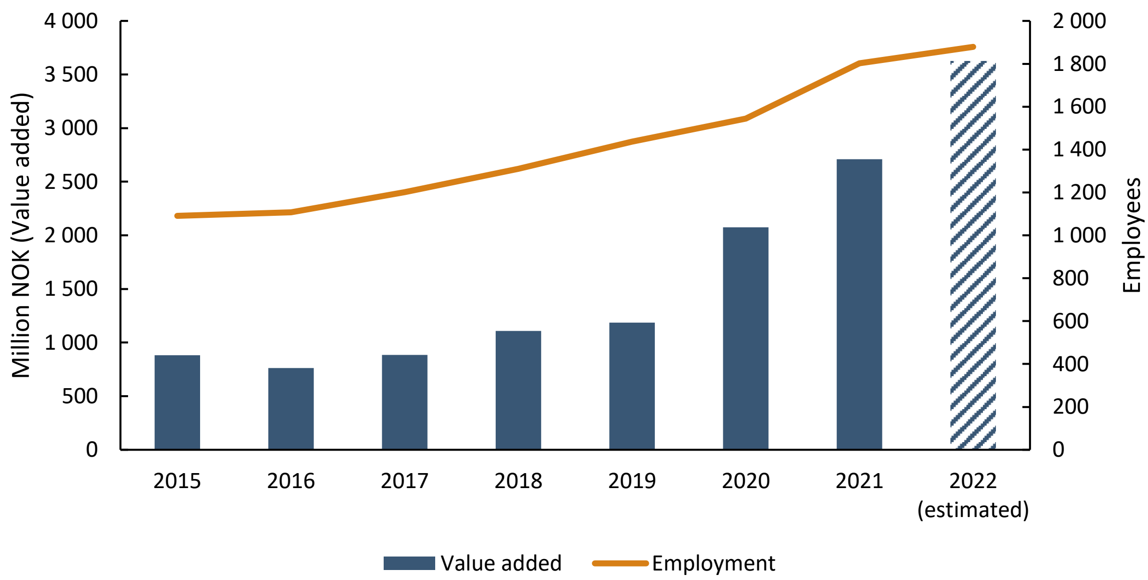
In our mapping, we have identified just under 50 Norwegian companies which work primarily within chip design, chip manufacturing, or assembly and packaging. Some of these companies have existed for over 30 years and have revenues in the hundreds of millions. Others were founded only in the past couple of years. In total, these companies employed over 1800 people and produced a value added of around 3.8 billion NOK in 2022. The total revenues were around 10 billion NOK, with the majority of income coming from customers abroad.

Table 1: The number of employees and value added in the semiconductor value chain. Source: Menon Economics

	2015	2020	2021	2022
Employees	1 090	1 520	1 780	1 850
Value added (bn NOK)	0.9	2.1	2.7	3.6 *
Revenue (bn NOK)	2.8	5.9	7.6	10.1 *

* = estimated

Figure 5: Value added and employees in the semiconductor value chain from 2015 to 2022. Source: Menon Economics



As can be seen from the figure, the industry has had a high growth rate over the past few years. The value added more than doubled from 2019 to 2021, and by our estimates, continued to grow rapidly into 2022.[16] The growth

[16] *Many companies have already reported financial data for 2022, and the 2022 estimate is therefore based mostly on actual, reported numbers.*

into 2022 was especially driven by a high growth for the largest company, Nordic Semiconductor, which accounts for over 60 percent of the total value added in the industry. Nordic Semiconductor is a global leader in low-power Bluetooth communications and Europe's largest fabless design company.

The largest companies in Norway are fabless designers which make *integrated circuits.* Integrated circuits are the chips most readers will usually think about when they hear the word "microchip". Integrated circuits are parts in computers, smartphones, and so on. These integrated circuits perform various functions, such as processing and storing information, or transmitting signals. The premier Norwegian expertise is in the field of power-efficient electronic chips, especially used for communications technologies, such as Bluetooth and Wi-Fi. The Norwegian actors are part of the global value chain, where they are heavily reliant on foreign suppliers, and have primarily international customers.

There are also other forms of semiconductors than integrated circuits, and their value chain is very different. The second most prominent category of semiconductors in Norway are **microelectromechanical systems, or MEMS**. Unlike integrated circuits, both design and manufacturing of MEMS is present in Norway. MEMS combine mechanical structures with electronic components, enabling them to sense physical phenomena such as motion, pressure, temperature, and acceleration. MEMS devices find applications in various fields such as automotive sensors, biomedical devices, environmental monitoring systems, and consumer electronics, where their ability to interact with the physical world provides unique advantages.

The third category of semiconductor chips made in Norway is **optoelectronic semiconductors**. These are specifically designed to interact with light and radiation, allowing them to generate, detect, or control light and radiation signals, and are used for applications such as displays, telecommunications, optical sensing, and optical data transmission.

Below we go through these three sub-sectors and their economic footprint in Norway.

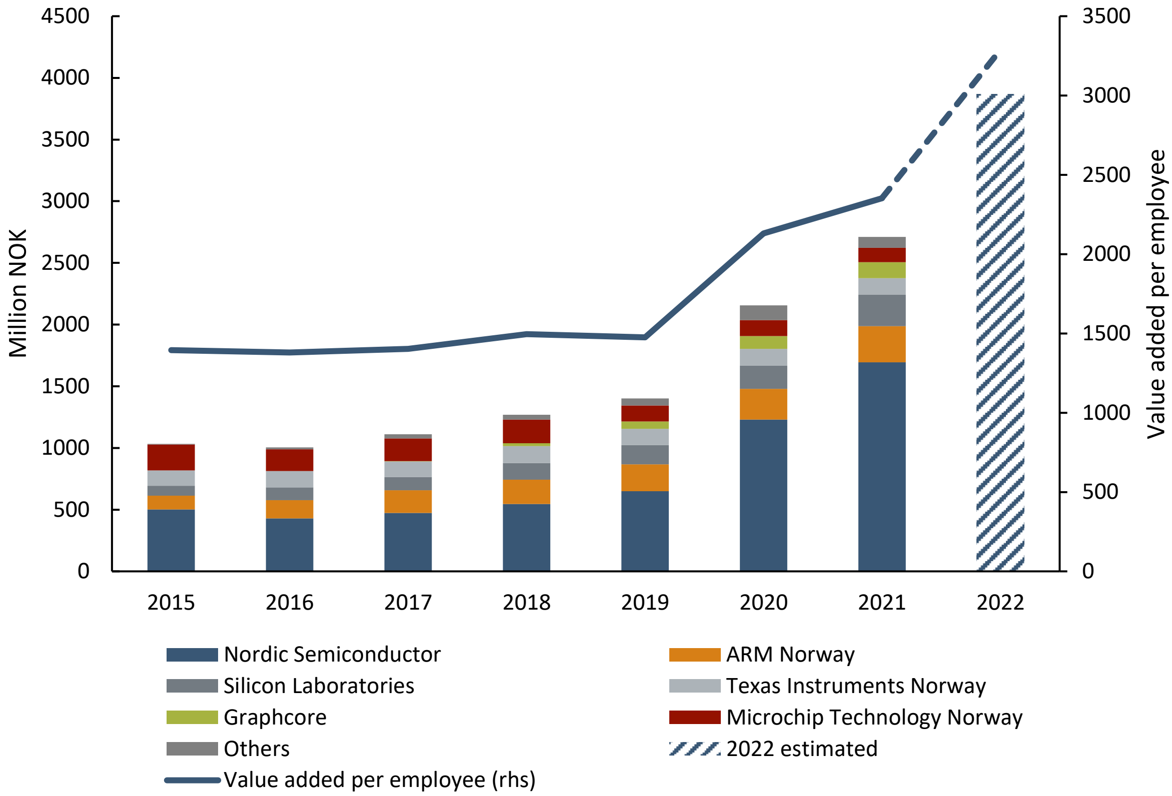
Integrated circuits

Integrated circuits are integral to all computers, and there are companies in Norway with great expertise in circuits used in both Bluetooth communications, Internet of Things (IoT), graphical processing units (GPUs), touch screens and more. The core expertise in Norway is especially on low-power wireless communications. The largest Norwegian company, Nordic Semiconductor, is the global leader in low-power Bluetooth communications, and several of the other large companies in Norway also focus on low-power wireless communications. These include Silicon Laboratories Norway and Texas Instruments Norway.

The Norwegian companies working within integrated circuits are all primarily chip designers, and none have manufacturing capabilities of their own. They are part of a global, highly complex and highly productive industry. The reason they have adopted this so-called "fabless" (fabrication-less, i.e., without a factory) model is that it allows the Norwegian actors to focus on their core competencies of chip design and innovation, while relying on specialised factories for efficient and cost-effective chip manufacturing.

The integrated circuits part of the value chain employed around 1200 people in 2022, and had a value added of over 3.5 billion NOK. It has grown substantially over the past few years, as shown in the figure below.

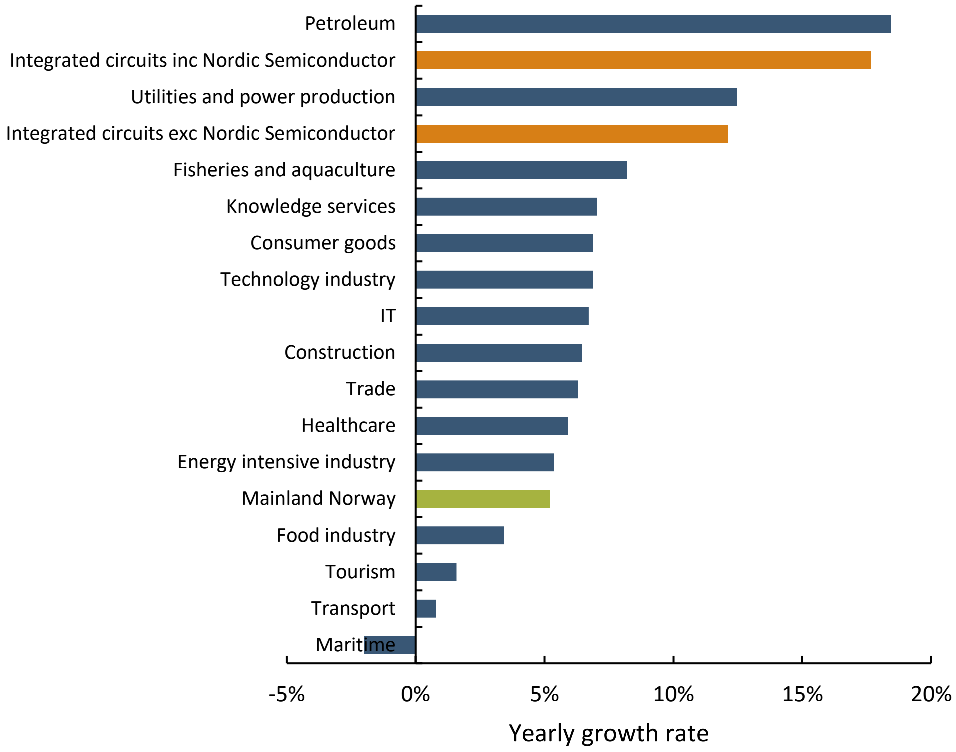
Figure 6: Value added in the integrated circuits value chain in Norway from 2015 to 2021, along with value added per employee. Numbers for 2022 are estimated. Source: Menon Economics



As can be seen from the figure, value added in integrated circuits has grown from a bit over 1 billion NOK in 2015 to over 2.6 billion in 2021, and we estimate over 3.6 billion in 2022. Most of this growth comes from Nordic Semiconductor, which grew its value added from 500 million NOK in 2015 to 1700 million in 2021 and around 2.4 billion in 2022. It now accounts for over 60 percent of the value added among the integrated circuits companies in Norway.

The rest of the companies in the integrated circuits value chain have had a combined growth in value added from a little over 500 million NOK in 2015 to roughly 1.2 billion in 2022. While this growth is not as high as Nordic Semiconductor's, it is still a *very high* growth rate. Almost no industries in Norway have grown at as high a pace as the fabless design industry. The figure below shows the average growth rate in value added for a series of industries from 2015 through 2021.

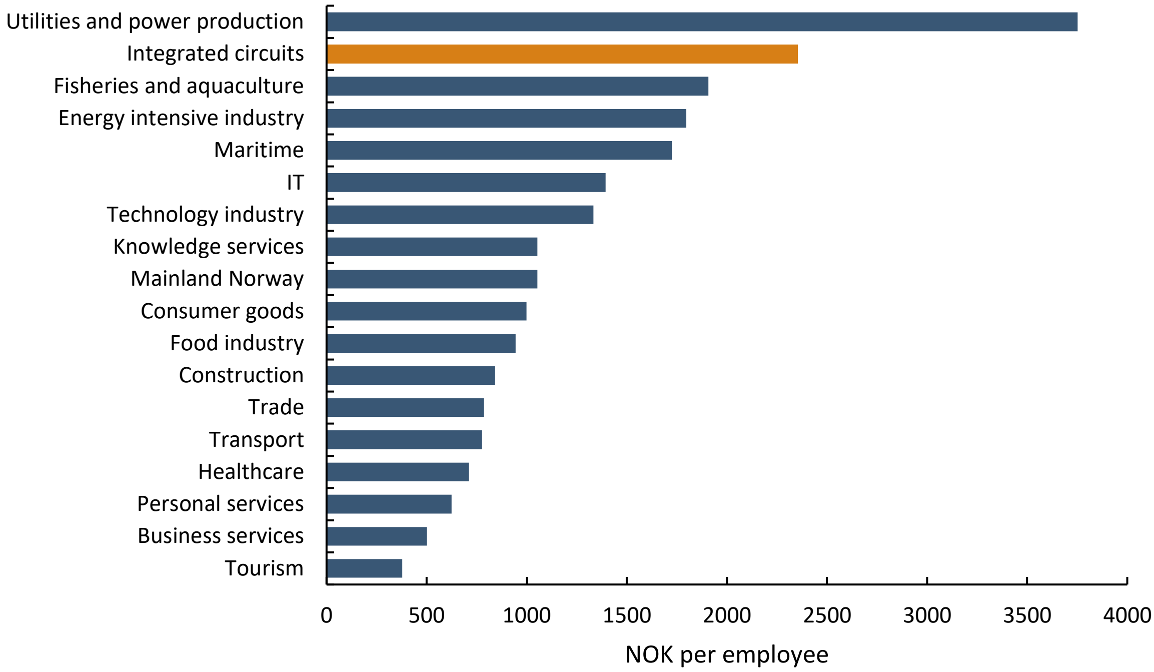
Figure 7: Yearly growth rate in value added from 2015 through 2021. Source: Menon Economics



As can be seen, only industries which have seen a large increase in commodity prices in the period have had as large an increase in value added as fabless design of integrated circuits has.

As mentioned in the previous chapter, fabless design is globally characterised by being a high productivity industry. This is also the case for the Norwegian chip designers of integrated circuits, as shown in the figure below.

Figure 8: Productivity, measured as value added per employee, in select industries. Numbers for 2021. Source: Menon Economics



As can be seen from the figure, the integrated circuits companies are highly productive, and also more productive than a series of other highly productive industries, such as the energy-intensive industry, the maritime industry and fisheries/ aquaculture.[17] Whereas the average value added for companies in mainland Norway (i.e., excluding the oil sector) is a bit over 1 million NOK per employee, it was almost 2.5 million NOK per employee in the chip design companies in 2021, and even higher in 2022.

Major companies within integrated circuits

- **Nordic Semiconductor** is Europe's largest fabless designer, specialising in innovative wireless communication solutions. They are especially focused on low-power technology and are a global leader in IoT and wireless connectivity, serving industries like wearables, smart homes, and industrial automation. Nordic Semiconductor was started in 1983 as a spinout from NTNU.
- **Microchip Norway** is the Trondheim branch of the US company Microchip Technology Inc. The Norwegian branch became a part of Microchip after Microchip bought Atmel. The Atmel Norway branch was built from the ground up as a chip-design firm in Norway, which made microcontrollers especially for use in touch screens. This activity has been continued as part of Microchip Technology Norway.
- **Texas Instruments Norway** is the Oslo branch of the US company Texas Instruments. The Norwegian branch was originally Chipcon before it was acquired by Texas Instruments. Texas Instruments Norway designs high-performance radio frequency microcontrollers (RF MCUs) for use in low-power Internet of Things applications.
- **Silicon Laboratories Norway** is the Oslo branch of the US company Silicon Laboratories. The Oslo branch was originally Energy Micro before it was bought by Silicon Laboratories in 2013. The expertise of the firm is on ultra-low energy consumption radios and transceivers.

[17] In Norway, the utilities industry consists mostly of power production.

- **ARM Norway** is the Trondheim branch of the British company ARM[18]. ARM internationally specialises in IP rights, while the Norwegian part concentrates on the design of Graphics Processing Units (GPUs). ARM bought the Norwegian firm Falanx in 2006[19].
- **Sony Semiconductor Norway** is a subdivision of the European branch and was established in 2020. They specialise in design and R&D of integrated circuits**.**
- **Graphcore AS** was the Oslo branch of the British firm Graphcore, specialising in the design of Intelligence Processing Units (IPUs). Graphcore Norway announced in November 2011 that it would down its activities in Norway 2022 as a result of a restructuring of Graphcore globally.[20]
- **TouchNetix** is specialised on capacitive touch technology, such as touch screens. Their current speciality is integrated circuits for touch screens in industrial and automotive applications, where there is a high need for robustness and longevity.
- **Onio** is an IoT company specialised in batteryless, self-powered microcontrollers that run on energy harvested from their surroundings.

MEMS and optoelectronics

MEMS and optoelectronics are semiconductors which are often used for helping computers interact with the real world. The majority of the firms using MEMS and optoelectronics in Norway make sensors that convert sound, pressure, light, and other stimuli into electrical signals that computers can understand. These chips are essential components for many industries, and chips manufactured in Norway are used for activities such as blood pressure monitoring, altitude control in airplanes, satellite instrumentation, subsea exploration, point-of-care medical diagnostics, high quality microphones, and much more.

Due to the variation in applications, designs, and properties of MEMS, they are typically far less standardized and less mass-produced than integrated circuits, resulting in a less global value chain and greater tailoring to each product. For MEMS, process and manufacturing knowledge significantly impacts designs, often leading to manufacturers being directly involved in the design process. This is partly why MEMS are manufactured in Norway.

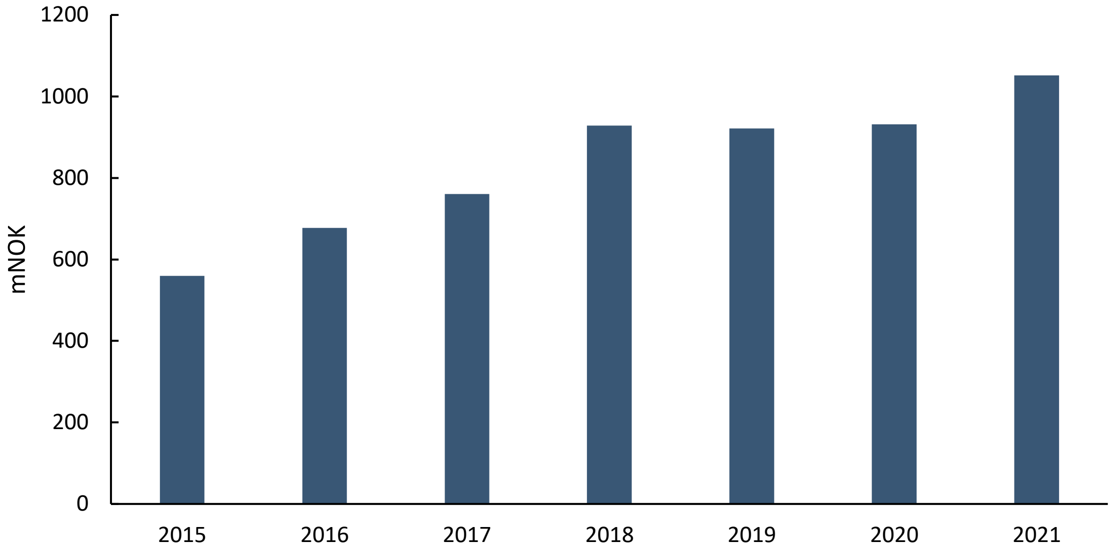
There is both manufacturing at the fabrication plant of Safran Sensing Technologies and through the Norwegian Infrastructure for Micro- and Nanofabrication (known as Norfab). Norfab consists of four nodes: the University of Oslo (UiO), NTNU, USN, and SINTEF MiNaLab. The three universities are involved in research, while SINTEF operates a manufacturing plant. All of these four are heavily involved with industry actors, and many companies produce their chips at SINTEF's plant.

Sensor chips can be seen as a "second wave" of microchips that take advantage of the technology from electronic microchips and create microchips with completely different applications. This is also seen in Norway, where the companies in the sensor industry tend to be young and still growing. The majority of the firms are not yet profitable – only around a third of the companies had an operating profit in 2021. To show an overview of the

[18] *ARM is again owned by the Japanese firm Softbank since 2016.*
[19] *https://www.digi.no/artikler/arm-kjoper-norsk-teknologiselskap/280866*
[20] *https://www.verdict.co.uk/meta-hires-graphcores-ai-team/*

development of the sensor industry, we therefore display the revenue of the firms from 2015 to 2021 in the figure below.[21]

Figure 9: Revenue for companies in the value chain for sensors in Norway from 2015 to 2021. Source: Menon Economics



From 2015 to 2021, the revenue of the sensor industry companies has grown from a little under 560 million NOK to over a billion. This is a growth of almost 90 percent in six years, or an average growth rate of 11 percent per year in revenue – a high growth rate.

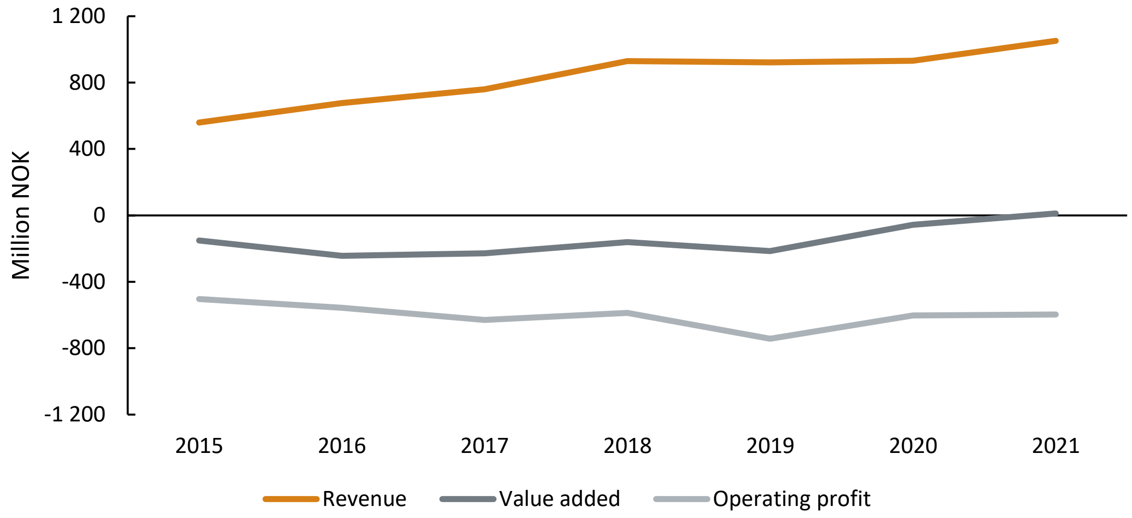
While the majority of the firms are young, the ones with the largest revenues are mostly rather old. Two of the largest firms are from 1985 – Safran Sensing Technologies is the continuation of the firm Sensonor, which has been making MEMS chips since 1985, and Norsk Elektro Optikk has been working on photonics since 1985. The largest company, Neo Monitors, is a spinout from Norsk Elektro Optikk.

Most of the growth has come from companies that were relatively small in 2015. While the five companies with the largest revenues (Safran, Memscap, Norsk Elektro Optikk, Neo Monitors and SINTEF MiNaLab) have grown their combined revenues by around 25 percent over the 6 years (from 460 to 580 million NOK), many of the smaller companies have grown from very low revenues to a more substantial level, and their total revenue has grown from under 100 million NOK in 2015 to over 470 million in 2021. Many smaller companies have in other words grown substantially over the period.

While the industry has grown, the sensor firms as a whole are still not profitable. While some of the more established ones, such as Safran, Neo Monitors, and Memscap, run a profit, many of the younger have losses that far outstrip the profits of Safran and Memscap. This is illustrated in the figure below.

[21] Few of the companies in MEMS and Optoelectronics have data for 2022 yet, and we have therefore not been able to estimate the total MEMS and optoelectronics market for 2022.

Figure 10: Revenue, value added and operating profit over time for the MEMS and optoelectronics industry in Norway. Source: Menon Economics



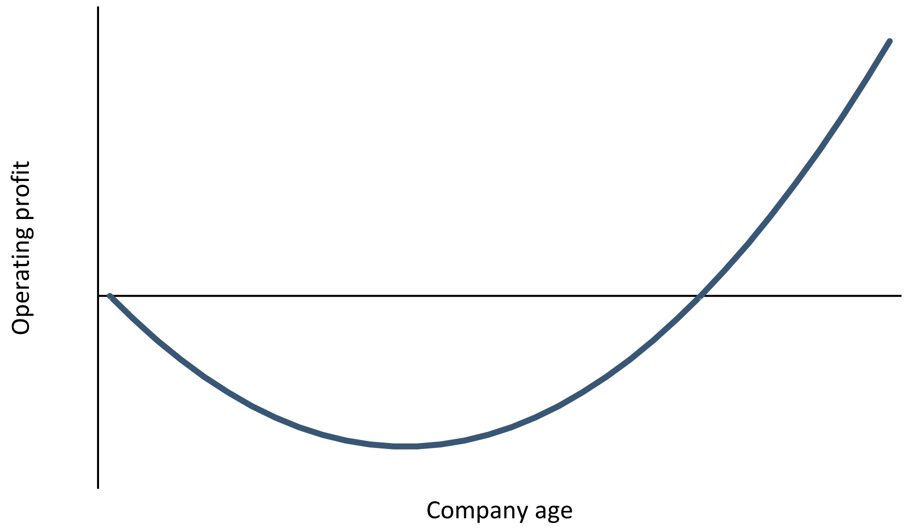
As can be seen, while revenue has increased, the operating profit has become more negative. Value added used to be negative, and has increased over the last few years, now reaching approximately zero. A negative value added may seem counterintuitive. Value added is calculated as the companies' revenue minus the purchase of goods and services. This also means that the value creation of the companies corresponds to the sum of labour costs and EBITDA.[22] Effectively, a negative value added therefore means that the operating loss is larger than the wage costs, and that the purchases of goods and services are larger than the revenues.

Negative value added is not uncommon for startups and young industries. The figure shows the profitability development of a maturing startup company, which often takes the form of a "J". Startup companies with growth potential require both capital and competent workforce to develop their products and services, resulting in short-term losses. The goal of these investments is to lay the foundation for future growth and value creation.

The J-curve is illustrated in the figure below.

[22] *EBITDA is operating profit before interest, tax expenses, and depreciation and amortization.*

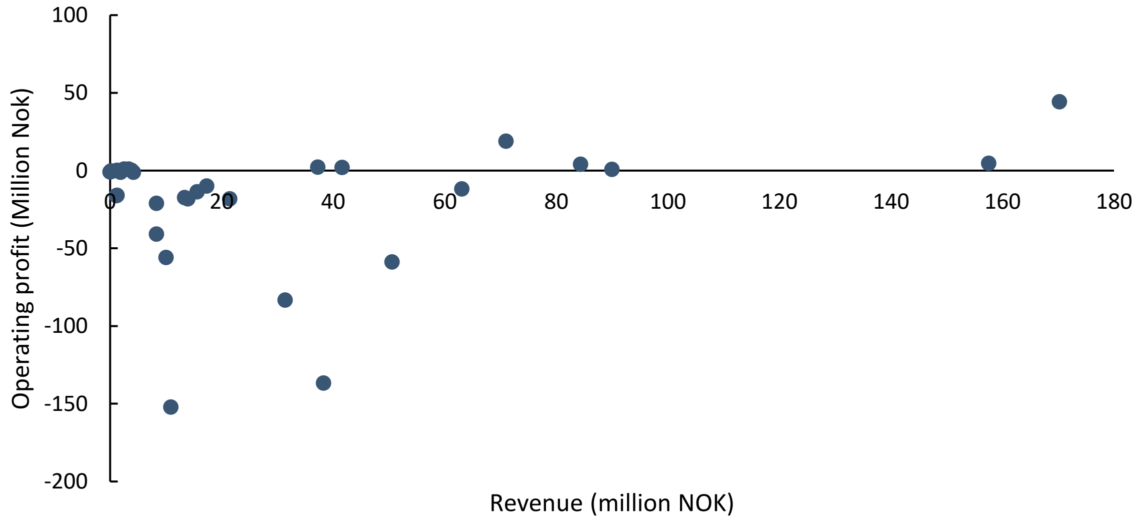
Figure 11: Illustration of the J-curve. Source: Menon Economics



The j-curve is particularly clear in high-tech, capital-intensive industries such as the semiconductor industry. Inventing new products and establishing business partnerships can take many years, while burning cash in the early years.

We empirically see strong signs of the j-curve among the sensor companies. There are many small companies with small revenues and large losses. Some firms have grown and have positive earnings, but none of these have very high earnings yet. The distribution of firms with regard to revenue and operating profit is shown in the figure below.

Figure 12: Sensor companies by revenue and operating profit. Source: Menon Economics

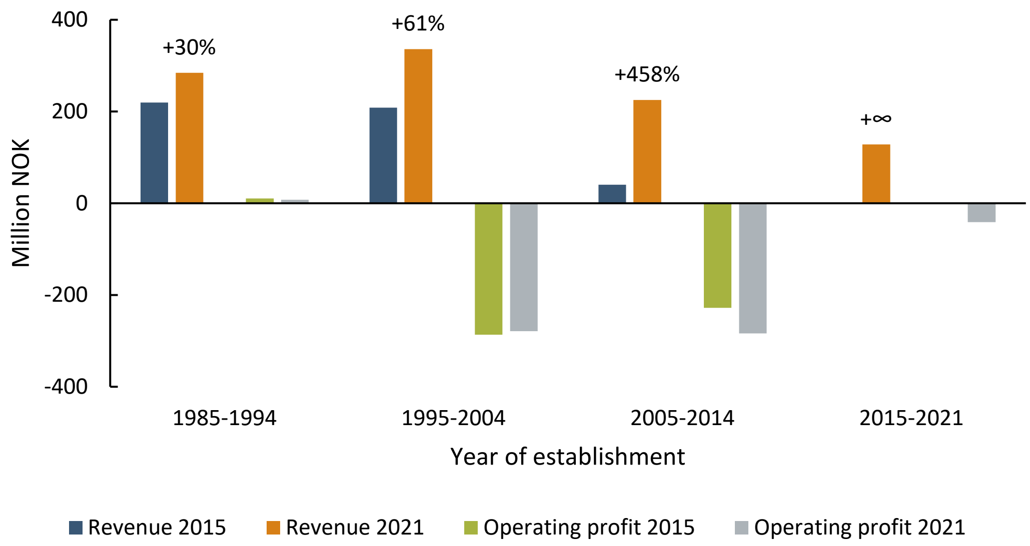


Many of the companies are still in an early phase where the products are not yet fully commercialised. As companies commercialize products and scale up their operations, they may enter a growth phase. Investments then pay off in the form of increased revenues and improved profitability. Over time, successful startup companies become growth companies that reap returns on their investments.

Becoming profitable takes time and does not necessarily happen. For example, the two firms with losses over 100 million NOK, Idex Biometrics and Novelda, are both more than 15 years old. This does not mean that they will never become profitable, but it illustrates that it may take a long time of sustained losses before the firms become profitable.

The figure below shows the revenue and operating profit of companies based on when they were established, grouped into age-brackets.

Figure 13: Revenue and operating profit in 2015 and 2021 for firms within MEMS and optoelectronics, grouped in age-brackets based on year of establishment. Source: Menon Economics



There are two main points to see from this figure. The first is that all age-brackets have had an increase in revenue from 2015 to 2021. The revenue growth has been especially large for companies established between 2005-2014, which had over 5 times as high revenues in 2021 as in 2015. Companies founded between 2015 and 2021 had a revenue of over 100 million NOK in 2021.

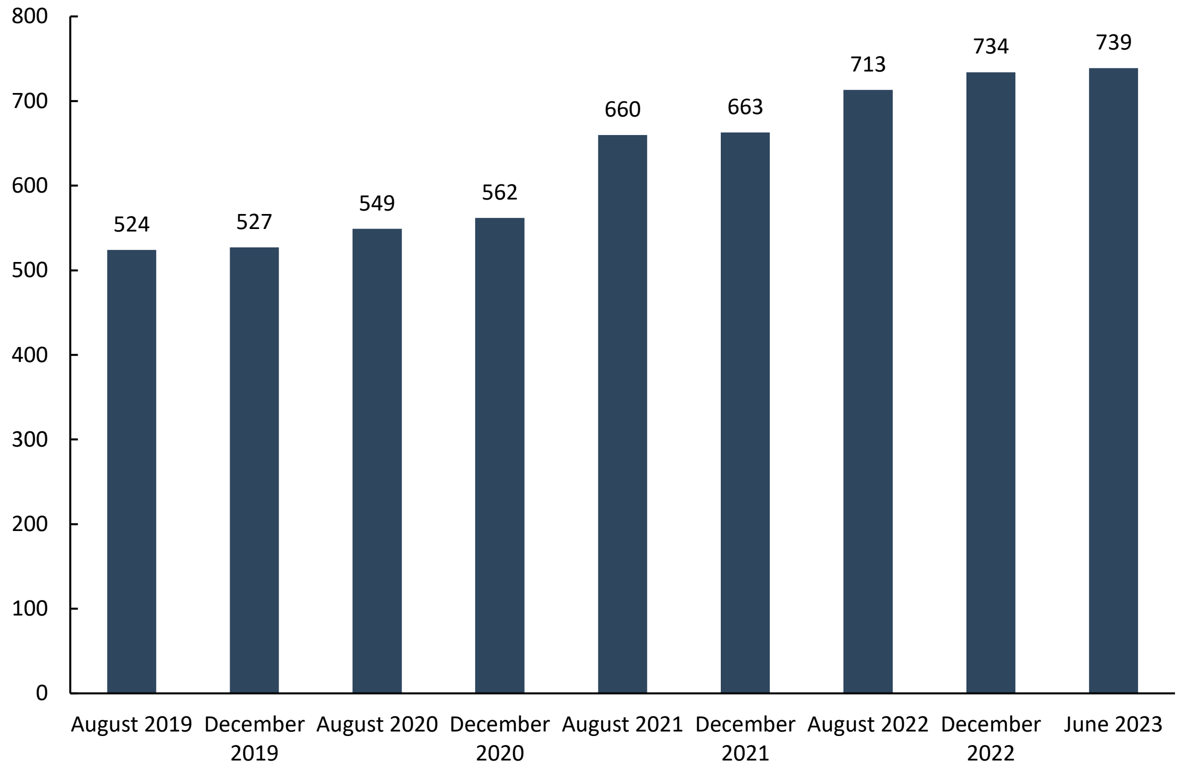
The second point is that, even though there has been growth in revenue, operating profit has not increased substantially for any age bracket. Only the companies founded before 1995 are profitable as a group, and even these are only slightly profitable. The companies founded between 1995 and 2015 are no more profitable in 2021 than they were in 2015. There is some consolation in the fact that the loss rate is falling – for each krone of revenue, the loss is lower. This may be a sign that the companies are edging towards becoming profitable in the future, but that is obviously uncertain.

Employment numbers and growth to 2023

While there is not sufficient data at the time of writing to estimate the value added and revenue for the MEMS and optoelectronics value chain for 2022, there is available data on employment.

The figure below shows the number of employees in each company, over time from 2019 to 2023.

Figure 14: Number of employees in MEMS and optoelectronics from 2019 to 2023. Source: Menon Economics



The number of employees has grown by around 41 percent from August 2019 to June 2023. Around half of this growth came from December 2020 to August 2021, when there was a marked jump. There was also a growth of approximately 10 percent from December 2021 to December 2022, while development in the industry has been relatively flat so far in 2023.

Select companies within MEMS and Optoelectronics

We have in total identified just over 30 companies in the MEMS and Optoelectronics value chain. Below are some of the most prominent ones:

- **Safran Sensing Technologies Norway,** formerly known as Sensonor, has been a leading provider of high-precision MEMS sensors since its establishment in 1985. Housing one of the two microchip production facilities in Norway, the company designs and produces MEMS sensors for applications requiring utmost precision, particularly in the inertial field (Gyro and IMU).
  Headquartered in Horten, Safran Sensing Technologies Norway has played a significant role in shaping the global MEMS industry for more than 35 years. The company has a remarkable track record, having shipped over 250 million pressure sensors, 250 million accelerometers, and 2 million gyros for use in numerous applications.
- **Memscap** was a spinoff from Sensonor, which has gone on to produce sensors which are used both in aerospace/defense, optical communications, medical and biomedical, and the IT/consumer market. Their sensors are both used for wireless communications of heart issues in the body, and for measuring pressures thousands of feet in the air.
- **Norsk Elektro Optikk** has worked on optoelectronics since its establishment in 1985. The company originally worked on Norwegian defence research and has since become the largest research firm on optoelectronics in Norway.

- **NEO Monitors** was started as a part of Norsk Elektro Optikk and has since become a major manufacturer of gas and dust analyzers for use in industrial environments across the world and has sold over 20,000 such analyzers.
- **Zimmer & Peacock Design** produces and delivers a range of services within electrochemical sensors, biosensors and medical diagnostics.
- **Elliptic Laboratories** creates sensors for human presence detection, and proximity-, position-, gesture-, breathing- and heartbeat-detection.
- **Tunable** produce gas analysers that can measure multiple gases simultaneously, based on their own proprietary micro- and nanotechnology.
- **Novelda** provides a sensor solution for human presence detection. Novelda's short-range radar sensors have a variety of indoor applications, including consumer electronic devices and smart building systems.
- **Sensibel** is developing and commercializing the world's most sensitive MEMS-based microphone technology for speech recognition applications.
- **Crayonano** is a startup specialising in semiconductors based on nanomaterials. While most semiconductors are based on silicon, Crayonano uses new materials and photonics.
- **poLight** was founded in 2005 and offers a tunable optics technology, designing MEMS-based optical lenses which replicate "the human eye". This technology is applicable in autofocus cameras in devices such as smartphones, augmented reality glasses, smartwatches, barcode scanners, machine vision systems and medical devices.
- **Optronics Technology** develops and produces high end, robust, optical gas detection to industries such as Oil & Gas, Marine, Mining and Biogas.

Elaboration on types of value chains within MEMS and Optoelectronics

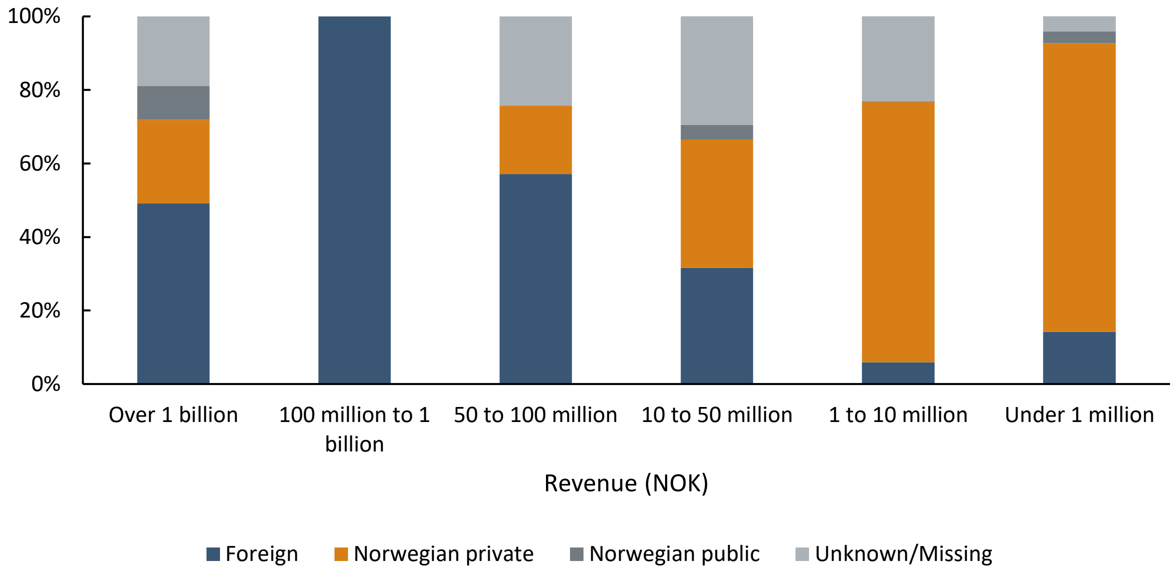
There are several forms of companies which use different strategies within MEMS and Optoelectronics. It is important to recognize the distinction between "fabless" design companies and manufacturers within this value chain. This distinction becomes evident through the following examples:

- SINTEF MiNaLab serves not only as an R&D company but also offers contract manufacturing, akin to conventional semiconductor foundries. In other words, they supply chips to companies that have their own designs.
- MEMSCAP is a prime illustration of a company that uses SINTEF as a contract manufacturer for their chip designs. The same applies to SensiBel, Tunable, Sonair, and others. The majority of SINTEF MiNaLab's customers follow a strategy where they create competitive products based on custom-made proprietary chip designs.
- Safran Sensing Technologies primarily manufactures chips exclusively for use in their own products. Consequently, Safran operates both as a chip manufacturer and chip designer.

Ownership of semiconductor companies

The semiconductor industry is a global industry with many large actors, and also large foreign ownership of Norwegian actors. The figure below shows the ownership of Norwegian semiconductor firms.

Figure 15: Ownership of Norwegian semiconductor firms, by revenue band. Source: Menon Economics



As can be seen from the figure, most of the smaller companies are owned by Norwegians, while the larger ones tend to be foreign owned. All of the firms with a revenue of over 100 million NOK are now foreign owned, except for Nordic Semiconductor, which is listed at Oslo Børs.

Many of the large firms which are now foreign owned were originally Norwegian owned before being sold to international actors. This includes Falanx (bought by Arm), Chipcon (bought by Texas Instruments), Energy Micro (bought by Silicon Laboratories), Neo Monitors (bought by Nederman), and Sensonor (bought by Safran Sensing Technologies).

Location of Norwegian semiconductor firms

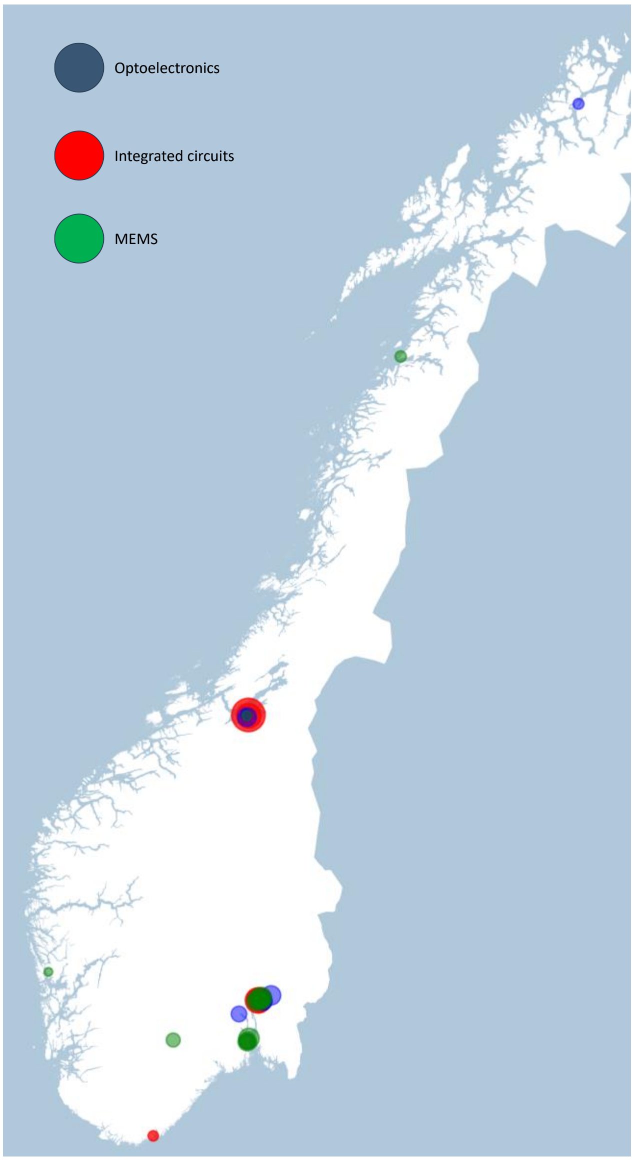
There are three main areas with several semiconductor firms in Norway: Oslo, Trondheim and Horten.

Trondheim has particularly many firms within integrated circuits, including Nordic Semiconductor, ARM Norway, Microchip Technology Norway and TouchNetix. Many of these are spinouts from NTNU. There are also some firms within Optoelectronics – including Crayonano and Integrated Optoelectronics.

Oslo has several firms within integrated circuits, including Texas Instruments, Graphcore, Silicon Laboratories, Omnivision Technologies, and more. There are also many MEMS firms in Oslo, including Elliptic Laboratories, Spinchip, Novelda, Tunable, Sensibel and more. Many of these MEMS-firms are spinouts of SINTEF MiNaLab. Finally, Oslo also has optoelectronic companies, including Optronics Technology and Neo Monitors.

Horten is MEMS-central. Safran Sensing Technologies, Memscap, Zimmer & Peacock, Sensocure and poLight are all headquartered there. There are also many firms that are more indirectly involved in the industry located in this area, which work together with the University of South-Eastern Norway, which is also located in Horten.

Figure 16: Location of the firms in the semiconductor industry. Size represents number of employees.



There are no typical business clusters or corporate networks in the Norwegian semiconductor value chain. However, many companies have close relations and cooperation with the universities and independent research organisations like SINTEF, creating a common meeting ground for the industry. The research institutions offer help and consultancy in form of both insights and access to test- and production facilities. In chapter 4, we will elaborate further on the important role of research institutions in the value chain, and how they are partly responsible for the clustering of semiconductor companies around Oslo, Trondheim and Horten.

4. Research and education

The semiconductor industry in Norway is tightly connected with research institutions and universities. The universities play a key role both in educating the future employees in the industry, in researching future technologies and in providing key infrastructure for the companies. In this chapter, we first examine the universities and research institutions in Norway before we look at the education of those in the industry.

Universities and research

The most important public infrastructure within the Norwegian semiconductor industry is the Norwegian Infrastructure for Micro- and Nanofabrication, known usually just as “NorFab”. NorFab is an alliance between the Norwegian University of Science and Technology (NTNU), the University of Oslo (UiO), the University of South-Eastern Norway (USN) and SINTEF, designed to conduct research in the field of micro- and nanotechnology. The three academic institutions have open-access cleanroom facilities, where both academic and commercial companies can come and perform hands-on research. Meanwhile, SINTEF’s Minalab cleanroom has manufacturing capabilities, and they manufacture semiconductors for dozens of companies.

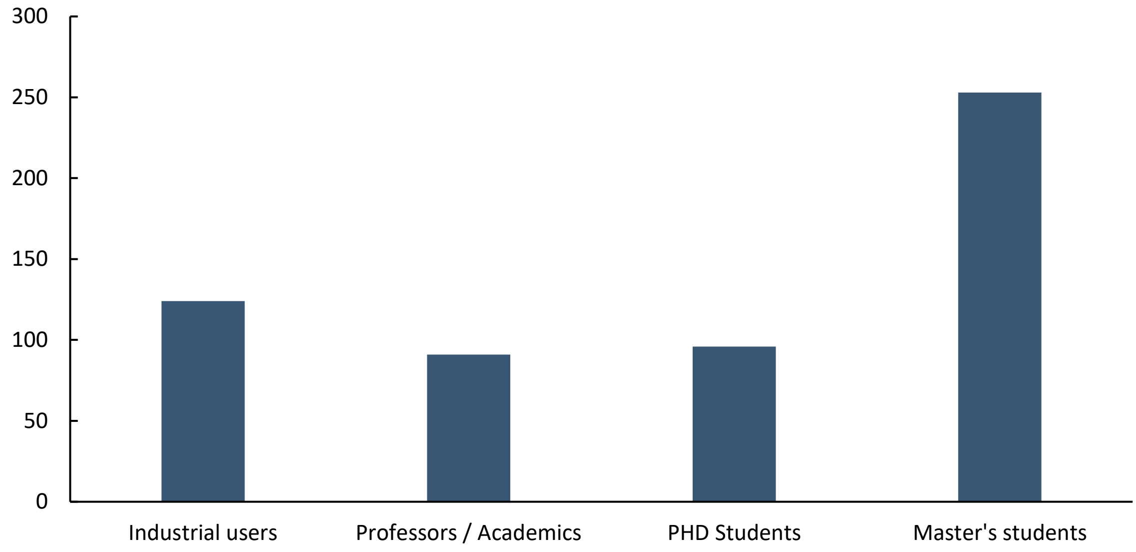
The four institutions are specialised on different segments of the value chain, contributing with unique areas of expertise to the overall research effort.

- UiO has a focus on materials and earlier phase research.
- NTNU has a focus on lithography and new materials.
- USN focuses on packaging and electronics.
- SINTEF Minalab concentrates on manufacturing.

The foremost reason for the division of focus is to avoid needless duplication of machinery at the different cleanrooms. The machinery at the cleanrooms is expensive, and specialising is therefore more cost-effective. The specialisation is also rooted in the core competencies of each university, as well as the skills of the surrounding companies. There is a clear overlap between where the companies are located, as seen in figure 14, and what each university is specialised in. Horten, where USN is located, houses the headquarters of several Microelectromechanical Systems (MEMS) companies, Horten is also home to companies with expertise within packaging of microchips. Trondheim has historically been the home of the larger integrated circuit companies, and more recently several “new materials” and optoelectronic microchip companies have also been spun out from NTNU. In Oslo, a number of MEMS companies have originated from UIO and SINTEF MiNaLab.

The interaction between industry and NorFab can also be seen in the users of NorFab’s cleanrooms. In 2021, 124 industrial actors used the NorFab universities’ cleanrooms (not counting SINTEF). The figure below illustrates all the users of these cleanrooms.

Figure 17: Number of users at NorFab's cleanrooms in 2021. Source: NorFab



Around 250 master's students, 100 PhD students, 90 professors/academics and 120 industrial users used the NorFab cleanrooms in 2021.

The NorFab institutions are also heavily involved with industrial actors that are not primarily semiconductor companies, but which use them occasionally. USN has over 50 industrial partners they cooperate with on packaging, and SINTEF manufactures for dozens of companies.

There are also universities performing semiconductor research other than those participating in NorFab. In the field of optoelectronics, the Arctic University of Norway (UiT) is quite active. For instance, professors from UiT have founded Chip NanoImaging, a company specializing in optoelectronic microchips. Furthermore, the University of Bergen's physics department has important contributions, and the Norwegian University of Life Sciences (NMBU) offers a specialized master's degree in photonics, a program of high relevance to the study of optoelectronics.

As a general rule, the research on semiconductors is rather interdisciplinary, and not isolated to a single academic field. There are researchers performing research within relevant fields for semiconductors coming from both physics, chemistry, engineering, data science, biophysics, and so on. Much of the research at the universities is basic research. At this level, there is not necessarily a distinction between different forms of chips. There is substantial overlap with semiconductors used for entirely different purposes than chips and electronics, such as for instance semiconductors for solar panels. The semiconductor competency is therefore spread across the universities, across different departments. There are therefore some interdisciplinary groups at each of the universities that are focused on semiconductor activities. Some that have been brought forward as particularly important are:

- The Centre for Materials Science and Nanotechnology (SMN) and the electronics group at the University of Oslo
- The department of electronic systems at the Norwegian University of Science and Technology
- The department for microsystems at University of Southeast Norway
- The research group Ultrasound, Microwaves and Optics at the University of Tromsø

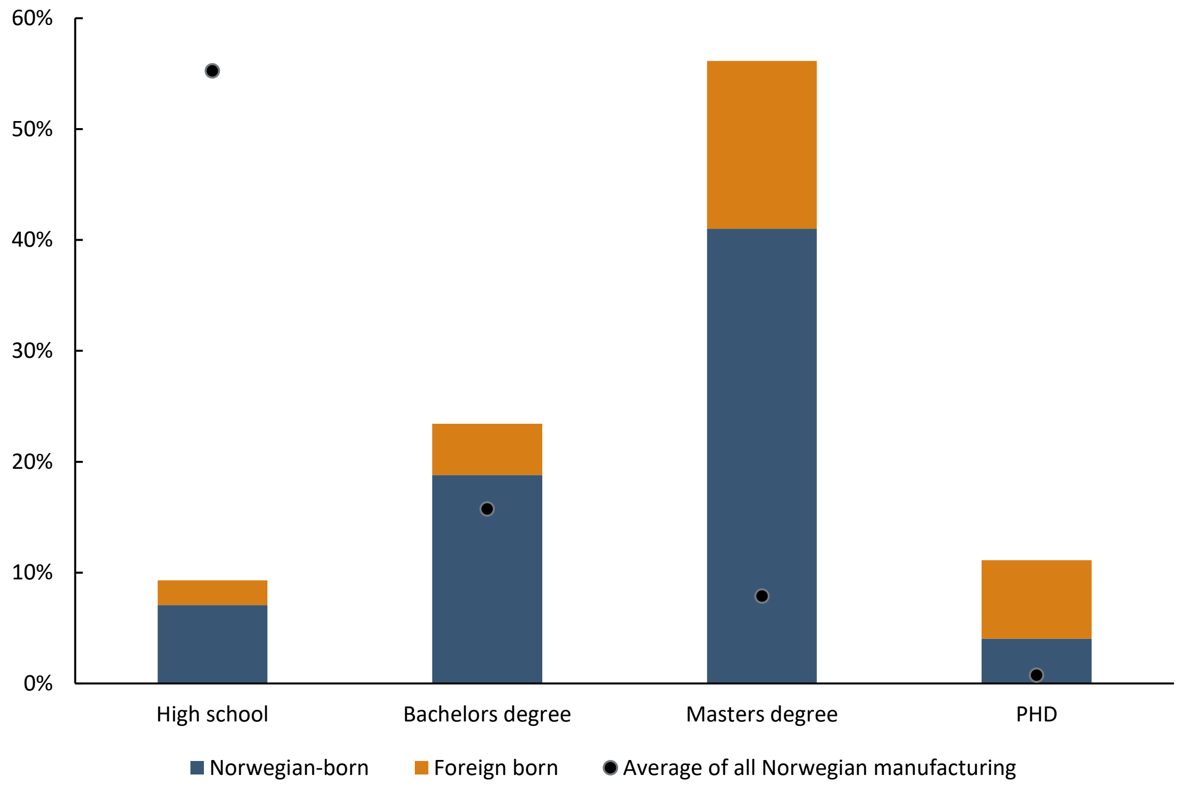
Education

The microchip industry relies on a highly competent and versatile workforce, with diverse educational backgrounds. Given the multifaceted and complex nature of microchip technology, industry requirements typically encompass individuals equipped with knowledge spanning many domains within the natural sciences such as physics, information technology, data science, chemistry, and material technology. Companies seek individuals who possess specialized insight in one or more of these disciplines.

To examine which skill sets are used in the industry, we use data from Statistics Norway's microdata.no.[23] Using data from our mapping together with microdata.no, we can extract data on the education of workers in the semiconductor industry, as well as information such as their gender and country of birth.[24] This approach however only allows us to identify roughly half the work force of the industry.[25]

The figure below shows the level of education in the industry and country of birth.

Figure 18: Level of education in the semiconductor industry. Source: Menon's estimates based on SSB's Microdata



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[23] The microdata.no service offers access to micro level data from Statistics Norway. It contains information on which industries people work in, where they work, what education level they have, and much more.
[24] Concretely, we gather employment data for combinations of industry (5-digit ISIC codes) and municipalities where semiconductor firms make up at least 70 percent of the total employment in the industry-municipality combination. This gives us 7 different regions: ISIC 26110 in Trondheim, ISIC 26110 in Oslo, ISIC 26110 in Horten, ISIC 26510 in Drammen, ISIC 72190 in Horten, and two smaller other combinations.
[25] We pick up on companies such as Nordic Semiconductor, NEO Monitors, Novelda, Numascale, Zimmer & Peacock, poLight, and more. These are companies within both MEMS, Optoelectronics and Integrated Circuits, and thus a relatively good sample for the entirety of the industry.

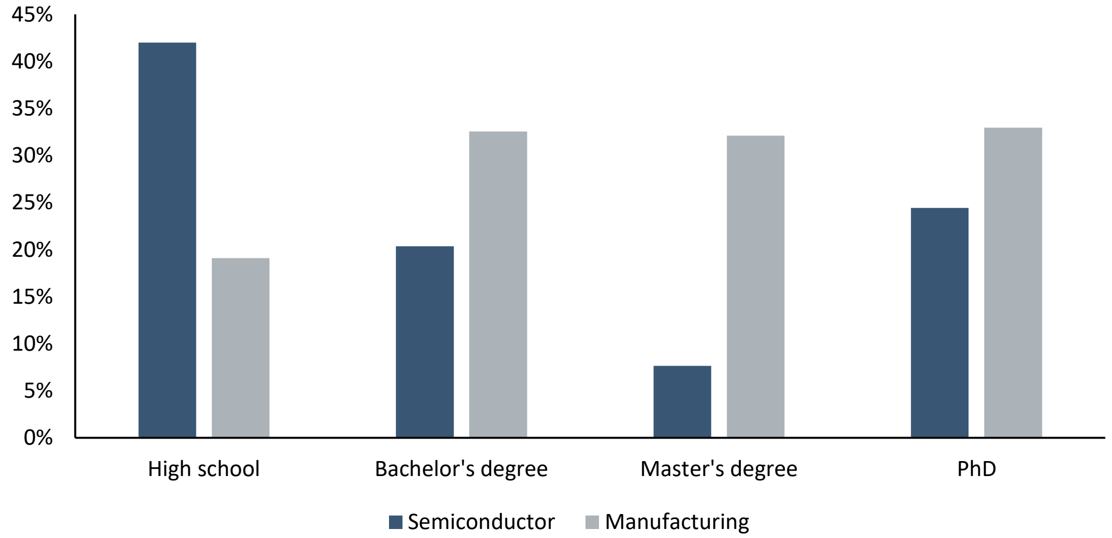
We find that about 11 percent of the workforce has a PhD-level background, and 56 percent has a master's degree. As can be seen from the figure, the most common education within manufacturing in Norway is high-school level, with over half the employees. Only around 8 percent of those employed within manufacturing as a whole have a master's degree, compared with 56 percent of those in the semiconductor industry. Compared to other industries in Norway, the level of education in the semiconductor industry is unusually high, reflecting the complexity of the industry.

In addition, we see that a substantial share of the employees is foreign born. Interestingly, we find that the higher the level of education, the larger the share of foreign-born employees. While one fifth of employees with a bachelor education are foreign born, a quarter of those with a master's degree are, and almost two thirds of those with a PhD.

Of those born outside of Norway, just shy of 50 percent are from Europe, while around 40 percent are from Asia, with India, China, the UK, France, Russia and Germany being the most common countries of birth.

The semiconductor industry employs relatively few women. Only around 16 percent of the employees we have identified are women. This is lower than within manufacturing as a whole, where 24 percent of employees are women. The numbers by highest level of education are shown in the figure below.

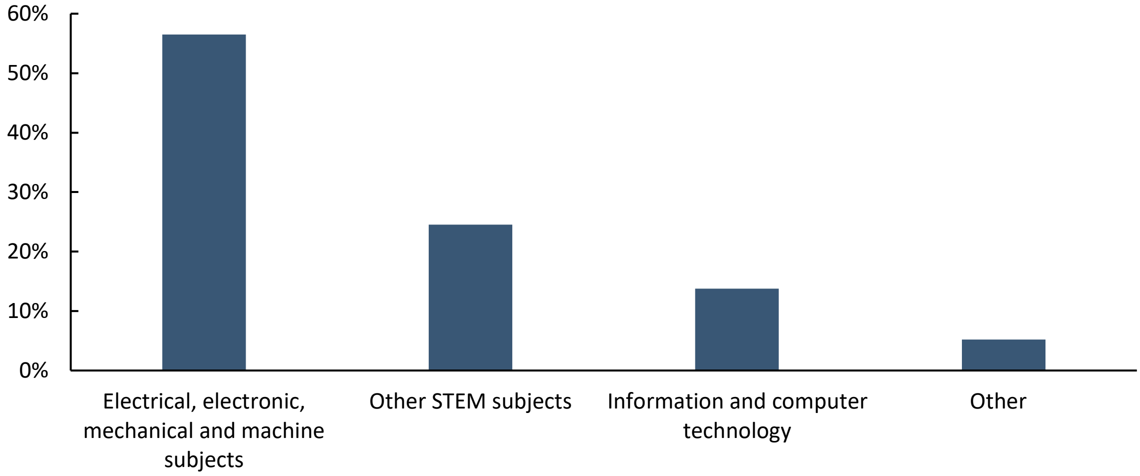
Figure 19: Share of women among those working in the semiconductor industry and those working within manufacturing, by highest level of education. Source: Menon's estimates based on SSB's Microdata



As can be seen from the figure, the share of employees in the semiconductor industry which are women is especially low for those with a master's degree. Only 8 percent of those with a master's degree are women. Of those with a high school education, a large share are women, but it is here important to remember that there are few employees with a high school education in the semiconductor industry, so not too much should be read into this percentage.

Looking into the master's degrees in more detail, Figure 20 shows how the educational backgrounds are overwhelmingly within the natural sciences but divided between several areas of studies. The most common background is within electronic and mechanical subjects, which includes fields such as microelectronics and robotics.

Figure 20: Master's degree backgrounds in the semiconductor industry. Source: Menon's estimates based on SSB's Microdata



The two other large groups of master's degrees are "other STEM subjects" and "information and computer technology". The "other STEM subjects"-group consists mostly of degrees labelled as "unspecified natural science subjects" according to the classification of education (NUS)[26]. "Other STEM subjects" also include degrees in physics, mathematics, and industrial economics[27]. The last category, "Other", consists of master's degrees that are not within the natural sciences, such as economics degrees.

It is challenging to provide a full picture of specific studies that are relevant for the microchip industry. People we have interviewed in both universities and the industry have mentioned that the industry often requires re-education of employees. People with general degrees in fields of study such as chemistry or physics may, through some targeted in-house training, gain knowledge specific to semiconductors.

The industry itself encompasses a myriad of niches, making it impractical to generate a comprehensive list of relevant studies. However, there are certain programmes that have been repeatedly pointed out as particularly relevant to the field:

- Nanotechnology at NTNU
- Electronics Systems Design and Innovation at NTNU
- Renewable Energy and nanotechnology at UiO
- Applied physics and mathematics with a speciality in photonics at UiT
- Photonics at NMBU
- Micro and nano systems technology at USN

This list is not exhaustive, but it includes some of the most common and relevant degrees.[28] Besides the ones mentioned, programmes such as cybernetics, civil engineering and microelectronics have been highlighted as particularly relevant.

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[26] NUS - SSB
[27] NUS categorization: Electrical, electronic, mechanical and machine subjects [75510, 755106, 755108, 755112, 755118, 755901] / [755] Other STEM subjects [752113, 759908, 759915, 759999]/ [752,759] Information and computer technology [754106, 754115, 754116, 754118]/ [754] other [741, 799]
[28] For the number of students at each of these programmes, see appendix D.

Our interviews with representatives from both the industry and academia reveal a consensus that, while the semiconductor industry in Norway currently faces a tight labour market, there is no severe talent deficit in the industry today. However, for future expansion, access to skilled personnel, alongside the challenge of capital acquisition, is perceived as the primary bottleneck.

An additional concern is that a general STEM skills-shortage could arise in Norway. Many of the people who are today re-educated into working with microchips could feasibly work within other industries that the Norwegian government is now putting heavy emphasis on, including battery production, hydrogen and carbon capture. Within battery production – the most labour-intensive of those industries – the overlap is very clear, with much of the same skill set required.[29] This causes a concern that the semiconductor industry may face a larger skills-shortage in the future.

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[29] *For more on the skills required in the battery industry, see chapter 5 here: https://www.menon.no/wp-content/uploads/2021-111-Ringvirkninger-og-samfunnseffekter-av-Freyrs-etablering-i-Mo-i-Rana.pdf (Available in Norwegian only)*

Appendices:

Appendix A: Broader applications of semiconductors

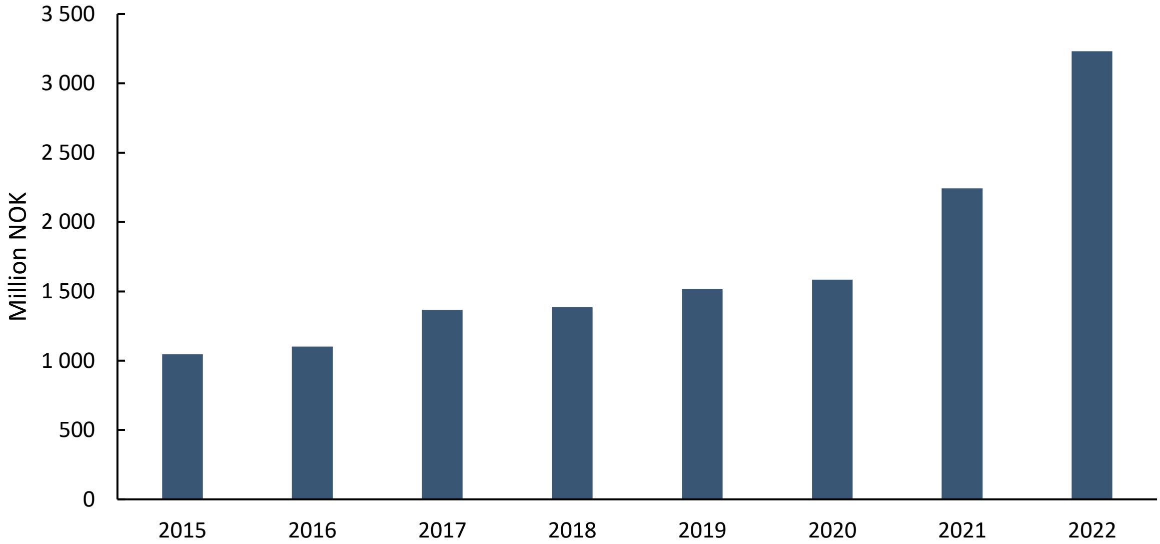
The main part of this report looked at the companies whose main activity is in the production or design of integrated circuits, MEMS, or optoelectronics, and at the interplay between these companies and universities/research organisations. Although these actors constitute the core of the semiconductor industry in Norway, the importance of semiconductors goes far beyond just those involved in their production. In this chapter, we will firstly look at the imports of microchips to Norway, before at we look at several areas in the Norwegian economy where microchips play an important role.

Imports of microchips

This importance is for example reflected by the large value of the annual import of semiconductors used in Norway. Semiconductors are considered a key enabling technology by the EU because they are important for a variety of other industries and drive innovation throughout the economy.

Over the past few years, the imports of semiconductors have grown substantially, as shown in the figure below.

Figure 21: Imports of semiconductors and parts of semiconductors. Source: Menon's estimates based on Statistics Norway's external trade in goods

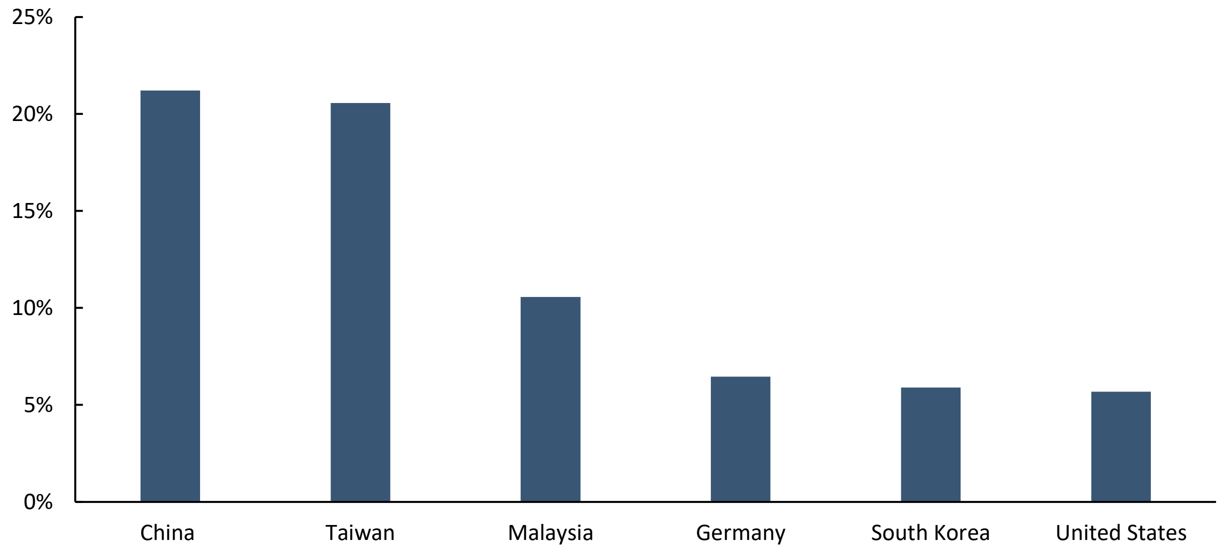


From 2015 to 2022, imports of semiconductors have more than trebled in value, from 1 billion NOK to over 3.2 billion. This is an average growth rate of over 17 percent over the period. The growth has been especially large from 2020 to 2022, where the value of the imports doubled.

The majority of these imported goods fall under the trade code “Electronic Integrated Circuits”. This category mainly comprises fully processed and packaged integrated circuits, ready for utilization in various applications. In 2022, the import value for these specific chips reached approximately 2.5 billion NOK.[30]

The majority of the imported chips comes from Asia, and especially China and Taiwan, as shown in the figure below.

Figure 22: Share of imports value for semiconductors imported to Norway, categorised by exporting country. Source: Menon’s estimates based on Statistics Norway’s external trade in goods



Important applications of microchips

Semiconductors are considered a key enabling technology by the EU.[31] Key enabling technologies are defined as technologies that act as drivers for economic growth, competitiveness, and societal advancement. They facilitate significant improvements in product creation, process enhancement, and the emergence of fresh industries.

The EU highlights six main industries where semiconductors are of particular importance[32]:

- Healthcare
- Aerospace, Defence and Security
- Energy
- Automotive industry
- Wireless communications

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[30] *The remaining 700 million NOK were attributed to the trade code "Diodes, Transistors, and Similar Semiconductor Devices". This grouping includes components that can serve as inputs to the semiconductor industry or be applied in other fields. From the “Diodes, transistors and similar semiconductors” grouping, we have excluded Photovoltaic cells assembled in modules or made up into solar panels, as solar panels are a separate value chain from the microchip-oriented semiconductors we are looking at in this report.*
[31] https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/key-enabling-technologies_en
[32] *https://digital-strategy.ec.europa.eu/en/library/european-chips-act-staff-working-document*

- Industrial Automation

Norway plays an important role in several of these industries. In this chapter, we briefly go through the individual industries and why semiconductors are important for them. We also provide some examples of companies we have identified in our mapping of the semiconductor industry.[33]

Healthcare

Most medical devices utilised in hospitals and medical practices, whether powered by the electrical grid or batteries, rely on semiconductor components for their functioning.

Semiconductors, and especially optoelectronics, are essential for various ***medical imaging*** technologies, such as ultrasound. Norway has a particular expertise in ultrasound technology, with firms such as GE Vingmed Ultrasound, Barco and Medistim.

In addition, medical sensors are now deployed inside the human body for ***diagnostic purposes***. Tiny semiconductor-based sensors are inserted intravenously to detect and identify medical problems. These sensors then transmit the collected data for analysis. Norwegian players in this field include Cardiaccs, Memscap, GE Vingmed Ultrasound and Medistim.

Developments within so-called *lab-on-a-chip* are important for ***point-of-care diagnostics***. Instead of full-blown analysis at the hospital, semiconductor chips allow for analysis where the patient is. SpinChip and Zimmer & Peacock are for instance important Norwegian actors here.

Lastly, there is currently interesting research going on in more experimental fields. Life Technologies has applied for grants to the Skattefunn-programme on research on how semiconductor technology can be utilised for better and more efficient DNA sequencing. SINTEF MiNaLab and other actors are working on so-called *organ-on-a-chip*, which is a technology that replicates the structure and function of human organs on tiny sensors, enabling laboratory studies and offering opportunities for drug development and personalized medicine.[34]

Aerospace, defence, and security

Semiconductors used in aerospace and defence must meet strict criteria for performance, dependability, and durability, especially under challenging environmental circumstances. When it comes to space applications, these semiconductors need to withstand intense mechanical and electrical pressures during both launch (vibrations and shocks) and space operations (radiation, solar wind, and temperature fluctuations).

While the Norwegian aerospace industry is relatively small, sensors produced in Norway are used both in commercial airplanes and in space applications. For commercial airplanes, MEMS sensors produced by Memscap measure pressure in some of the planes of Boeing and Airbus.[35] These sensors are highly sensitive and can pick up extremely small changes in altitude. In space applications, other sensors from Memscap have left the planet and are used in the Mars Rover.[36] Kongsberg Defence and Aerospace is another example of a substantial user of

[33] *It is important to note that the methodology is not intended to pick up all firms which are related to the semiconductor industry, but that it picks up many.*
[34] *See for instance https://norwegianscitechnews.com/2023/06/ground-breaking-knowledge-from-minute-organs-grown-on-microchips/ for more on this.*
[35] *See for instance https://www.tu.no/artikler/norskutviklede-sensorer-skal-kutte-jetmotorenes-drivstofforbruk/507074 (in Norwegian only)*
[36] *https://www.tu.no/artikler/norsk-teknologi-pa-mars/245034*

semiconductor technology.[37] They hold several patents within the field, for instance within electro-optics for space.[38]

Energy

The EU Chips Act highlights that the semiconductor industry is highly important for renewable energy, especially in the interplay between power generation and power transmission. As the energy mix becomes more renewable and less based on fossil fuels, it also becomes increasingly reliant on power which is dependent on uncertain and varying factors, most notably wind and sun. Semiconductors are essential for both power generation, transmission, and conversion. Especially for high voltage transmission grids, the EU considers semiconductors to be a key enabling technology.

The green transition will require a large build-out of renewable energy in Norway. The Norwegian government plans to allocate areas with potential for 30 GW of offshore wind production on the Norwegian shelf by 2040. This will be followed by plans to make substantial investments in the power grid, and especially the high-voltage grid. Over the next decade, the capacity of the power grid may need to be doubled. In addition, the government hopes to increase the production of green technology in Norway, including both battery and green hydrogen production. All these will most likely result in a substantial increase in the use of semiconductors in Norway.

In our mapping, we have identified few examples of companies in the energy sector. One possible reason for this may be that the energy companies in Norway are purely users of semiconductors, and do not themselves work much with the semiconductor industry, but this is uncertain. The companies that we have identified within the energy sector are mostly within the petroleum industry, and these companies primarily use MEMS sensors to identify oil and gas reserves.[39]

Wireless communications

Wireless communications is a key expertise of the Norwegian semiconductor industry. As mentioned in chapter 3, several of the largest Norwegian semiconductor companies specialise in low-power wireless communications, including the by far largest one, Nordic Semiconductor.

Wireless communications has become ubiquitous over the past few decades. According to the EU, communication is together with computing the largest segment of the semiconductor market, with revenues around 200 billion USD. Over 90 percent of this market is wireless communication.

The largest driver for wireless communications has been the growth in smartphones, but other factors such as the Internet of Things have also driven the development. The number of devices with SIM cards for the internet of things in Norway is shown in the figure below.

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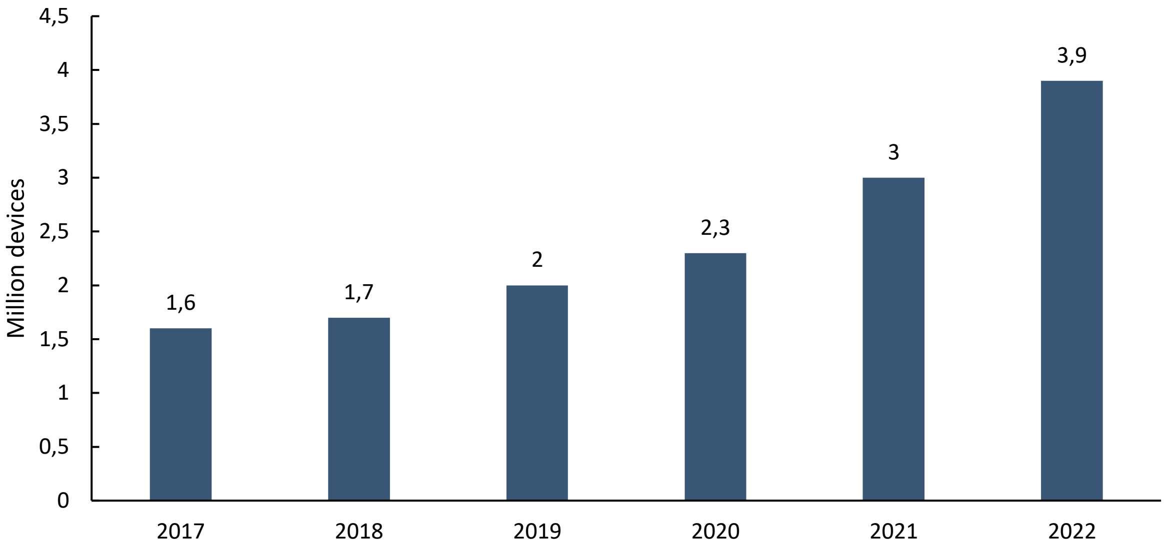
[37] Kongsberg in general is an important company within the application of semiconductors. Kongsberg Maritime for instance uses MEMS sensors in their Motion Reference Units ("MRUs"), used for measuring movement at sea. See for instance https://www.kongsberg.com/maritime/products/vessel-reference-systems/motion-and-heading-sensors/mru/#relatedArticles for more.

[38] See for instance https://www.kongsberg.com/kda/what-we-do/space/products/optics/electro-optics/

[39] See for instance https://sst.semiconductor-digest.com/2013/01/astar-and-pgs-to-collaborate-on-mems-sensor-for-oil-and-gas-applications/ for more on this.

Figure 23: Number of active SIM cards for IoT communication in Norway. Source: The Norwegian Communications Authority[40]



The number of active IoT devices in Norway has more than doubled from 2018 to 2022, with the largest growth coming in 2021 and 2022. The rise of IoT relies heavily on the advancements in the semiconductor industry. IoT devices require small, energy-efficient and powerful chips to handle data processing, communication, and sensor management.

As IoT proliferates across industries, the demand for specialized chips tailored to specific applications also increases. A variety of industries will be affected by IoT and developments within wireless communications. One core example is transportation, with intelligent transport systems (ITS), autonomous vehicles, efficient logistics, and real-time traffic management. A key Norwegian actor in this field is Q-Free.

Industrial automation

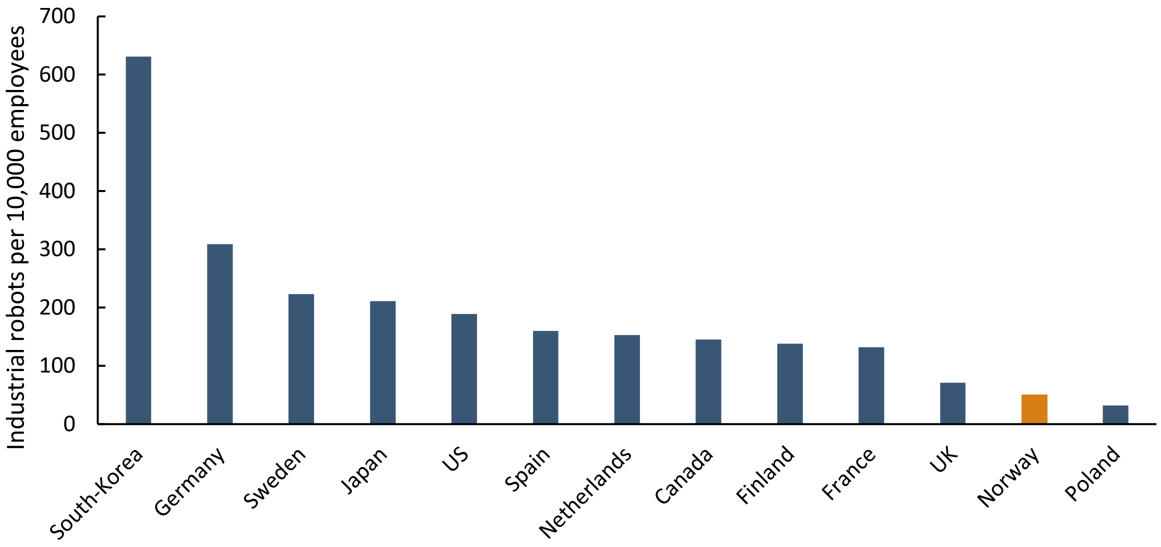
The EU's Chips Act points out that digitalisation and automation is currently modernising industrial manufacturing. One key trend is the "Industrial Internet of Things", which refers to the network of interconnected devices, machines, and sensors in industrial settings that collect and share data to enhance operational efficiency and enable advanced analytics. A second key trend is industrial robotics, which involves the use of automated machines and systems to perform tasks and operations in various industrial processes, improving efficiency and precision.

Together, these trends mean that there is a large potential in industrial automation, which the EU considers will likely include a large increase in the usage of microchips.

Some European countries have already started automating their industry substantially, but this is an area where Norway may be struggling. One measure for industrial automation is the use of industrial robots, which is shown in the figure below.

[40] *Collected from the Norwegian Communications Authority's annual report 2023.*

Figure 24: Relative use of industrial robots in manufacturing, per 10,000 employees. Source: IFR and World Robotics



Industrial automation comes in various forms, and robotisation is just one of them. However, this highlights the relatively limited level of industrial automation in Norway so far. The reason behind the scarcity of robots in Norwegian industries can potentially be attributed, in part, to the unique industrial structure of Norway. Many of the country's major industries, which heavily rely on raw materials, have not traditionally embraced robot usage. Embracing automated and robotized solutions more extensively may, however, be crucial for sustaining and bolstering competitiveness over the long run. According to McKinsey's calculations, about 60 percent of jobs in Norway's industrial sector have the potential for automation.[41]

While Norway lags somewhat in industrial automation, there are several success stories. One example of this is Tomra, which uses MEMS sensors and optoelectronics in their reverse vending machines. They hold several relevant semiconductor patents, and have also had extensive partnerships with SINTEF in using new forms of MEMS in their vending machines.[42] Another example is the installation of MEMS-based gas sensors at Equinor's gas refineries and oil rigs.[43]

Another set of companies that perform industrial automation are Electronic Manufacturing Services (EMS) companies. These companies offer outsourced electronics manufacturing and assembly services to businesses, handling the production of electronic components and products. In our mapping, we have identified several EMS companies, such as Kitron, Hapro and Norautron, which have received funding for R&D projects for industrial automation of the EMS process through Skattefunn. The EMS companies are also important suppliers of semiconductors and components for other companies. The chip crisis affected these companies substantially, as it reduced their ability to source chips both for their own production, and for their customers.[44]

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[41] *Where machines could replace humans – and where they can't (yet). Available here: https://public.tableau.com/app/profile/mckinsey.analytics/viz/InternationalAutomation/WhereMachinesCanReplaceHumans*

[42] *See for instance https://www.sintef.no/siste-nytt/2018/har-du-hort-om-piezomems-teknologi/ (in Norwegian only)*

[43] *See for instance https://www.gassecure.com/storage/assets/Documents/statoil-kalundborg-refinery-cs-9105813-en-1806-2-V2.pdf*

[44] *See for instance https://kitron.com/blog/electronics-manufacturing-component-market# or https://www.dn.no/teknologi/frykter-nytt-skrekkscenario-vi-kan-vare-tilbake-til-nokia-5110/2-1-1462631 (the latter in Norwegian only)*

Appendix B: Glossary

Semiconductor: A material that has the ability to conduct electricity, but only partially. Semiconductors are fundamental to the creation of microchips and electronic devices.

Microchip: A tiny piece of semiconductor material on which electronic circuits are etched or fabricated. Microchips serve as the "brains" of electronic devices, controlling their functions.

Integrated Circuit (IC): A complete electronic circuit that is built onto a single piece of semiconductor material. ICs can contain thousands to billions of transistors, capacitors, and other components, enabling complex functionalities within a small space.

MEMS (Micro-Electro-Mechanical Systems): Tiny mechanical devices integrated onto microchips, often using processes similar to those used to manufacture electronic circuits. MEMS devices can sense, manipulate, and respond to physical phenomena like pressure, motion, and temperature.

Optoelectronics: The study and application of devices that convert between electrical signals and light signals (photons). Examples include light-emitting diodes (LEDs) and photodetectors, which are crucial for technologies like displays, optical communication, and sensors.

Photonics: The science and technology of generating, controlling, and detecting photons (particles of light). Photonics is essential for high-speed data transmission, optical computing, and various applications in telecommunications and medicine.

Transistor: A fundamental electronic component that acts as an on/off switch for controlling the flow of electrical current. Transistors are the building blocks of microchips, allowing them to perform calculations and logic operations.

Silicon: The most commonly used material in semiconductor manufacturing. Silicon is abundant and has properties that make it an excellent semiconductor, allowing for the creation of reliable and efficient microchips.

Wafer: A thin, flat slice of semiconductor material (usually silicon) on which multiple microchips are fabricated simultaneously. Wafers undergo various processes to create intricate circuit patterns and components.

Fabrication: The process of creating electronic components and circuits on a semiconductor wafer. This involves multiple steps such as etching, deposition, and lithography to build the intricate structures that make up microchips.

Lithography: A crucial process in semiconductor manufacturing where light is used to create intricate patterns on a wafer's surface. This step defines the circuitry and components of microchips.

Packaging: The process of enclosing a microchip in a protective case and connecting it to the external world. Packaging ensures proper functioning, heat dissipation, and compatibility with various devices.

Semiconductor Fabrication Plant (Fab): A specialized facility equipped to manufacture semiconductor devices. Fabs are designed with cleanrooms to maintain a dust-free environment, critical for producing high-quality chips.

Fabless design: A business model in the semiconductor industry where a company focuses on designing microchips and outsources their fabrication to specialized manufacturing facilities known as foundries. This allows companies to concentrate on innovation without investing in costly fabrication plants. ("Fabless" being short for fabrication-less, i.e., without a factory)

Sensor: A device that detects and measures physical properties such as temperature, light, pressure, or motion. Sensors are integrated into microchips for various applications, including smartphones and environmental monitoring.

Appendix C: Methodology for the mapping

We have employed a comprehensive methodology for mapping the semiconductor value chain. Generating a complete dataset is more challenging in the semiconductor industry than for most other industries. There are no directly applicable industry codes under which most of the companies are in the semiconductor industry. As Ciani & Nardo (2022)[45] among others point out, a naïve approach using industry codes would lead to misclassifying companies, both including ones that are not part of the value chain and overlooking others that actually are. This complexity is very clear in Norway: the two industry codes with most semiconductor companies in Norway are "Other research and experimental development on natural sciences and engineering" (72.190) and "Other engineering activities" (71.129), which are both broad categories with a majority of companies not related to semiconductors.

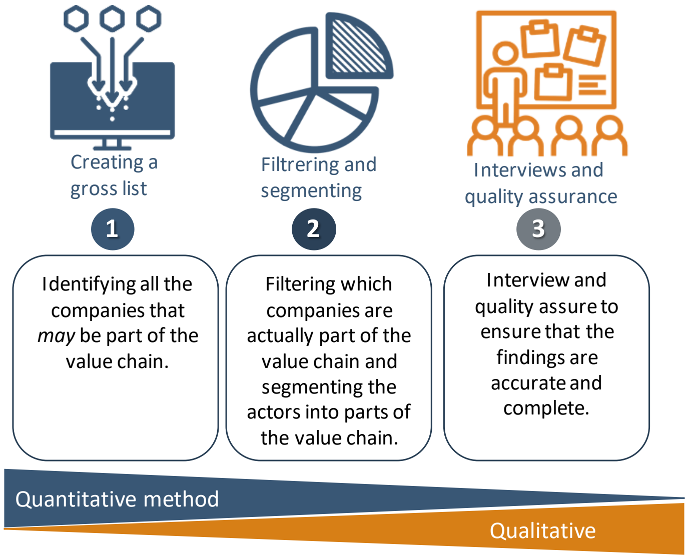
A second challenge is how broad the categorisation should be. The definition of the value chain could defined as so broad that almost all companies are part of the value chain – very few companies do not at all use semiconductors. Such a definition would be so broad that it has little meaning. We have opted for a more narrow definition of the industry: companies which perform of chip design, manufacturing or assembly, their specialised suppliers, as well as their immediate customers that assemble semiconductors into their own "unique" products, for whom this presents a competitive advantage.

For the latter, we limit ourselves to those for whom the unique products make up a substantial portion of their business activity. Companies such as for instance Tomra and Kongsberg utilise semiconductors for a competitive advantage, but this is not their primary business, and disentangling how much of their activity is semiconductor-related is not feasible in this project. These companies are therefore instead discussed in appendix A.

The process for the mapping is shown in the figure below:

[45] *Ciani & Nardo (2022): The position of the EU in the semiconductor value chain: evidence on trade, foreign acquisitions, and ownership*

Figure 25: Illustration of the process for mapping the semiconductor industry



To identify the companies in the semiconductor industry, we have utilised a broad range of data, both quantitative and qualitative.

- **Companies which have semiconductor-related patents**.
  We use data from Orbis Intellectual Property, which has information on which patents firms hold. The patent codes which are semiconductor-related are collected from an EU report "*Study on the changing role of intellectual property in the semiconductor industry*".
- **Companies with applications for R&D grants for semiconductor-related projects to the Skattefunn-programme.**[46]
  Skattefunn is a Norwegian government initiative that encourages research and development (R&D) by offering tax incentives to businesses undertaking eligible R&D projects. Through this scheme, companies can deduct a portion of their R&D expenses from their taxable income, reducing their tax burden and promoting innovation and technological advancement within Norway. In the applications to Skattefunn, companies write a text explaining what the R&D project is about. We use a language model to go through the over 65 000 Skattefunn applications to identify which are related to the semiconductor industry. We also use this to categorise which part of the industry the different companies are in.
- **Companies with relevant self-defined statutory purposes or self-defined activities.**
  All companies in Norway must self-report a statutory/corporate/statutory purpose with Brønnøysundregistrene, as well as provide a text explanation of their activity/industry. We use our language model to identify which firms have an activity or statutory purpose related to the semiconductor industry.
- **Menon's company database**
  Menon maintains a database of all Norwegian companies accounting data with substantial metadata going back to 2004, along with a categorisation of all companies into which industries they belong to.
- **Interviews with industry actors and universities.**

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[46] *The SkatteFUNN R&D tax incentive scheme is a government program designed to stimulate research and development (R&D) in Norwegian trade and industry. The incentive is a tax credit and comes in the form of a possible deduction from a company's payable corporate tax.*

We have interviewed several companies, professors at the major universities and NorFab to ensure that we have a proper understanding of the companies in the industry, and how the Norwegian value chain may best be categorised.

- **Lists of customers from SINTEF MiNaLab and companies having corporate partnerships with the universities.**
  We have received lists of which Norwegian companies have used the production facilities of SINTEF MiNaLab (only companies not bound by confidentiality), and spoken with several university professors about which companies they have worked with, and who their respective universities has interacted with in research projects.

Appendix D: Number of academics and students at select relevant research departments and studies

There are a little over 400 academic staff including professors, postdocs, researchers and PhD students working at the centres or departments we identified. It must be noted that this list is, however, not a complete list of university researchers within semiconductors in Norway. There are several other university departments in Norway that teach and study topics within the field of semiconductors. Also, not all academic staff in these departments study only semiconductors but many also work on related research topics.

Table 2 Number of academic staff in relevant research departments.[47]

	UiO **The Centre for Materials Science and Nanotechnology (SMN)**	NTNU **The department of electronic systems**	USN **The department for microsystems at University of Southeast Norway**	UiT **The research group Ultrasound, Microwaves and Optics**
Academic staff	**110**	**142**	**123**	**31**

Below, we list the number of students at the relevant programmes.

Table 3 Number of master's degree students in the relevant programmes.[48]

	NTNU **Nanotechnology**	NTNU **Electronics Systems Design and Innovation**	**UiO** **Renewable Energy and nanotechnology**	**UiT** **Applied physics and mathematics with a speciality in photonics**	NMBU **Photonics**	**USN** **Micro and nano systems technology**
Students	**80**	**220**	**90**	**60**	9	**30**

As mentioned in chapter 4, this is not an exhaustive list of students relevant for the semiconductor industry, as the students of many natural sciences and computer sciences are relevant for the industry, just with a need for specific training.

[47] *Numbers based on the employees listed on the departments websites (31.08.2023).*
[48] *Numbers of students is estimated based on the enrollment limits of the programs. For NMBU- photonics, we obtained exact number of students from the university itself.*

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