OVIN
AUTONOMOUS • CONNECTED • ELECTRIC

Ontario

OVIN INSIGHTS
Specialized Series

Ontario's Unique Position: Hardware Electronics and Semiconductors and Their Role in the Automotive and Mobility Sector

Quarterly Specialized Report

OCI
Where Next Happens

Table of Contents

Executive Summary

Semiconductors play an essential role in modern life, enabling advances in a multitude of areas – transport, communications, computing, gaming, healthcare, military systems, and clean energy, to name but a few. They are a vital component of all electronic devices, providing the functionality to process, store, and transmit data. One sector in which they play a particularly significant role is the automotive and mobility sector.

The end-to-end semiconductor lifecycle encompasses a wide range of processes from mining raw materials, processing, and refining to packaging. As such, a broad range of actors and players are required to ensure this ecosystem functions cohesively.

The semiconductor sector is expected to grow rapidly in the coming years, with the emergence of artificial intelligence (AI), the Internet of Things (IoT), and machine learning (ML) technologies providing new opportunities for market development.[1] It is expected to be a USD $1T industry by 2030.[2] In the automotive sector alone there is expected to be a tripling in demand for semiconductors by 2030, reaching a USD $150B market value, thought to be due to the increasing demand for electric vehicles (EVs).[3] This growth in the market has resulted in an estimated 1M additional skilled workers being needed in the semiconductor sector globally by 2030.[4]

The semiconductor supply chain is a highly complex, fragile network which can be vulnerable to global events such as extreme weather and geopolitical tensions,[5] due to semiconductor manufacturing currently being highly concentrated in a few countries. The sector also faces challenges around its impacts on the climate, in terms of carbon emissions and high water usage, and the need to transition to a low-emission economy.

There are several organizations and facilities based in Ontario that are playing a core role in driving Canada's semiconductor sector. The province is a hub for semiconductor design, with companies such as Teledyne DALSA and Onsemi choosing to base themselves here. Canada's only semiconductor-focused lab and incubator, ventureLAB's Hardware Catalyst Initiative, is also located in Ontario. ventureLAB is one of OVIN's Regional Technology Development Sites (RTDS), which enable SMEs to develop, test, and prototype their advanced automotive technologies and smart mobility solutions, and tap into advice, expertise, and knowledge around key areas of focus for the automotive and mobility industry. Taiwan Semiconductor Manufacturing Company's (TSMC) Design Centre is also located in the province. Ontario is also at the forefront of semiconductor research, with several leading electronics-related research programs in the province – including the University of Waterloo and the University of Toronto.

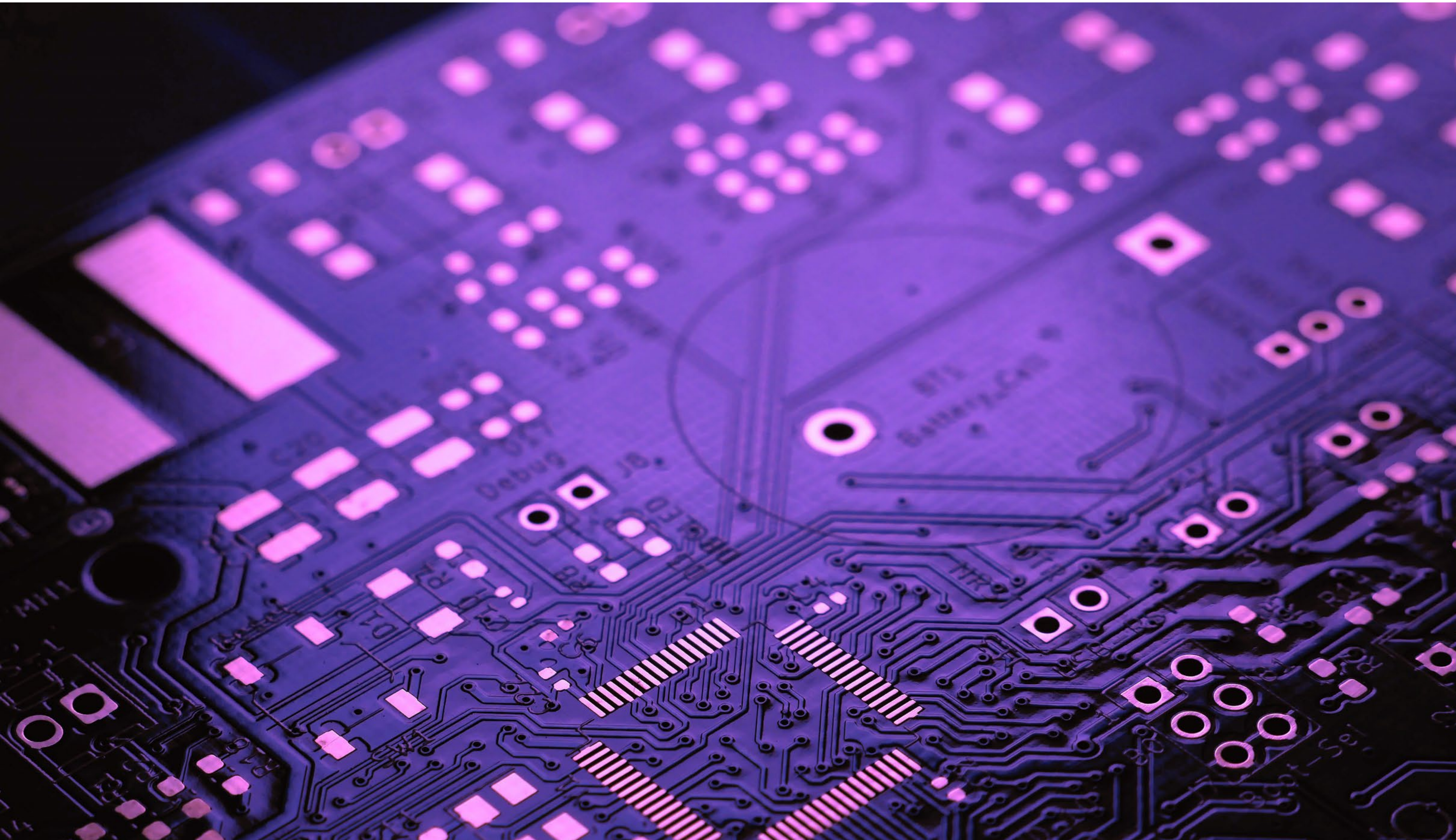
Ontario is uniquely positioned to be a central player in the semiconductor supply chain. The province is home to sought-after technical expertise and key industrial dependencies in automotive and advanced manufacturing. Ontario can play a leading role in the semiconductor space through its robust automotive sector, providing the link between chip manufacturing, EVs, and advanced automotive and mobility technologies.

This report presents an overview of semiconductors, highlights their role in the automotive industry, and examines Ontario's existing strengths in the semiconductor supply chain. This report also discusses global trends within the broader semiconductor ecosystem and identifies opportunities for Ontario to secure its role as a central player in multiple stages of the semiconductor lifecycle.

"Canada has the talent, capability, and tools to grow and expand in the hardware and semiconductor space. The benefits of growing this vital sector are numerous and include creating good jobs, boosting the economy, and standing out in the global market."[6]

– The Honourable Mélanie Joly, Minister of Foreign Affairs

1. An Overview of Hardware Electronics and Semiconductors and Their Application in the Automotive Industry



Chapter overview

Semiconductors are at the heart of nearly all electronics. Their lifecycle includes a careful balance between a range of processes and players. This section defines semiconductors and outlines the processes involved in each stage of the semiconductor lifecycle to facilitate understanding of the complexity of this ecosystem. Moreover, this section outlines the applications and benefits of semiconductor use in the automotive industry.

An introduction to semiconductors

Semiconductors are sets of miniaturized electronic circuits composed of active discrete devices (transistors, diodes), passive devices (capacitors, resistors), and the interconnections between them, layered on a thin wafer of semiconductor material.[7] Modern semiconductor chips are tiny, allowing electronic devices to become ever smaller and more compact.

Semiconductors can be made from pure elements, such as silicon or germanium, or compounds, such as gallium arsenide.[8] Sometimes referred to as "integrated circuits" (ICs) or "chips", their conductivity can be altered through a process called doping, where small amounts of impurities are introduced, depending on the needs of the electronic device.[9]

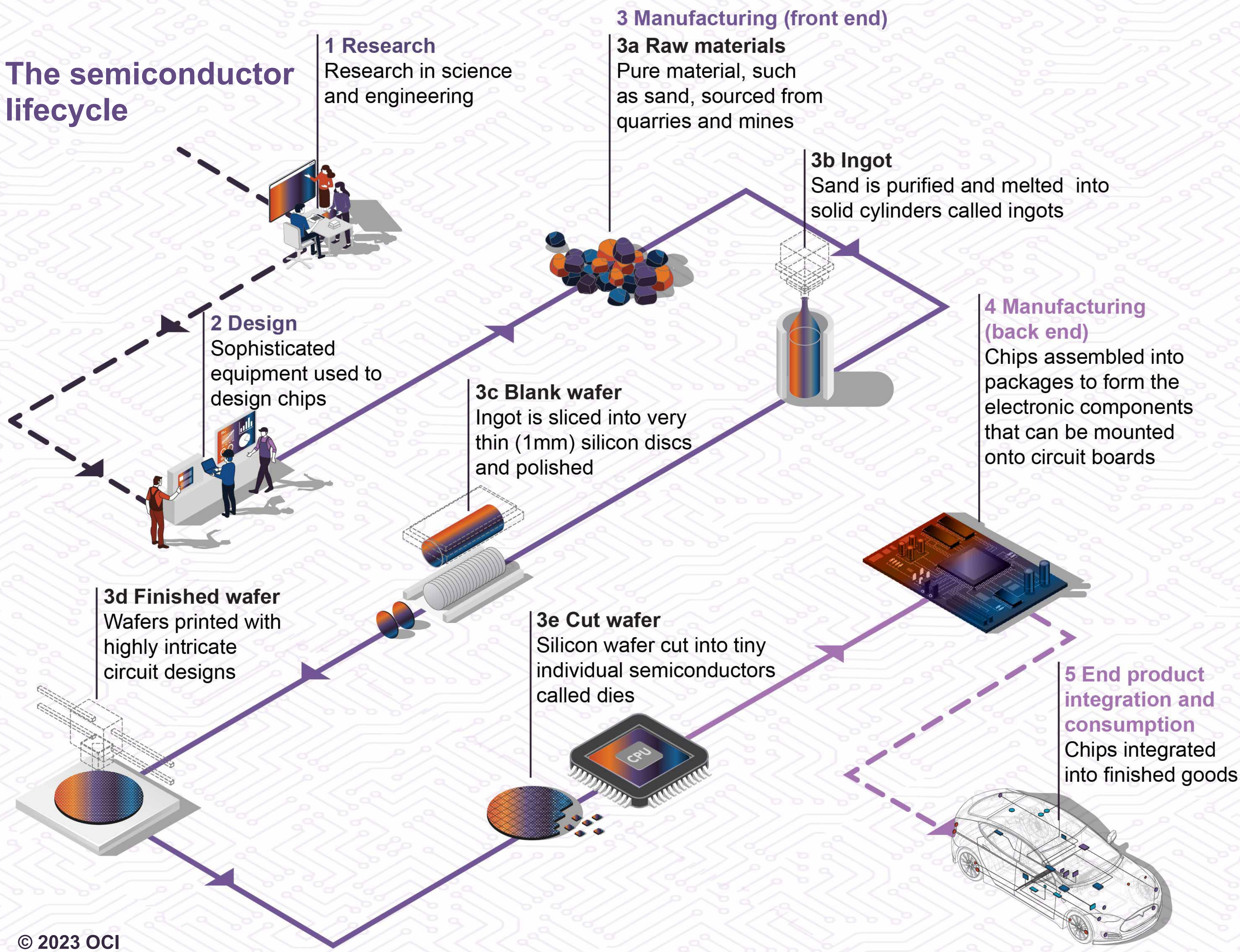
There are a vast number of uses for semiconductors, which can broadly be classified into three categories:

- **Logic** – serve as the "brains" of computing, functioning on binary codes (0 and 1).
- **Memory** – store information necessary to perform computation.
- **Discrete, Analog, and Other (DAO)** – transmit, receive, and transform information dealing with continuous parameters such as temperature and voltage.[10]

Semiconductor lifecycle

Semiconductor manufacturing usually begins with a research and design phase, followed by the production of silicon wafers. These silicon wafers are then packaged ready for integration into the end product. An overview of the semiconductor lifecycle is as follows:

1. **Research** – basic research in science and engineering to ensure innovation and competition.
2. **Design** – highly sophisticated equipment used to design chips for either specific or general product usage.
3. **Manufacturing (front end)** – silicon wafers produced and divided into chips.
   a. Raw materials – Pure material, such as sand, sourced from quarries and mines.
   b. Ingot – Sand is purified and melted into solid cylinders called ingots.
   c. Blank wafer – Ingot is sliced into very thin (1mm) silicon discs and polished.
   d. Finished wafer – Wafers printed with highly intricate circuit designs.
   e. Cut wafer – Silicon wafer cut into tiny individual semiconductors called dies.[11]
4. **Manufacturing (back end)** – chips assembled into packages to form the electronic components that can be mounted onto circuit boards.
5. **End product integration and consumption** – chips integrated into finished goods by Original Equipment Manufacturers (OEMs) and Electronics Manufacturing Service (EMS) companies and shipped worldwide to companies, retailers, and consumers.[12]


The semiconductor lifecycle
1 Research
Research in science and engineering
2 Design
Sophisticated equipment used to design chips
3 Manufacturing (front end)
3a Raw materials
Pure material, such as sand, sourced from quarries and mines
3b Ingot
Sand is purified and melted into solid cylinders called ingots
3c Blank wafer
Ingot is sliced into very thin (1mm) silicon discs and polished
3d Finished wafer
Wafers printed with highly intricate circuit designs
3e Cut wafer
Silicon wafer cut into tiny individual semiconductors called dies
CPU
4 Manufacturing (back end)
Chips assembled into packages to form the electronic components that can be mounted onto circuit boards
5 End product integration and consumption
Chips integrated into finished goods
© 2023 OCI

Semiconductors and their application in the automotive industry

Semiconductors have a vital role for a number of functions in the automotive industry, including driver assistance, electrification, communication, and entertainment. According to estimates, the average non-electric car has over 1,000 semiconductor chips.[13] Hybrid EVs can contain more than 3,500 semiconductors.[14] As demand for EVs and advanced automotive and mobility technologies – such as connected autonomous vehicles (CAV) – grows, so will the demand for semiconductors.

The benefits of semiconductor technology in the automotive industry

Semiconductors present a number of benefits in the automotive industry, the foremost being their ability to improve safety. They enable features such as alerting drivers when they are drifting out of their lane, automatic emergency braking and collision avoidance, blind-spot detection systems, and airbag controls.

Another benefit of having semiconductors in cars is their ability to improve connectivity, allowing drivers to use features such as route mapping and road closures using in-vehicle GPS, and identifying available parking spot locations.[15]

In addition to these safety and connectivity benefits, semiconductors also support advanced driver-assistance systems (ADAS), such as cruise control, active steering, and parking cameras and sensors. In this regard, semiconductors act as a bridge between software solutions and the vehicular functions of modern-day cars.[16]

Semiconductors can also be used in engine control systems, for both internal combustion engine (ICE) vehicles and hybrid vehicles. For ICE vehicles, they allow for more precise control of the engine, leading to improved fuel economy and lower emissions. In hybrid vehicles, they manage fuel combustion efficiency, and restore energy in the electric vehicles from regenerative braking systems.[17]

Regarding EVs, semiconductors deliver high efficiency by allowing for a substantial decline in power losses through their ability to turn on and off thousands of times per second. This enables batteries to last longer and extends range.[18]

Semiconductors have also enabled the introduction of new features – including more energy efficient LED lighting systems, wireless charging, and hands-free calls – along with more sophisticated capabilities, such as those needed for autonomous vehicles. As the industry continues to innovate and evolve, semiconductors will continue to expand new features and capabilities.

Semiconductors and their application in cars

Electrical

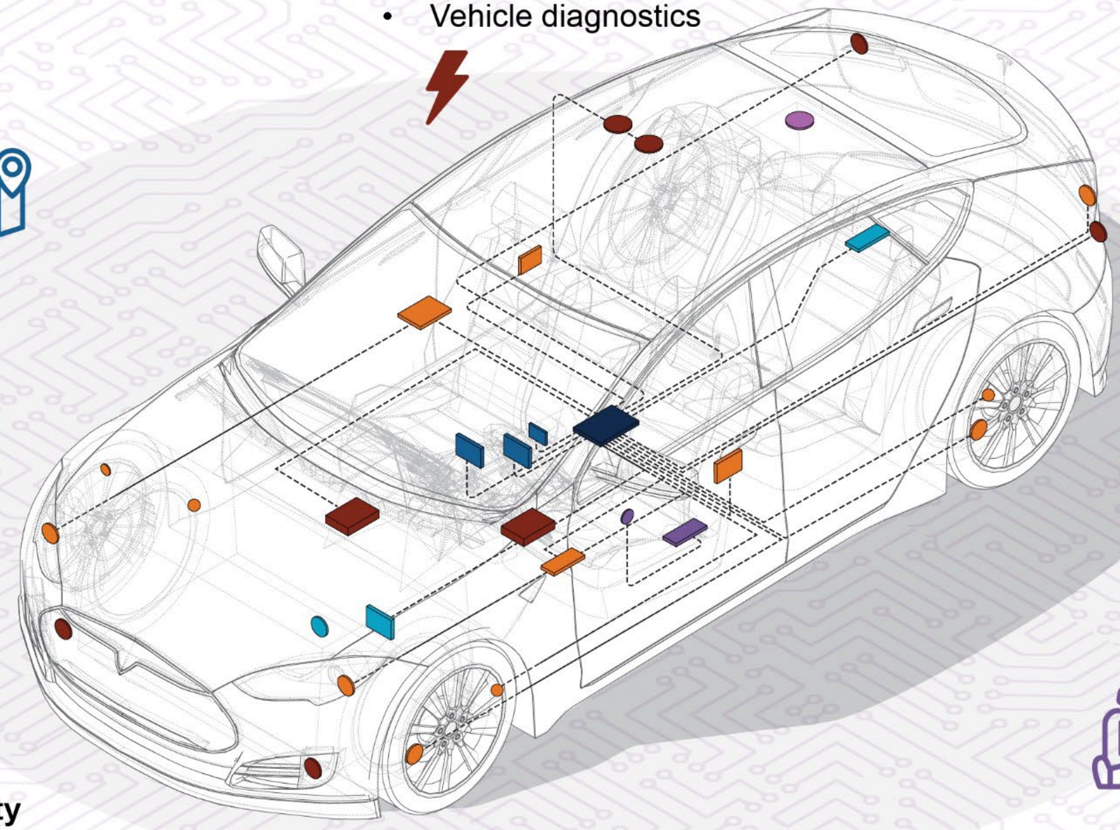
- Starter
- Lighting system
- Vehicle diagnostics

Infotainment

- Audio/video
- Driver display
- Navigation

Powertrain

- Engine control
- Fuel injection system
- Hybrid electric control
- Transmission control



Comfort

- Window/mirror controls
- Seat controls
- Climate control

Connectivity

- Controller Area Network (CAN)
- Broadband, Wifi,
- Bluetooth
- Over-the-air software updates

Safety

- Airbag controls
- Collision avoidance
- Parking assistance system
- Power locks
- Braking assistance system
- Tire pressure monitoring
- Traction control system

2. Global Trends in the Semiconductor Sector

Chapter overview

As the clean energy transition progresses, demand for semiconductors is forecasted to increase significantly due to their wide-ranging application in EVs, advanced automotive technologies, mobility solutions, and electrical components for renewable energy. In this context, several overarching trends, which are detailed below, are shaping the future of the semiconductor sector.

Supply chain diversification

The global semiconductor market is forecast to reach USD $1T by 2030, but semiconductor activity is currently highly concentrated in a few countries and companies. This is due to the technically complex nature of chips, and the requirement for high levels of investment in R&D and capital expenditure.[19] This concentration constrains access and reduces resilience, as made apparent by the chip shortage in 2020-2022 which forced the automotive industry to delay production plans.[20] As a result of this, policymakers across the world are taking action to make their domestic industrial capacity more self sufficient, whilst also recognizing that there will likely always be a need to have some reliance on manufacturing in other countries.[21]

Increasing geographic diversity of the supply chain to improve agility and resilience has been identified as a key operational expectation by semiconductor executives.[22] A supply chain mix of onshoring (in the same country), nearshoring (in geographies very close to the country), and friendshoring (in countries considered as friends or allies, which may be near or far), whilst also relying on offshoring, is likely to be the best approach.[23]

In 2022, the United States federal government introduced the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act, which provides funding of around USD $280B to strengthen domestic semiconductor manufacturing, design, and research.[24] A key output of the Act is the building of integrated supply chains across North America, with Canada and the United States pledging to create a bilateral semiconductor packaging corridor.[25]

Supply chain complexity

The semiconductor supply chain is highly complex, with a wide range of industries dependent on production running effectively. It is a fragile network which can be vulnerable to global events such as extreme weather and geopolitical tensions – such as the trade tensions between the United States and China[26] – due to semiconductor manufacturing currently being highly concentrated in a few countries.[27] Additionally, any disruption to the global supply chain could slow down the clean energy transition due to its reliance on semiconductor supply.[28] This imbalance between supply and demand can also impact the automobile and medical industries.[29]

Currently, there are four main types of business models throughout the supply chain: Integrated Device Manufacturers (IDMs) are involved in most production stages, fabless firms are only involved in design, foundries are focused on fabrication, and outsourced assembly and testing (OSATs) firms focus on back-end manufacturing.[30] Production is also supported by a broad network of materials, equipment, software design tools, and core intellectual property suppliers.[31]

It is a global ecosystem, with the components of a chip travelling over 40,000 kilometres before it is even integrated into the final product and crossing international borders 70 times or more before reaching the end consumer.[32] The lead time from a customer placing an order for a product containing a semiconductor chip to receiving the final product can take up to 26 weeks.[33]

The need for repeated imports and exports throughout the semiconductor lifecycle results in extended lead times and inhibits the ability of companies to make timely adjustments to market fluctuations.[34] However, the global nature of the supply chain enables the semiconductor sector to innovate and generate advancements through having access to a diverse talent pool.[35] It also allows for flexibility and adaptability to mitigate against risk, by enabling the sector to react to incidents and challenges in specific locations and shift operations to a different region.[36]

The journey a semiconductor makes around the world…

40K km

Distance a chip travels before it is integrated in the final product.

70+ border crossings

Made by semiconductor components during the manufacturing process before reaching the end consumer.

26 weeks

The lead time for receiving the final product containing a semiconductor from date of placing order.

Increasing demand for EVs

It is becoming ever clearer that the future of transport is electric. Semiconductors are a core component of EVs, enabling a multitude of functionalities that would not be possible without them. There is an increasing desire from consumers for more accessible and affordable EVs, as people are becoming more aware of the changes needed to curb climate change. According to KPMG's 2022 Auto Survey, 71% of Canadians would consider buying an EV the next time they purchase a car.[37] It is predicted by the International Energy Agency that there may be up to 240M EVs on roads globally by 2030.[38]

In support of this, the Government of Canada has taken action to make it more affordable for Canadians to purchase, charge, and drive EVs through additional investment in the Incentives for Zero-Emission Vehicles (iZEV) Program,[39] and the Zero Emission Vehicle Infrastructure Program (ZEVIP).[40]

Additionally, the federal government has set a mandatory target for 100% of new light-duty car and passenger truck sales to be low-emission by 2035.[41] The federal government also plans to introduce regulations requiring that 100% of certain medium-and heavy-duty vehicles sold be low-emission by 2040.[42]

Transition to a low-emission economy

Semiconductors are at the heart of the transition to clean energy. They are critical for solar energy systems, wind turbines, and other electric equipment used in the renewable energy supply chain.[43] Canada's transition to a low-emission economy is reliant on the use of semiconductors.

Semiconductors are also increasingly being used to make the electric grid more intelligent by means of smart meters, sensors, wireless communications, and control systems.[44] The use of semiconductors in the global renewable energy market is expected to grow with a compound annual growth rate (CAGR) of 8-10% through to 2027.[45]

Canada has committed to achieving a net-zero electricity grid by 2035. In support of this it is developing new Clean Electricity Regulations and complementary measures that will ensure remaining fossil-fuel generated electricity is phased out.[46]

However, manufacturing semiconductor chips is energy and water intensive, and so the sector is beginning to consider how it can reduce and mitigate its climate impacts in order to meet net zero goals.[47] A growing number of chip manufacturers are seeking to source energy from renewable sources, and are setting their own emissions reduction targets.[48] The world's largest chipmaker – TSMC – has pledged to reach net zero emissions by 2050 and, along with American company Intel, has committed to source 100% of its energy from renewable sources by 2030.[49] Energy consumption currently accounts for 62% of TSMC's emissions, and so it is actively seeking opportunities to invest in clean energy sources.[50] Another possibility for mitigating the climate impact of the sector has been identified: improving the efficiency of regulating air and water temperature, humidity, and pressure at semiconductor fabs, and using machine learning to turn off tools when they are not in use.[51]

The sector is also vulnerable to the impacts of climate change, with extreme weather events affecting production around the world. Taiwan is the biggest producer of semiconductors globally and is very vulnerable to these extreme weather events. For example, droughts in Taiwan impact the water supply and hydroelectric power supply of manufacturing sites.[52]

Skills and employment trends

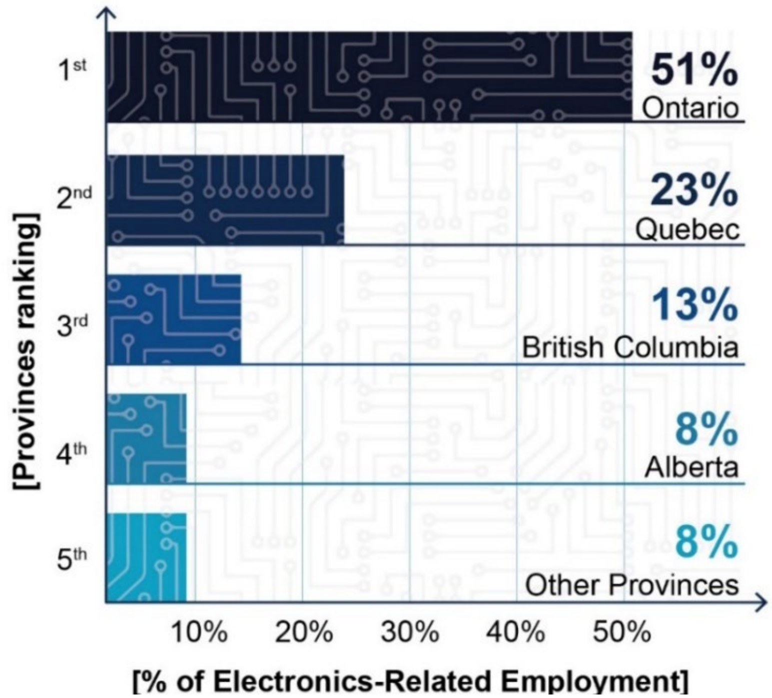
Semiconductor companies play a vital role in global value chains, and so they need the skills and talent required to continue to innovate and be global players.[53] The employment market is more competitive than ever, with the demand for technology skills predicted to rise 20% above 2019 levels by 2030 across all markets.[54] It is estimated that in excess of an additional 1M skilled workers will be needed in the semiconductor sector globally by 2030.[55]

In Canada, Ontario is leading the way in electronics-related employment with 51% of the market share – over 180,000 electronics-related jobs are based in Ontario.[56] Along with semiconductor and other electric component manufacturing, these include jobs in computer and peripheral equipment manufacturing, communications equipment manufacturing, industrial machinery manufacturing and computer systems design and related services. As the semiconductor market is expected to grow, companies will need to ensure they are attractive to new talent and can retain existing personnel.[57] In the United States alone it is estimated that 58% of new jobs in the semiconductor sector, across manufacturing and design, will risk going unfilled by 2030.[58]

Semiconductor jobs have a multiplier of 6.7, according to the Semiconductor Industry Association, meaning that for every direct job in the semiconductor sector, an additional 5.7 jobs are supported in the wider economy.[59] According to Canada's Semiconductor Council, "Canada's semiconductor sector creates close to 2 million indirect and direct jobs that are critical to our most strategic economic sectors of automotive, energy, health, agriculture, and advanced manufacturing and the underpinning for every digitally enabled industry."[60]

Between 2010 and 2020, employment in the Canadian electronics sector increased at a CAGR of 3.93% per year.[61] In 2018, 1.89% of all Canadian jobs were in electronics-related employment.[62] Canada's Semiconductor Council estimates that employment in the Canadian electronics sector will continue to grow year on year, with an expected growth rate of 0.26% per year up to 2030 for the semiconductor component manufacturing sector.[63]

Top provinces by electronics-related employment (2020)[64]



Global Success Story: Wales – addressing the semiconductor skills shortage

Located in South Wales and supported by Innovate UK – the UK's national innovation agency – the Compound Semiconductor Applications Catapult is working to identify skills gaps and future shortages in the sector, and to deliver solutions that will help build a specialized workforce.[65]

Through its Skills Academy, the Catapult has designed a suite of interventions to address gaps in the skills pipeline. These include leading three STEM (Science, Technology, Engineering, and Maths) outreach interventions targeting primary schools, and supporting a scholarship program to provide a bursary and year-long internship for Bachelor of Engineering and Master of Engineering students across five key technology areas.[66] In addition, the Catapult sponsors PhD research at the Computer Science Centre for Doctoral Training and the Sustainable Electrical Propulsion Centre for Doctoral Training.[67]

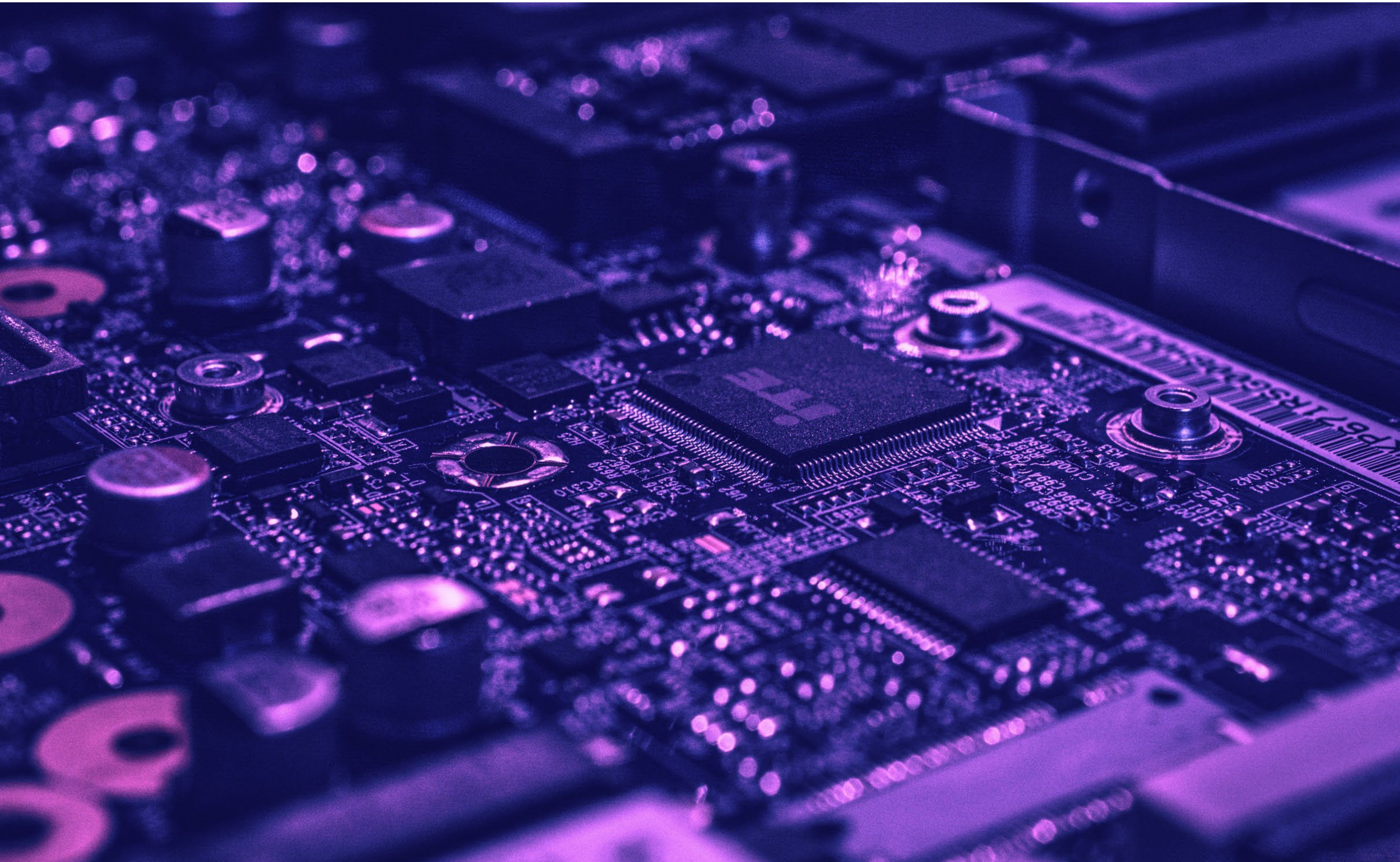
Global Success Story: United States – the CHIPS and Science Act

In 2022 the United States federal government signed into law the CHIPS and Science Act. As a result, a significant share of new semiconductor chip manufacturing capacity and research and development is expected to be located in the United States.[68]

The Act provides significant funding to enable the United States to continue its leading role in the semiconductor sector; USD $52.7B in spending is being targeted to boost American semiconductor research, development, manufacturing, and workforce development.[69] USD $200B is allocated for scientific research and development and commercialization, and USD $24B worth of tax credits have been allocated for chip production.[70]

The CHIPS Act, according to the Semiconductor Industry Association, has already stimulated around USD $200B in private investment, over 50 new semiconductor ecosystems projects, and 44,000 new jobs.[71]

3. Ontario's Unique Position in the Semiconductor Sector



Chapter overview

Ontario has the potential to play a key role in the global semiconductor sector. A growing level of influence suggests that Ontario could be at the forefront of semiconductor innovation. This section summarizes the current state of Ontario's semiconductor ecosystem, outlining its position in the market, contribution to employment, and the key actors and facilities located within the province.

Market position

Competitive advantage

Ontario has a key role in the design of semiconductors, with a concentration of design facilities being located in the province. This includes being home to a design facility for the largest semiconductor manufacturer in the world – TSMC's Design Centre in Ottawa.

Ontario also has a combination of top-quality electronics manufacturing talent – with companies such as Teledyne DALSA and Onsemi having manufacturing facilities in the province – clean energy supply, access to investment-ready sites, and a commitment to streamline the approvals process, making it an attractive destination for major investments.[72]

The province has a unique position in the semiconductor market due to key aspects of research infrastructure being located here – ventureLAB's Hardware Catalyst Initiative, which is one of OVIN's RTDSs, and several leading semiconductor related research facilities, such as the Vector Institute, and the National Research Council (NRC) Advanced Electronics and Photonics Research Centre.

OVIN is building capacity around automotive and smart mobility technology in the province through its upskilling and research funding programs, such as the R&D Partnership Fund, the Talent Development program and the Regional Future Workforce (RFW) program.[73]

Furthermore, four of the top ten universities across Canada in terms of electronics research and development funding are located in Ontario – University of Waterloo, University of Toronto, McMaster University, and Carleton University – providing a substantial talent pool for the semiconductor sector in the province.[74]

In terms of the global market, Ontario is a tariff-free zone for manufacturers and has access to free trade agreements with 51 countries, making it an appealing option as a base for semiconductor manufacturers.[75] Specifically, Ontario has free trade access to a number of leading semiconductor jurisdictions, such as South Korea and Japan – via the Canada-Korea Free Trade Agreement[76] and the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP), respectively.[77] Additionally, the Government of Canada has recently taken steps to invest in Ontario's semiconductor innovation and manufacturing, through a $36M contribution – via the Strategic Innovation Fund – to Ottawa-based Ranovus Inc.[78] This is to support a $100M project which aims to advance domestic manufacturing of semiconductor products and services.[79]

Ontario also has exploration potential for key materials involved in the manufacture of semiconductor chips – gallium and germanium.[80] This is supported by a thriving mining industry in the province.[81]

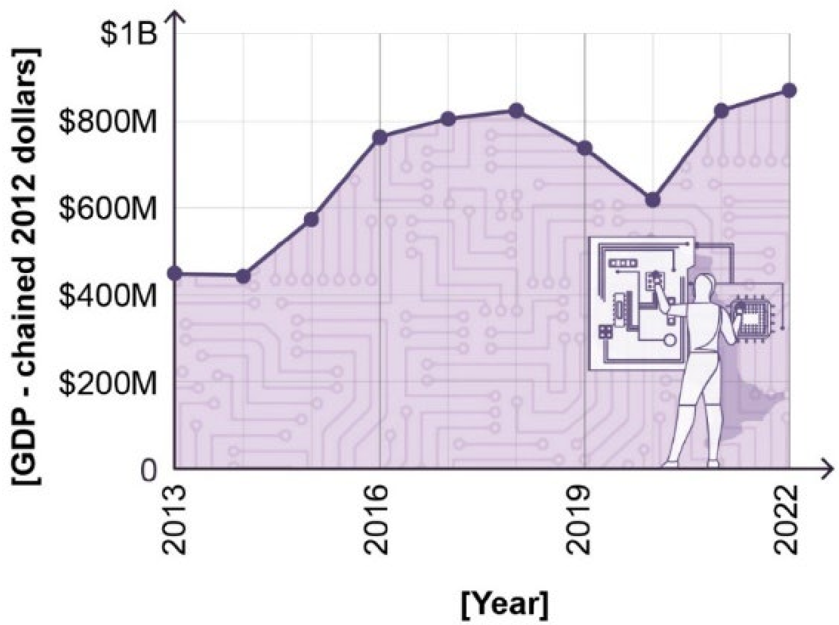
Increasing GDP contribution

The semiconductor sector in Ontario makes a significant contribution towards Canada's GDP, and continues to grow beyond pre-pandemic levels, having made a convincing recovery.

In 2022, the sector in Ontario contributed over $800M to the province's GDP.[82]

The Canadian semiconductor market overall is forecast to reach a revenue of $6.96B in 2023 and is expected to grow with a CAGR of 6.52% to $8.96B by 2027.[83] In comparison, the United Kingdom's semiconductor market is projected to reach a revenue of $2.95B in 2023, with a comparative CAGR of 6.11%, resulting in a market value of $3.74B in 2027.[84]

Ontario's GDP from semiconductor and other electronic component manufacturing (NAICS 3344)



Key facts…

$800M+

The semiconductor sector's contribution to Ontario's GDP in 2022.

$3.3B+

The value of Ontario's total semiconductor and other electronic component manufacturing imports in 2022.

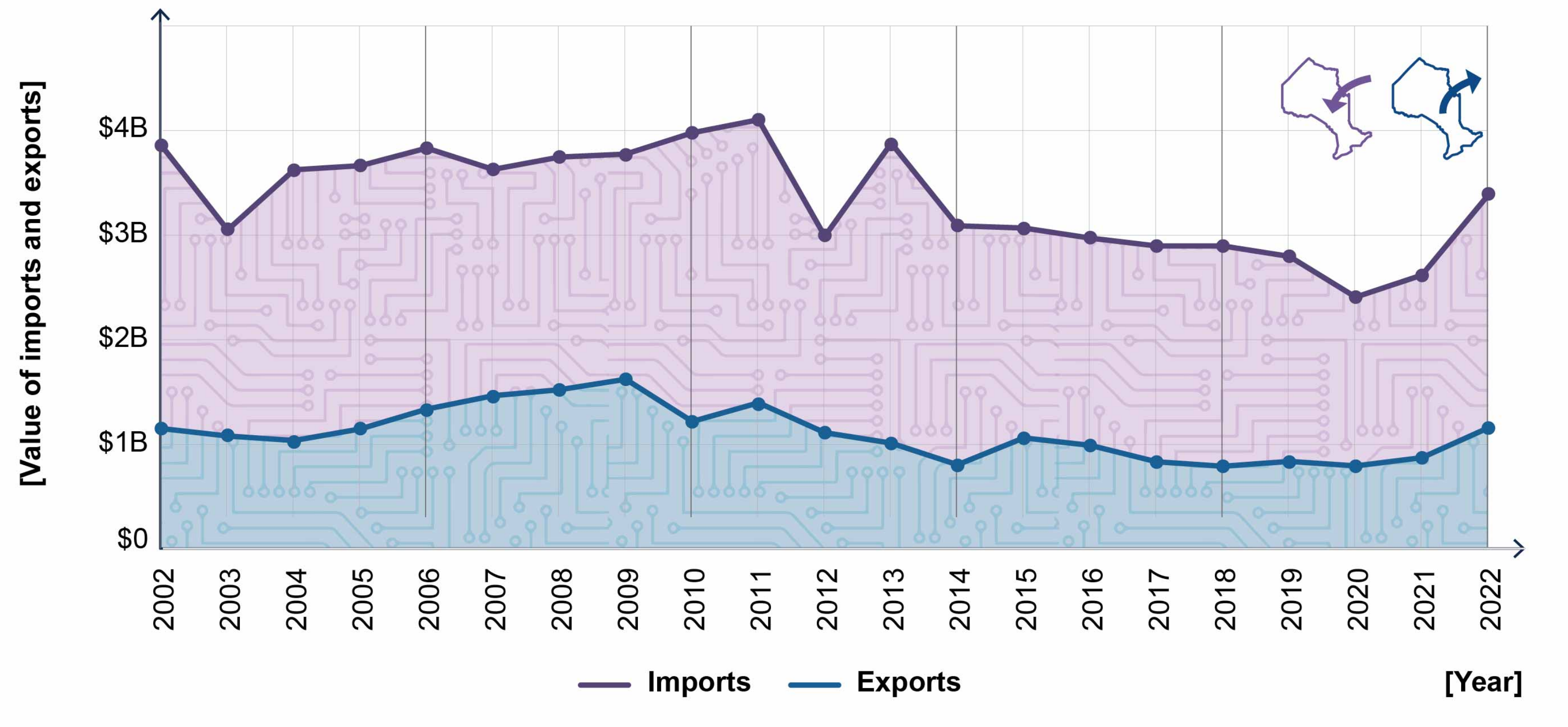
8.5K+

The number of employees working in Ontario's semiconductor and other electronic manufacturing sector in 2022.

2,000+

The number of tech ventures supported by ventureLAB.

Value of Ontario's total imports and exports in semiconductor and other electronic component manufacturing (NAICS 3344)[85]

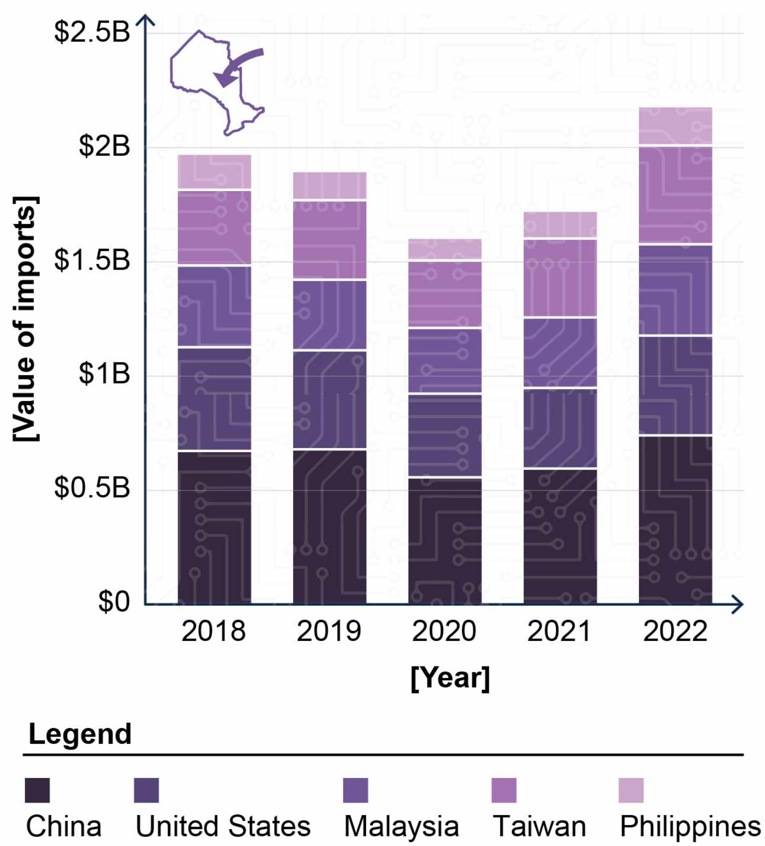


Expanding domestic and international exports

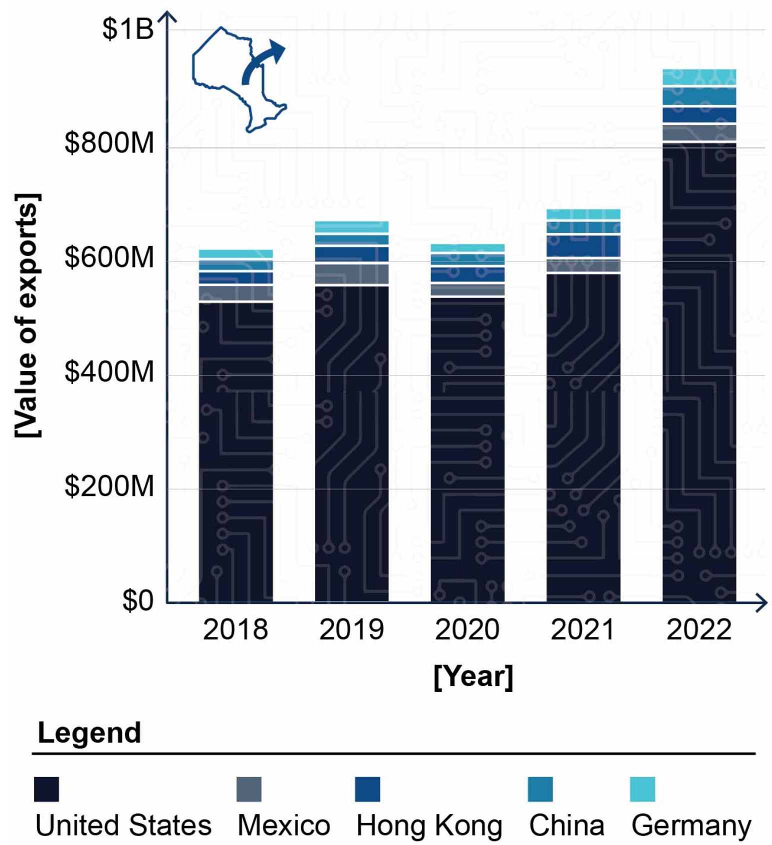
Ontario's international and domestic exports from semiconductors and other electronic component manufacturing (NAICS 3344*) are expanding. In 2022 total exports were valued at over $1.1B, with domestic exports valued at nearly $700M.[86] Following a global reduction during the COVID-19 pandemic due to supply chain challenges, the market in Ontario has made a strong recovery, and continues to grow. Total imports are also on the rise, valued at over $3.3B in 2022. As demand for semiconductors and the electronic devices they provide functionality for increases, Ontario can continue to play a key role internationally by increasing its capacity for exports.

* NAICS 3344 – the North American Industry Classification System code for Semiconductor and Other Electronic Component Manufacturing

Ontario's imports from top five countries over the last five years in semiconductor and other electronic component manufacturing (NAICS 3344) [87]



Ontario's exports to top five countries over the last five years in semiconductor and other electronic component manufacturing (NAICS 3344) [88]



Growing role in the international market

In 2022, Ontario's imports, in order of size, came from China (over $0.7B worth), followed by the United States and Taiwan (over $0.4B each).[89] Imports from the international market continue to grow each year, exceeding pre-pandemic levels by over $0.5B. Ontario exports semiconductors and other electronic components to a number of countries worldwide. The United States is Ontario's biggest market by a wide margin, with exports there valuing over $800M in 2022.[90] Exports to China, Mexico, Germany, and Hong Kong are valued at around $30M each. There is an opportunity for Ontario to build on what is already a strong export market, exploring opportunities in countries beyond the United States.

"The growing global hardware sector presents an exciting opportunity for Canadian innovators to step forward with their world-class products and add value to global supply chains. Our government is committed to ensuring growth and competitiveness in this vital sector by supporting Canadian businesses to seize the opportunities before us as we work towards a strong, inclusive, and digital economic recovery from COVID-19."[91]

- The Honourable Mary Ng, Minister of Export Promotion, International Trade and Economic Development and Member of Parliament for Markham–Thornhill

Ontario's Success Story: VSemi 3D autonomous parking system

VSemi – a Canadian technology SME based in Ontario – conducted a semiconductor research project with a Chinese Automotive OEM called SAIC Motor through OVIN's R&D Partnership Fund. The aim of the project was to develop a **3D autonomous parking system** that enables autonomous parking in various complex environments.

The project utilized 3D near range LiDAR and was a **revolutionary development** for empowering the vehicle with 3D awareness instead of traditional 2D understanding. Unlike the traditional single-point ultrasonic radar or 2D backup cameras, the 3D near range LiDAR unlocks the autonomous parking operation in previously problematic environments.

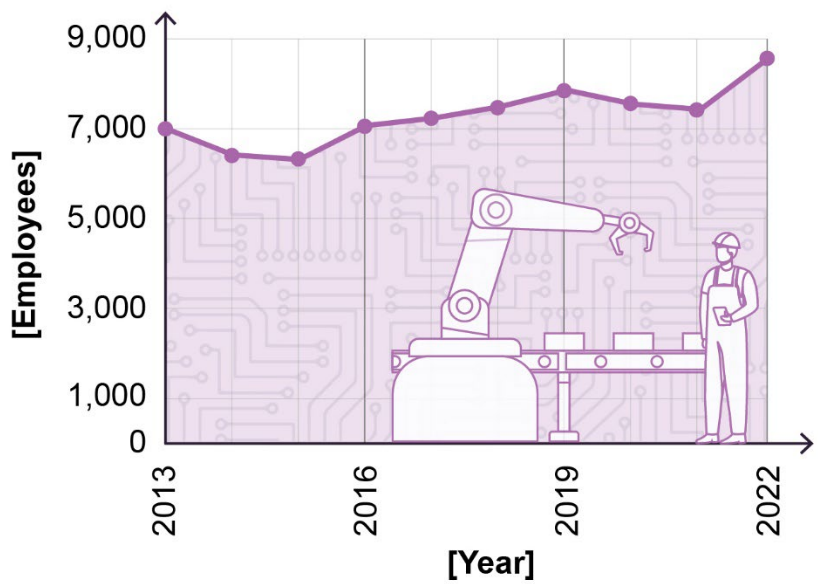
The project's success empowered the autonomous technology communities in Ontario with a novel solution and created opportunities to prepare for the next generation of autonomous vehicle technology. It also introduced the advanced Canadian semiconductor technologies to OEMs in China and Asia, bringing more business opportunities for Canada to collaborate and succeed globally.

Contribution to employment

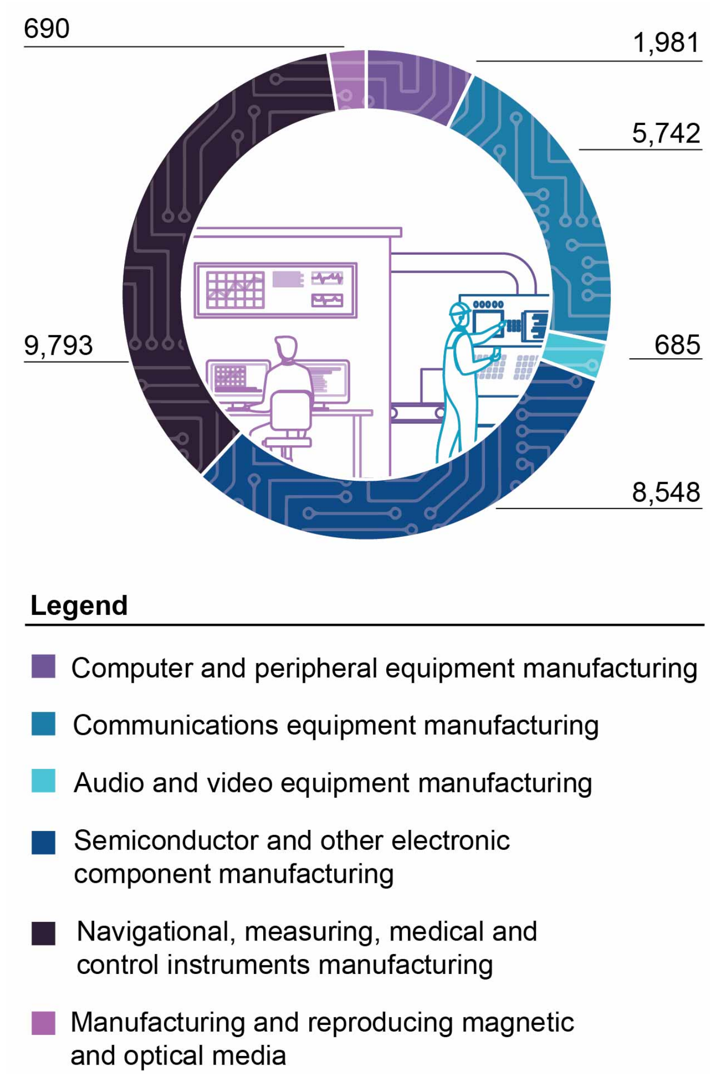
Rising levels of employment

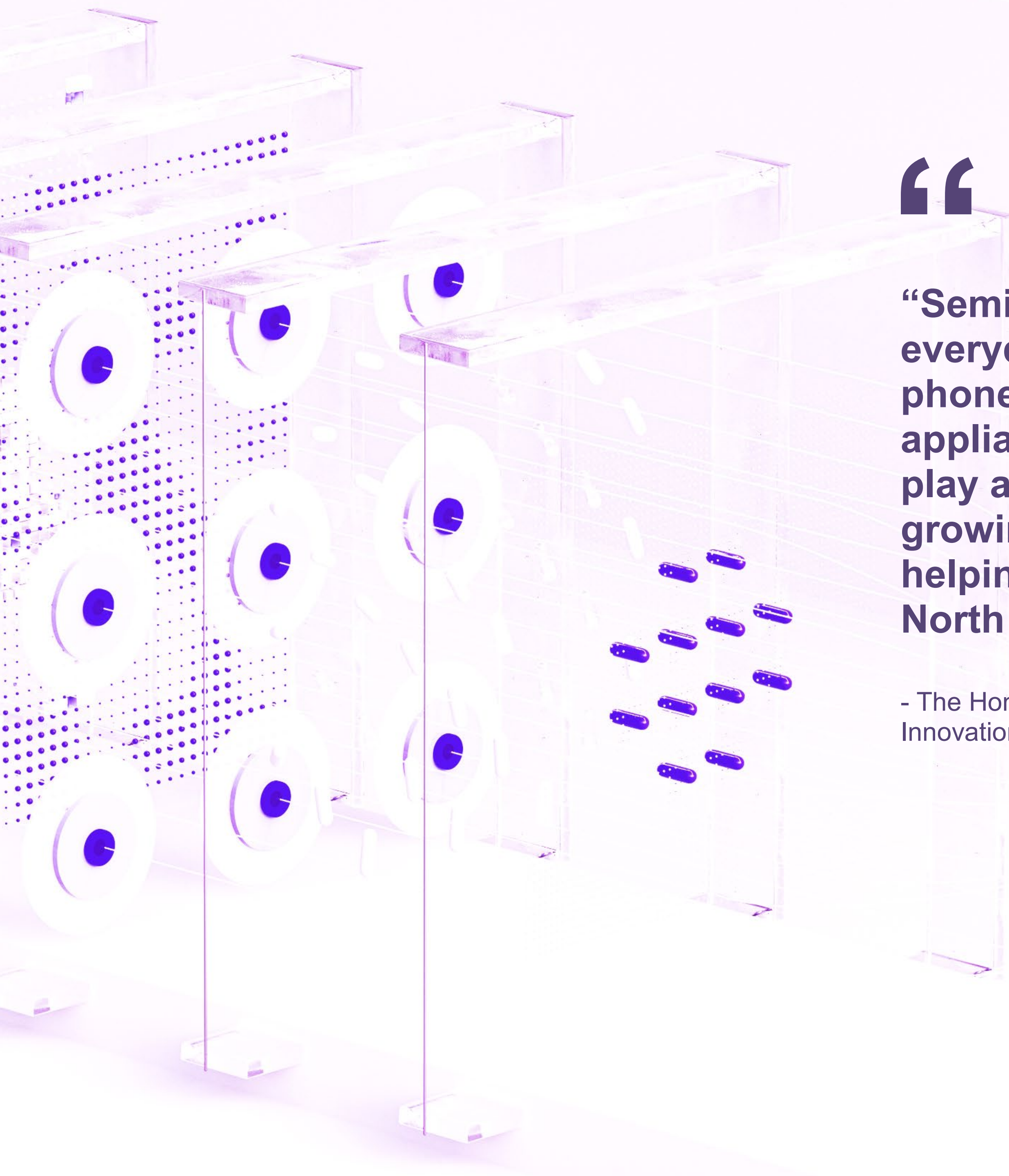
In 2022, over 8.5K people were employed in the semiconductor and other electronic component manufacturing sector in Ontario.[92] The number of employees working in the semiconductor manufacturing sector in the province has steadily grown since 2013, with recruitment picking up pace between 2021 and 2022, and showing resilience during the COVID-19 pandemic. This increased level of recruitment can expect to continue as the semiconductor sector grows, along with Ontario's reputation as a key player.

Employment in semiconductor and other electronic component manufacturing (NAICS 3344) in Ontario[93]



2022 breakdown of employment within computer and electronic product manufacturing (NAICS 334) in Ontario[94]





“Semiconductors are part of our everyday life. They are in our phones, our cars and our appliances...Canada will continue to play a leading role in the rapidly growing semiconductor industry, helping to strengthen and secure the North American supply chain.”[95]

- The Honourable François-Philippe Champagne, Minister of Innovation, Science and Industry

Ecosystem players

Industry drivers in Ontario

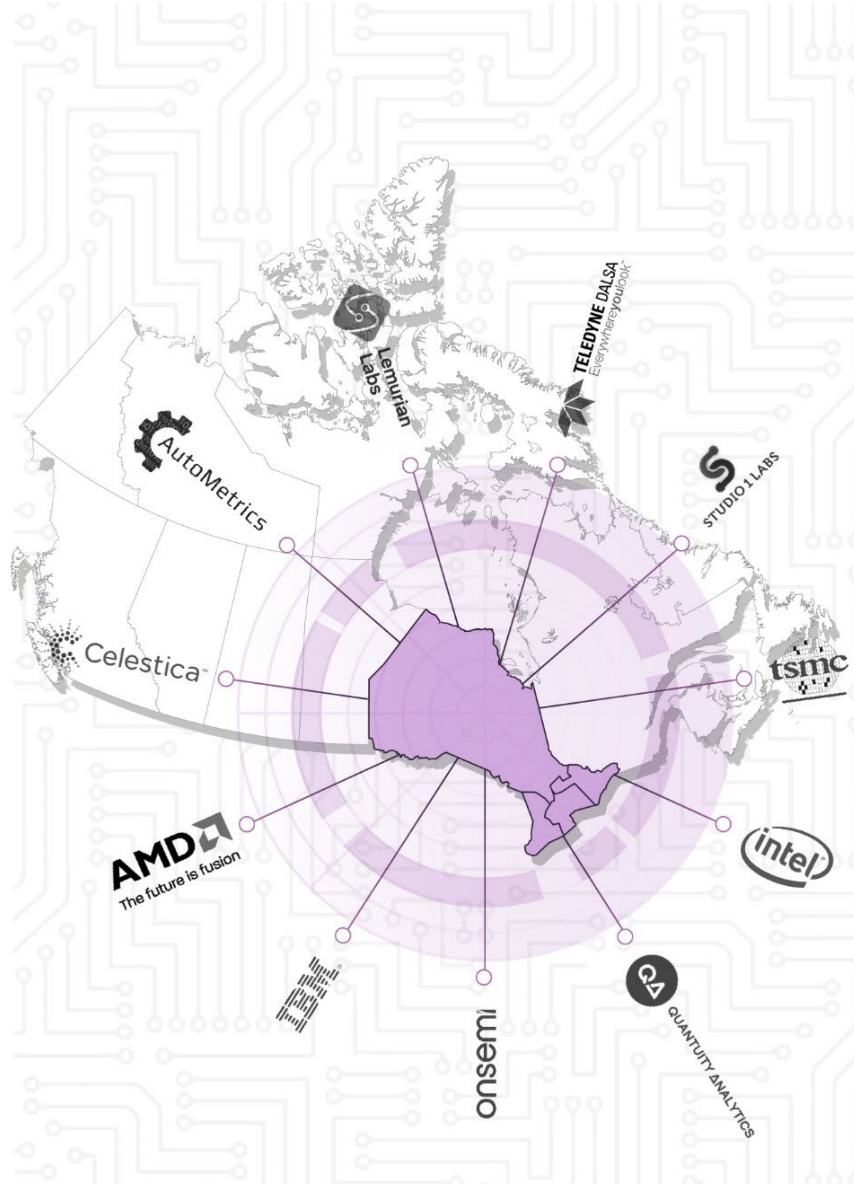
There are several organizations and facilities based in Ontario that are playing a core role in driving Canada's semiconductor sector. This includes ventureLAB, a leading technology development hub which has worked with over 2,000 tech ventures since 2011, providing support and direct connections for founders to raise capital, attract and retain talent, and commercialize technology and IP.[96]

ventureLAB is one of OVIN's RTDSs. These are located across Ontario, enabling SMEs to develop, test, and prototype their advanced automotive technologies and smart mobility solutions, and tap into advice, expertise, and knowledge around key areas of focus for the automotive and mobility industry.[97]

Ontario's unique labs

Ontario is home to Canada's only semiconductor-focused lab and incubator, ventureLAB's Hardware Catalyst Initiative. This initiative helps technology companies accelerate the time it takes them to reach the market, enabling Canadian hardware and semiconductor companies to not only grow and scale locally, but also to compete globally.[98] The Hardware Catalyst Initiative has enabled over $340M to be invested in Canadian technology companies.[99]

Ontario is also home to TSMC's Design Centre. TSMC works with innovators in the semiconductor sector, helping them transform their designs into functioning products – which can be manufactured at volume – by providing independent design and processing capability.[100]



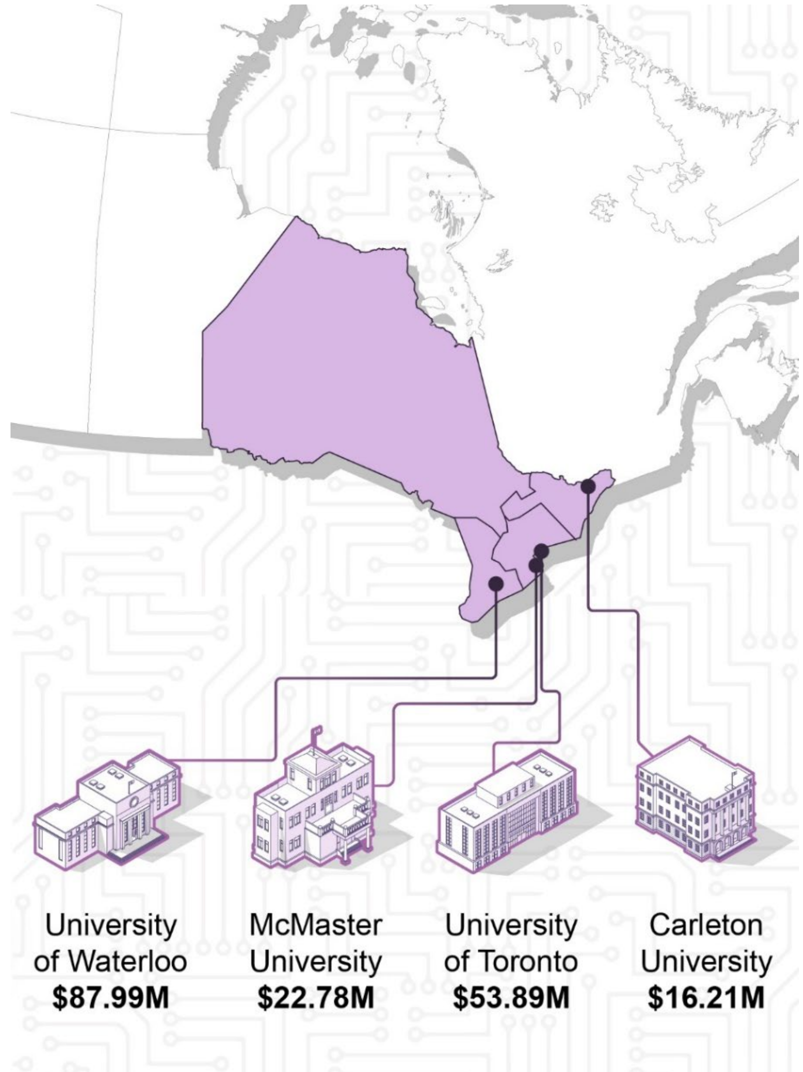
Organizations in Ontario

Ontario is home to sought-after technical expertise and key industrial dependencies in automotive and advanced manufacturing.[101] A selection of ecosystem players in Ontario are highlighted below.

- Teledyne DALSA – manufacturing company which specializes in integrated circuit and electronics technology, software, highly engineered semiconductor wafer processing, and machine vision for automotive manufacturing, with headquarters in Waterloo, Ontario.[102]
- Onsemi – semiconductor manufacturer, specialized in automotive solutions, with production scale assembly and test facilities in Burlington, Ontario, and design engineering in multiple locations in Ontario.[103]
- Celestica – design, manufacturing, and supply chain solutions company with an Electronics Testing Lab in Newmarket, Ontario.[104]
- IBM – global software company with Canadian headquarters in Markham, Ontario.[105]

Research institutions in Ontario

Ontario has a number of leading electronics-related research programs. Four of the top ten universities across Canada in terms of electronics research and development funding call the province home. The University of Waterloo leads the way in electronics-related research, with nearly $88M in Natural Sciences and Engineering Research Council of Canada (NSERC) funding between 2015 and 2020, followed by the University of Toronto, with nearly $54M.[106] Carleton University is also active in semiconductor research, with a focus on device design and novel device structures, and semiconductor sensors.[107] McMaster University has a research focus on microelectronic, nanoelectronic, and optoelectronic components and systems, as well as exploring low-cost manufacturing technologies for sensors and integrated sensor systems.[108]



Ontario's Success Story: OVIN Talent Development Program

OVIN's Talent Development Program provides support for PhD graduates and post-doctoral fellows, to work on industry-driven research and development projects related to automotive and smart mobility technology. A recent example of this is an image sensor research project with VSemi.

Present photodetectors in Complementary Metal Oxide Semiconductor (CMOS) image sensors are based on doped silicon P-N junctions – the interface between two semiconductor material types. While their performance has been sufficient for consumer applications, requirements for the imaging system and detector performance have been more demanding in recent years.

VSemi's backside illumination image sensor is driven by a novel, transparent conductive oxide/Si based heterojunction photodetector that offers the possibility to naturally align the light absorption region and signal collection region, and eliminates the need for special substrates.

Unlike standard CMOS image sensors, the new technology will have the pixel control/readout circuits and photodetectors built on either side of the substrate. The proposed research will develop optimal fabrication process for the pixel circuit components and the photodetector using a novel low temperature process for heterojunction photodetector fabrication.

This project will not only demonstrate the functional device but will also optimize the processes to improve large area uniformity, fabrication yield, and device reliability.

Regulatory and policy framework

Canada is seen as a desirable place for doing business, having been ranked among the top three countries in the G20[109] – the primary forum for international economic cooperation among the world's leading developed and emerging economies – in the last five years, and the easiest place to start a business in the G20.[110] It also has strong foreign trade relationships, providing semiconductor manufacturers and designers preferential market access via 15 free trade agreements to 51 countries.[111] In terms of semiconductors, Canada has over 100 national and multinational companies conducting research and development on chips, attracted by these trade agreements.[112]

Furthermore, Canada was the first country in the G20 to become a tariff-free zone for manufacturers, with the federal government eliminating over 1,500 tariffs on manufacturing inputs, machinery, and equipment.[113] This tariff relief helps to encourage innovation, improve productivity, and eliminate the administrative burden of complying with regulations, providing semiconductor manufacturers in Canada with a competitive advantage.

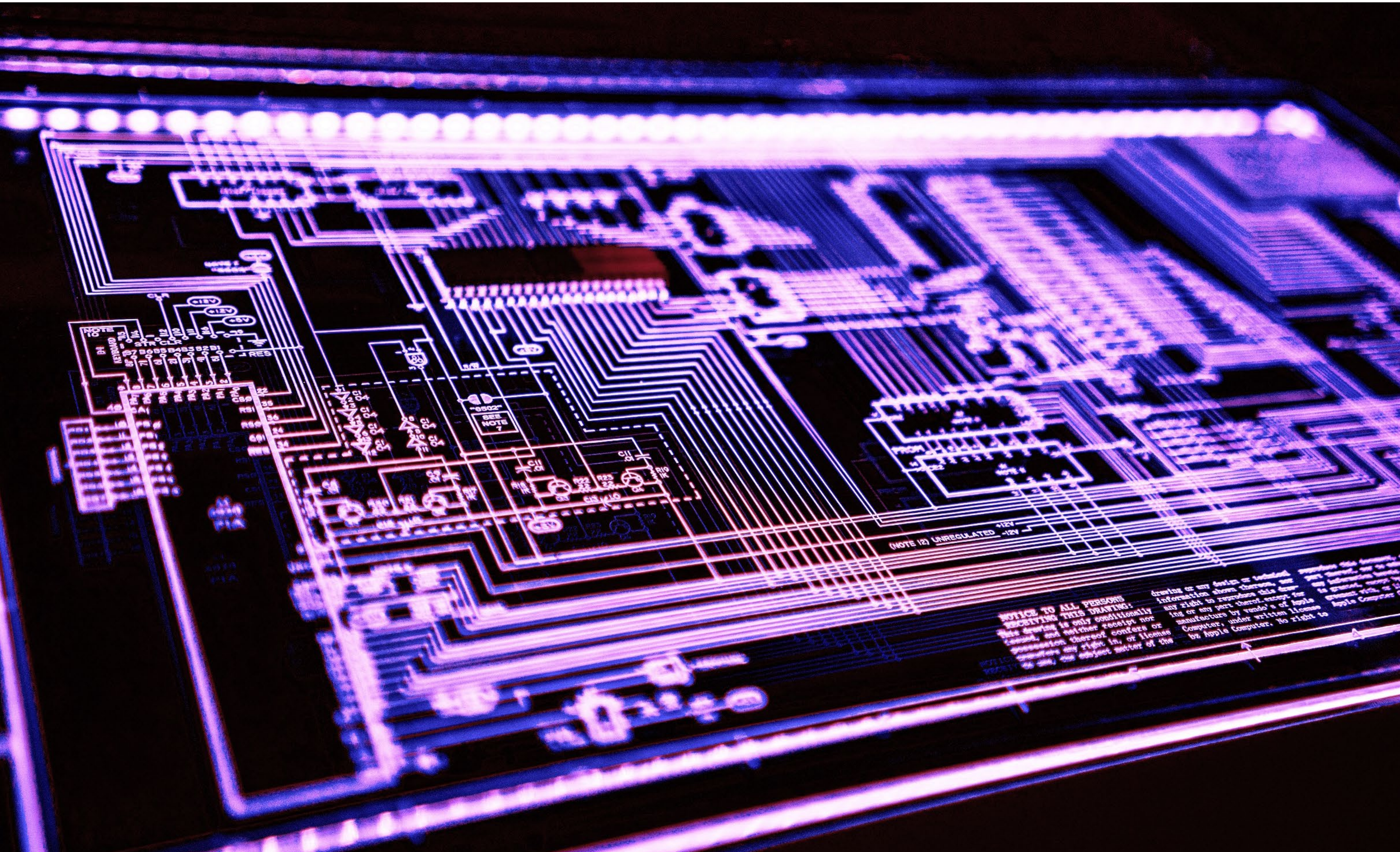
Moreover, the CHIPS and Science Act was signed into law in 2022 by the Biden-Harris Administration in the United States, which aims to build integrated supply chains across North America.[114] Off the back of this, Canada and the United States pledged to create a bilateral semiconductor packaging corridor in March 2023.[115]

In addition to being a desirable place for semiconductor manufacturers to operate, Canada has fostered a research and development environment that promotes innovation and competitiveness. This is apparent in it being the first country in the world to develop a national AI strategy.[116] Given the exponentially larger volume of data which can be stored and processed with AI applications, it is expected to have a significant impact on the design of future semiconductors.[117]

In 2022, the Government of Canada announced the Semiconductor Challenge Callout, a $150M fund to boost research and development, build on manufacturing strength, and position Canada as a critical global supplier of semiconductors.[118]

In addition to the nationwide trade agreements, tariff regime, and investment in research, Ontario has a general "open for business" attitude. It provides further support for businesses located in the province, by providing electricity to manufacturing companies at reduced costs through the Northern Energy Advantage Program (NEAP)[119] and the Comprehensive Electricity Plan.[120]

4. Opportunities for Ontario in the Semiconductor Sector



Chapter overview

As demand for semiconductors expands, global market resiliency is becoming increasingly important. The sector faces challenges related to climate impacts and the need to transition to a low-emission economy, along with a growing need for skilled workers, and supply chain diversity. Ontario is well-positioned to leverage its existing strengths not only to support sector stability and resiliency, but also to foster and secure its own position as a key player in the end-to-end semiconductor lifecycle.

The following section casts a light on some of the immediate opportunities to continue the development of Ontario's semiconductor ecosystem, along with interview highlights from industry experts around the trends and opportunities for Ontario.

Expand semiconductor research and design programs

Research plays a pivotal role in putting Ontario at the forefront of Canada's semiconductor sector. It is key to ensuring that the province continues to lead as a scientific and technological innovator. As mentioned in chapter 3, Ontario is home to a number of leading semiconductor related research facilities, such as the Vector Institute in Toronto, which focuses on AI, the Giga-to-Nanoelectronics Centre and the Institute for Quantum Computing at the University of Waterloo, and the NRC Advanced Electronics and Photonics Research Centre.[121]

Increasing funding to expand on these research facilities, and to cultivate the synergy between these scientific and technological advancements – such as AI and quantum computing, and semiconductors – is a key opportunity.[122] This will allow Ontario to build on its role as a specialized research and design hub, fostering innovation in the semiconductor sector, and leading the global drive for advancement in this domain. Building on Ontario's central role in taking research and early-stage design to the commercialization stage, there is a key opportunity to increase investment in this area, further expanding on assets such as the Hardware Catalyst Initiative.[123] This will help promote Ontario as a nucleus for acceleration of the semiconductor sector.

Continue to invest in the talent pipeline

Canada has a greater availability of qualified engineers in the workforce than any other G7 country – an informal grouping of seven of the world's advanced economies – and is the leading country in the G7 for higher-education sector research and development performance.[124;125]

There is an opportunity to ensure that the specialized skills required for designing and manufacturing semiconductors are developed and retained in Ontario. The semiconductor sector should be seen as an attractive choice for students and workers. This can be done through investment in scholarships, internships, and apprenticeships right across the semiconductor lifecycle, from research and design, to fabrication plant construction and maintenance, to packaging and assembly.[126]

There is also an opportunity to ensure that the semiconductor sector in Ontario is better connected to education institutions, so these skills are not lost to other sectors or locations. Canada's Semiconductor Council has recommended that the federal government build a national talent pipeline to ensure engineering students are enabled to become semiconductor entrepreneurs and innovators.[127] Ontario is in a position to lead this through its existing academic institutions and the companies and facilities based there that are part of the semiconductor ecosystem.

Ontario as a source of raw materials

Ontario has a thriving mining industry, with 35 active mining operations producing $13.5B worth of materials in 2022.[128] Gallium and germanium, key materials in the manufacture of semiconductors, have exploration potential in Ontario but are not currently produced here.[129] Building on Ontario's reputation as one of the top jurisdictions in the world for mineral exploration spending, with $989M invested in 2022, there is an opportunity to concentrate research and exploration on the potential of Ontario as a source for gallium and germanium.[130]

China is currently the leading producer of both materials; 60% of the world's germanium[131] and 80% of gallium.[132] China is now restricting exports of these materials, which may in the shorter-term affect production levels of semiconductors, but in the longer term presents an opportunity for Canada – and Ontario in particular – to explore mining potential with a view towards establishing itself as a key producer.[133]

Beyond the raw materials needed to create the silicon wafers, there is also an opportunity for Ontario to explore its supply of high purity chemicals and the materials required for other key stages in the semiconductor manufacturing lifecycle, such as lithography, cleaning, or etching.[134] This will support the province in onshoring the manufacture of chips, strengthening the domestic market, and reducing reliance on external players.

Invest in technological advancement

Ontario's strength in semiconductor research and design can be further supported by building on specialities in other technologies, such as those that rely on chips to operate. This includes EVs and sensors.[135]

Ontario has a robust automotive industry, which has been built on a strong foundation of research and development. Multiple research centres, development sites, and innovation networks are situated in the province, supporting innovation and the commercialization of new technologies, particularly within the EV sphere. The Centre for Hybrid Automotive Research and Green Energy Lab at the University of Windsor is simulating and testing EVs to obtain practical insights in order to inform EV development.[136] The Waterloo Centre for Electrochemical Energy at the University of Waterloo is a hub of electrochemical storage research which is helping to develop more efficient and environmentally friendly energy technologies for portable electronics and EVs.[137]

Ontario also funds research and development led by SMEs through OVIN's R&D Partnership Fund, which provides funding to support development, testing, and validation of all advanced auto and smart mobility technologies, including EV and battery-focused technologies.[138] Furthermore, Ontario led Project Arrow, which was an initiative launched by the Automotive Parts Manufacturers' Association in partnership with OVIN, to develop and build the first all-Canadian low-emission vehicle.[139] The objective of Project Arrow was to accelerate development of next-generation electric, connected, and autonomous vehicle and mobility technologies.[140] This project highlights Ontario's potential in being at the forefront of technological innovation.

Sensor and micro-electromechanical systems (MEMS) technology has many wide-ranging applications, such as automotive, agriculture, and medical devices.[141] By supporting innovation in these technologies, Ontario can continue to expand on Canada's strength in semiconductor research and design.[142] Design engineering and production scale assembly and test facilities for sensors and MEMS are located in Southern Ontario. The province is also at the forefront of research in this domain, with the

University of Waterloo being home to the Sensors and Integrated Microsystems Laboratory,[143] and the Nano and Micro Systems Laboratory.[144]

Developing robust and resilient domestic supply chains in these areas can be supported by the province through its proven expertise in research. Increasing investment in research and development of technologies in the province will solidify Ontario's role as an advanced manufacturing hub and encourage talent development.

Facilitate the transition to a low-emission economy

Semiconductors play a core role in the transition to a low-emission economy, through their contribution to the renewable energy supply chain. The production of semiconductor chips, however, is energy and water intensive. There is an opportunity, alongside facilitating the transition to a low-emission economy, for innovation in the semiconductor manufacturing process to reduce carbon emissions and water use.[145]

Ontario is already recognised as a clean manufacturing hub, through the implementation of the province's Low Carbon Hydrogen Strategy and the Hydrogen Innovation Fund, which was announced in March 2023.[146] It also has the largest cleantech industry in Canada, with major innovative advances taking place in the province.[147] Ontario is therefore well-placed to lead the way in exploring options to reduce the impact of semiconductor manufacturing.

Industry expert insights

The following section presents highlights from interviews with industry experts around their insights on trends and opportunities for Ontario in the semiconductor sector.

The experts

- Avinash Persaud **-** Vice President of the Hardware Catalyst Initiative at ventureLAB
- Mark Donaldson - Founder and CEO of Quantuity Analytics Incorporated
- Professor Wai Tung Ng - Professor at the University of Toronto
- Chris Ouslis - Chair of the Alliance for Semiconductor Innovation Canada (ASIC)
- Cormac O'Connell - Director of the Ottawa Design Centre for TSMC

The key questions

1. What do you consider to be the key global trends in the semiconductor sector?
2. What do you see as the key opportunities and challenges facing the semiconductor sector in the future?
3. What role can Ontario play in the global semiconductor sector?

Avinash Persaud

Avinash Persaud is the Vice President of the Hardware Catalyst Initiative at ventureLAB, a leading global founder community for hardware technology and enterprise software companies in Canada. Avinash draws on his expertise and experience in semiconductors to encourage the development and commercialization of semiconductors, sensor technology, and microelectronics.

Interview #1

"We are going to see more and more localized processing, or intelligence on the edge of the network, rather than the transmitting of data from a device to the cloud and back to the device. Localized processing will remove throughput or network outage concerns associated with sharing data with the cloud. Certainly with vehicles we cannot entertain the risk of network outages impacting data processing. A lot of the devices that will leverage localized processing are battery operated and need to use power very efficiently. Instead of general-purpose microcontrollers or processers, we are now seeing more purpose-built semiconductors and sensor technology required to make operations more efficient."

"Every company I've spoken with has indicated that the availability of talent is a key determiner when selecting where to build a new foundry. If we are a talent magnet for employees with the right training and experience, we can rebuild our semiconductor industry."

"Industry and academia can work closer together to shorten the time between graduating from an undergraduate program and becoming a fully contributing engineer or technologist by identifying opportunities for cross collaboration earlier in students' educational careers."

"Canada's immigration policy should single out people with semiconductor experience as key professionals that are needed."

"Manufacturing jobs in the semiconductor industry are sticky jobs. They tend to stay for a long time because of the large investment in infrastructure. Once you've set down the buildings, you will start to see an expansion of semiconductor skills because you are bringing talent together and creating an opportunity."

"Our investments in semiconductors will not be starting with a blank slate. We are investing in complementary technologies, like electric-vehicle batteries, that will need power semiconductors. We can invest in an evolutionary path that makes logical sense."

"Just like any investment for the future, we need to invest in the semiconductor industry now in order for results to be seen in the future. We can leverage our natural resources, but we cannot be considered a resource country for the rest of the world moving forward. We need to be building our knowledge and economy using the amazing brain power this country has. We can be second to none if we are committed to doing this."

Mark Donaldson

Mark Donaldson is the Founder and CEO of Quantuity Analytics Incorporated, an Ontario-based start-up serving the needs of the commercial trucking and transportation industry by providing intelligent Internet of Things (IoT) devices that save valuable time, meet or exceed regulatory compliance, promote vehicle and operator safety, and reduce operating risk.

Interview #2

"One of the biggest trends in the semiconductor industry is Generative AI or Edge AI. Companies have had to redesign their chips from the ground up to include packaging or chip dyes that include ultra-efficient CPUs, neural processing units to accelerate AI models, and digital signal processors so you can provide customized Edge AI inference. This helps to take the load off of sending the data to the cloud, performing inference on the cloud, and sending info back, which is very energy intensive and creates data privacy risk."

"Ontario can create policies and incentives that encourage major manufacturers to build in Ontario, thereby reducing risk and spreading the semiconductor supply chain throughout NATO-allied nations and encouraging economies of scale that lower product costs and benefit the consumer."

"One of the most important global trends in semiconductor manufacturing is onshoring or friendshoring. Many countries are trying to reduce geopolitical risks through local manufacturing and packaging."

"Ontario's stable political environment, lack of extreme weather events, mineral-rich resources, and steady water supply make it a prime candidate for semiconductor manufacturing."

"We need to be making chips in Canada. To do that, we need to have a culture around creating a pipeline from academia to industry to make sure that students are encouraged to look at job opportunities around the semiconductor industry, not just in chip design, but in chip engineering as well."

Interview #3

Chris Ouslis

Chris Ouslis currently works with the National Research Council's Industrial Research Assistance Program and is the Chair of the Alliance for Semiconductor Innovation Canada (ASIC). He previously founded two companies focused on semiconductor design and manufacturing.

"Semiconductors are in everything. They give us the ability to innovate in every sector from sustainability, to health, to the automotive industry."

"While artificial intelligence technology is based in software, some of it is now going into chips and hardware to either speed up processing or conduct processing without the cloud."

"One of our key strengths in Ontario has always been education. The excellent education leads to some very, very good semiconductor engineers."

"Ontario has a cluster of companies that are particularly skilled in developing high-speed digital interfaces that allow data to be communicated into and out of chips electronically and optically (via lasers). That is incredibly important today given that artificial intelligence relies on enormous amounts of data. Although this is a tiny function on a bigger chip, it has a large role to play in linking a chip and the rest of the world. This element adds huge value, and Ontario universities provide a solid education that supports that very particular sector."

"Vehicles in the future will be very different from vehicles today. They will still transport people, but they will do so autonomously and electrically, working in concert with all of the other vehicles on the road. I think that Ontario can play a big role in supporting this future vision of what a vehicle can be by leveraging our niche strength in designing the high-speed digital interfaces that play a critical role in sharing data between devices, between vehicles, and to central systems."

"We need to bring back semiconductor manufacturing jobs in order to strengthen national security and our geopolitical position. We can certainly achieve greater independence, greater strength, and greater benefits by increasing semiconductor manufacturing here."

Cormac O’Connell

Cormac O'Connell is the Director of the Ottawa Design Centre for TSMC, the world’s leading dedicated semiconductor foundry. At the Ottawa Design Centre, Cormac oversees work related to memory compilers and application-specific integrated circuits (ASIC) into next-generation processes.

Interview #4

"A key trend in the semiconductor industry was the consolidation of manufacturing. The semiconductor industry started with integrated device manufacturers (IDMs) when almost all electronics companies had their own manufacturing capabilities, so they would manufacture their own chips to be used in their products. In those early years, a semiconductor startup with an innovative design but no funding to build and equip a multi-million-dollar fabrication plant had to outsource production to IDMs, when IDMs had spare production capacity. Those early fabless startups had to compete with the IDM’s own in-house products for capacity, which constrained their growth and innovation.

“TSMC’s founding in 1987 was the beginning of a new, specialized industry 100% dedicated to providing manufacturing capacity to support those fabless companies’ innovations. Semiconductor foundries such as TSMC focus our resources on manufacturing capacity expansion and process technology advancements. This enables fabless design houses, who do not operate fabs, to outsource production and put all their resources towards product design and innovation. With foundry companies’ steady commitment on manufacturing capacity and technology advancements, semiconductor innovators are enabled to unleash innovation and constantly expand the universe of products to benefit people’s lives."

"The semiconductor industry needs a long-term approach to collaborate with universities, providing resources and supports that the schools need to foster the future semiconductor professionals."

"Ontario benefits from a stable economy and stable political environment; low-cost, reliable energy; and its location next to the United States, the world's largest electronics market. I believe Canada can expand the semiconductor industry here with a coherent, long-term approach with an emphasis on education and training."

"There are synergies between the semiconductor industry and Ontario's existing industries and current research focuses. For example, Ontario has some great researchers focusing on machine learning and artificial intelligence, which is critical for applications such as advanced driver assistance systems in vehicles and power-management chips enabling EV Battery production. The underlying silicon hardware and architecture play a crucial role in enabling green, autonomous-vehicle systems. Without the underlying semiconductors, systems cannot achieve the necessary performance, power and size/weight requirements."

Interview #5

Professor Wai Tung Ng

Wai Tung has been a Professor at the University of Toronto for the past 30 years. During that period, much of his work has focused on power semiconductor devices and power integrated circuits. Most recently, he is working with a local automotive parts manufacturer to develop liquid cool power modules.

"Ontario plays a key role in the design of semiconductor devices. There is a concentration of world-leading design houses in the Waterloo to Ottawa corridor."

"The University of Toronto, the University of Waterloo, the University of Windsor, McMaster University, York University, Queens University, and Carleton University are all graduating students who will start their own semiconductor-related start-ups. It is very important that we have a strong semiconductor industry in Ontario that is able to hire these graduates and ensure the talent is retained in Ontario."

"To attract potential semiconductor manufacturers to Ontario, the government can start offering incentives similar to those being provided to battery manufacturing companies. The time to solicit foreign investment is quite good. Canada has a lot to offer, including cheap energy and plenty of land. Semiconductor manufacturing is also a relatively clean industry in terms of pollution. There are well developed regulations and technology that help ensure these factories produce minimal emissions."

5. Glossary

ADAS	Advanced Diver-Assistance Systems
AI	Artificial Intelligence
CAGR	Compound Annual Growth Rate
CAV	Connected and Autonomous Vehicle
CMOS	Complementary Metal Oxide Semiconductor
CPTPP	Comprehensive and Progressive Agreement for Trans-Pacific Partnership
DAO	Discrete, Analog, and Other
EMS	Electronics Manufacturing Service
EVs	Electric Vehicles
ICE	Internal Combustion Engine
ICs	Integrated Circuits / Chips
IoT	Internet of Things
iZEV	Incentives for Zero-Emission Vehicles Infrastructure Program
MEMS	Micro-Electromechanical Systems
ML	Machine Learning
NEAP	Northern Energy Advantage Program
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council
OCI	Ontario Centre of Innovation
OEMs	Original Equipment Manufacturers
OVIN	Ontario Vehicle Innovation Network
RFW	Regional Future Workforce
RTDS	Regional Technology Development Sites
ZEVIP	Zero Emission Vehicle Infrastructure Program

6. About OVIN

OVIN is a key component of Phase Two of Driving Prosperity, the Government of Ontario's ambitious plan that positions Ontario as a North American leader in developing and building the car of the future through emerging technologies and advanced manufacturing processes. The Government of Ontario has committed an additional $56.4 million, for a total investment of over $141 million to date, through OVIN's innovative programming to support research and development (R&D) funding, talent development, technology acceleration, business and technical supports, and testing and demonstration.

OVIN, led by Ontario Centre of Innovation (OCI), is supported by the Government of Ontario's Ministry of Economic Development, Job Creation and Trade (MEDJCT) and Ministry of Transportation (MTO).

The initiative comprises five distinct programs and a central hub. The OVIN programs are:

- Research and Development Partnership Fund
- Talent Development
- Regional Technology Development Sites
- Demonstration Zone
- Project Arrow

The OVIN Central Hub is the driving force behind the programming, province-wide coordination of activities and resources, and Ontario's push to lead in the future of the automotive and mobility sector globally. Led by a dedicated team, the Central Hub provides the following key functions:

- A focal point for all stakeholders across the province;
- A bridge for collaborative partnerships between industry, post-secondary institutions, broader public sector agencies, municipalities, and the government;
- A concierge for new entrants into Ontario's thriving ecosystem; and
- A hub that drives public education and thought leadership activities and raises awareness around the potential of automotive and mobility technologies and the opportunities for Ontario and for its partners.

To find out the latest news, visit www.ovinhub.ca or follow OVIN on social media @OVINhub

7. OVIN Objectives

- Foster the development and commercialization of Ontario-made advanced automotive technologies and smart mobility solutions.
- Showcase the Province of Ontario as the leader in the development, testing, piloting and adoption of the latest transportation and infrastructure technologies
- Drive innovation and collaboration among the growing network of stakeholders at the convergence of automotive and technology
- Leverage and retain Ontario's highly skilled talent, and prepare Ontario's workforce for jobs of the future in the automotive and mobility sector
- Harness Ontario's regional strengths and capabilities, and support its clusters of automotive and technology

8. Meet the OVIN Team

Automotive and Mobility Team

Raed Kadri
Head of Ontario Vehicle Innovation Network
rkadri@oc-innovation.ca

Mona Eghanian
Assistant Vice-President, OVIN
meghanian@oc-innovation.ca

Greg Gordon
Director, Strategic Partnerships
ggordon@oc-innovation.ca

Dan Ruby
Director, Sector and Regional Development
druby@oc-innovation.ca

Ghazal Momen
Manager, Strategic Partnerships
gmomen@oc-innovation.ca

Stephanie Rodrigues
Manager,
Strategic Initiatives
srodrigues@oc-innovation.ca

John George
Sector Manager Electric Vehicles
jgeorge@oc-innovation.ca

Shane Daly
Program Portfolio Manager, Automotive & Mobility
sdaly@oc-innovation.ca

Natalia Rogacki
Portfolio Manager, Automotive & Mobility
nrogacki@oc-innovation.ca

Joelle Monje
Outreach and Engagement Specialist
jmonje@oc-innovation.ca

Homeira Afshar
Research and Insights Analyst
hafshar@oc-innovation.ca

Srikanth Ramesh
Innovation Strategy Specialist
sramesh@oc-innovation.ca

Shirin Sabahi
Team Coordinator
ssabahi@oc-innovation.ca

Skills, Talent & Workforce Development Team

Natalia Lobo
Project Manager
nlobo@oc-innovation.ca

Alèque Juneau
Project Lead Workforce Development
ajuneau@oc-innovation.ca

Shannon M. Miller
Project Lead Strategic Partnerships
smiller@oc-innovation.ca

Rodayna Abuelwafa
Project Lead, Skills Development
rabuelwafa@oc-innovation.ca

Deepan Parikh
Technical Analyst
dparikh@oc-innovation.ca

9. Disclaimers

This report was commissioned by the Ontario Centre of Innovation (OCI) through a Request for Proposals titled "Ontario Vehicle Innovation Network (OVIN) – Annual Comprehensive Sector Report & Quarterly Specialized Reports," dated August 25, 2023, and has been prepared by Arup Canada Inc. It is one of five reports covering an analysis of Ontario's automotive technology, electric vehicle and smart mobility landscape while incorporating implications for the sector's skills and talent landscape.

This report contains general information only, and by means of this communication, OCI is not rendering professional advice or services. Accordingly, readers are cautioned not to place undue reliance on this report and to perform their due diligence, investigations, and analysis before making any decision, relying on the report, or taking any action that may affect readers' finances or business.

No representations, warranties, or undertakings (express or implied) are given as to the accuracy or completeness of the information in this report. OCI shall not be liable or responsible for any loss or damage arising directly or indirectly in connection with any person relying on this report.

Copyright images cannot be used without explicit written consent and must be treated as general illustrations only and not relied upon to accurately describe the scheme.

10. References

[1] Fortune Business Insights. (2022, April). The global semiconductor market is projected to grow from $573.44 billion in 2022 to $ 1,380.79 billion by 2029, at a CAGR of 12.2% in forecast period, 2022-2029. https://www.fortunebusinessinsights.com/semiconductor-market-102365

[2] McKinsey & Company. (2022, April). The semiconductor decade: A trillion-dollar industry. https://www.mckinsey.com/industries/semiconductors/our-insights/the-semiconductor-decade-a-trillion-dollar-industry

[3] Ibid.

[4] Deloitte. (2022). The global semiconductor talent shortage. https://www2.deloitte.com/us/en/pages/technology/articles/global-semiconductor-talent-shortage.html

[5] Center for Strategic & International Studies, CSIS. (2022, February). Chip Shortages in the Light of Geopolitics and Climate Change. https://www.csis.org/blogs/strategic-technologies-blog/chip-shortages-light-geopolitics-and-climate-change

[6] Government of Canada. (2021, June). Minister Ng reinforces importance of made-in-Canada hardware and semiconductor products at ventureLAB's HardTech conference. https://www.canada.ca/en/economic-development-southern-ontario/news/2021/06/minister-ng-reinforces-importance-of-made-in-canada-hardware-and-semiconductor-products-at-venturelabs-hardtech-conference.html

[7] Semiconductor Industry Association & Boston Consulting Group. (2021, April). Strengthening the Global Semiconductor Supply Chain in an Uncertain Era. https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/

[8] Semiconductor Industry Association. (2023. October). What is a Semiconductor?. https://www.semiconductors.org/semiconductors-101/what-is-a-semiconductor/

[9] Ibid.

[10] Semiconductor Industry Association & Boston Consulting Group. (2021, April). Strengthening the Global Semiconductor Supply Chain in an Uncertain Era. https://www.semiconductors.org/strengthening-the-global-semiconductor-supply-chain-in-an-uncertain-era/

[11] Semiconductor Industry Association. (n.d.). What is a Semiconductor? https://www.semiconductors.org/semiconductors-101/what-is-a-semiconductor/

[12] Visual Capitalist. (2021, December). Visualizing The Global Semiconductor Supply Chain. https://www.visualcapitalist.com/sp/visualizing-the-global-semiconductor-supply-chain/

[13] Electronics Sourcing. (2022, May). How Many Chips Are In Our Cars? https://electronics-sourcing.com/2022/05/04/how-many-chips-are-in-our-cars/

[14] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[15] Saurabh Singh. (2023, September). Semiconductors in the Automotive Industry: A Game Changer for the Tech-First Automobile Space. Appinventiv. https://appinventiv.com/blog/benefits-of-semiconductor-technology-in-automotive/

[16] Ibid.

[17] Ibid.

[18] Ibid.

[19] Rabobank. (2023, June). Mapping Global Supply Chains – The Case of Semiconductors. https://www.rabobank.com/knowledge/d011371771-mapping-global-supply-chains-the-case-of-semiconductors

[20] Hiroyuki Okabe. (2023, August). The future of semiconductor procurement - The changing semiconductor supply chain. EY. https://www.ey.com/en_jp/supply-chain/the-future-of-semiconductor-procurement-in-response-of-changing-semiconductor-supply-chain

[21] Deloitte. (2023). 2023 Semiconductor Industry Outlook. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/technology-media-telecommunications/us-tmt-semiconductor-industry-outlook.pdf

[22] Ibid.

[23] Deloitte. (2023). 2023 Semiconductor Industry Outlook. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/technology-media-telecommunications/us-tmt-semiconductor-industry-outlook.pdf

[24] KPMG. (2023, February). Global semiconductor industry outlook for 2023. https://assets.kpmg.com/content/dam/kpmg/sg/pdf/2023/02/Global-semiconductor-industry-outlook-2023-FINAL.pdf

[25] The White House. (2023, March). FACT SHEET: Strengthening the United States-Canada Partnership. https://www.whitehouse.gov/briefing-room/statements-releases/2023/03/24/fact-sheet-strengthening-the-united-states-canada-partnership/

[26] Viola Caon. (2023, January). Asia-Pacific continues to dominate the global semiconductor market. Investment Monitor. https://www.investmentmonitor.ai/features/asia-pacific-continues-to-dominate-the-global-semiconductor-market/

[27] Center for Strategic & International Studies, CSIS. (2022, February). Chip Shortages in the Light of Geopolitics and Climate Change. https://www.csis.org/blogs/strategic-technologies-blog/chip-shortages-light-geopolitics-and-climate-change

[28] Ibid.

[29] Hiroyuki Okabe. (2023, August). The future of semiconductor procurement - The changing semiconductor supply chain. EY. https://www.ey.com/en_jp/supply-chain/the-future-of-semiconductor-procurement-in-response-of-changing-semiconductor-supply-chain

[30] Rabobank. (2023, June). Mapping Global Supply Chains – The Case of Semiconductors. https://www.rabobank.com/knowledge/d011371771-mapping-global-supply-chains-the-case-of-semiconductors

[31] Ibid.

[32] Global Semiconductor Alliance & Accenture. (2020). Globality and Complexity of the Semiconductor Ecosystem. https://www.accenture.com/_acnmedia/PDF-119/Accenture-Globality-Semiconductor-Industry.pdf

[33] Semiconductor Industry Association. (2021, February). Chipmakers Are Ramping Up Production to Address Semiconductor Shortage. Here's Why that Takes Time. https://www.semiconductors.org/chipmakers-are-ramping-up-production-to-address-semiconductor-shortage-heres-why-that-takes-time/

[34] Hiroyuki Okabe. (2023, August). The future of semiconductor procurement - The changing semiconductor supply chain. EY. https://www.ey.com/en_jp/supply-chain/the-future-of-semiconductor-procurement-in-response-of-changing-semiconductor-supply-chain

[35] Global Semiconductor Alliance & Accenture. (2020). Globality and Complexity of the Semiconductor Ecosystem. https://www.accenture.com/_acnmedia/PDF-119/Accenture-Globality-Semiconductor-Industry.pdf

[36] Ibid.

[37] KPMG. (2022). KPMG 2022 auto poll. https://home.kpmg/ca/en/home/insights/2022/01/kpmg-2022-auto-poll.html

[38] International Energy Agency. (2023, April). Global EV Outlook 2023. https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf

[39] Ibid.

[40] Government of Canada. (2023, January). Government of Canada Launches New Intake Model for Zero-Emission Vehicles Infrastructure Funding. https://www.canada.ca/en/natural-resources-canada/news/2023/01/government-of-canada-launches-new-intake-model-for-zero-emission-vehicles-infrastructure-funding.html

[41] Government of Canada. (2023, May). 2030 Emissions Reduction Plan – Sector-by-sector overview: Transportation. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/sector-overview.html#sector6

[42] Ibid.

[43] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[44] Ibid.

[45] Lucintel. (2022, January). Power Semiconductors in the Global Renewable Energy Market Report: Trends, Forecast and Competitive Analysis. https://www.reportlinker.com/p06244226/Power-Semiconductors-in-the-Global-Renewable-Energy-Market-Report-Trends-Forecast-and-Competitive-Analysis.html?utm_source=GNW

[46] Government of Canada. (2022, December). Proposed regulated sales targets for zero-emission vehicles. https://www.canada.ca/en/environment-climate-change/news/2022/12/proposed-regulated-sales-targets-for-zero-emission-vehicles.html

[47] Padraig Belton. (2021, September). The computer chip industry has a dirty climate secret. The Guardian. https://www.theguardian.com/environment/2021/sep/18/semiconductor-silicon-chips-carbon-footprint-climate

[48] Ibid.

[49] Ibid.

[50] Ibid.

[51] Ibid.

[52] Center for Strategic & International Studies, CSIS. (2022, February). Chip Shortages in the Light of Geopolitics and Climate Change. https://www.csis.org/blogs/strategic-technologies-blog/chip-shortages-light-geopolitics-and-climate-change

[53] McKinsey & Company. (2022, September). How semiconductor makers can turn a talent challenge into a competitive advantage. https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-makers-can-turn-a-talent-challenge-into-a-competitive-advantage

[54] Ibid.

[55] Deloitte. (2022). The global semiconductor talent shortage. https://www2.deloitte.com/us/en/pages/technology/articles/global-semiconductor-talent-shortage.html

[56] Statistics Canada. (2023). Table 36-10-0489-01 Labour statistics consistent with the System of National Accounts (SNA), by job category and industry. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610048901

[57] McKinsey & Company. (2022, September). How semiconductor makers can turn a talent challenge into a competitive advantage. https://www.mckinsey.com/industries/semiconductors/our-insights/how-semiconductor-makers-can-turn-a-talent-challenge-into-a-competitive-advantage

[58] Semiconductor Industry Association. (2023, July). Chipping Away: Assessing and Addressing the Labor Market Gap Facing the US Semiconductor Industry. https://www.semiconductors.org/chipping-away-assessing-and-addressing-the-labor-market-gap-facing-the-u-s-semiconductor-industry/

[59] Semiconductor Industry Association. (2021, May). Chipping in: the U.S. Semiconductor Industry Workforce and how Federal Incentives will increase domestic jobs. https://www.semiconductors.org/wp-content/uploads/2021/05/SIA-Impact_May2021-FINAL-May-19-2021_2.pdf

[60] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[61] Ibid.

[62] Ibid.

[63] Ibid.

[64] Statistics Canada. (2023). Table 36-10-0489-01 Labour statistics consistent with the System of National Accounts (SNA), by job category and industry. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610048901

[65] Catapult Network. (n.d.). We're facing a global compound semiconductor skills shortage: what now. Innovate UK. https://catapult.org.uk/our-work/case-studies/were-facing-a-global-compound-semiconductor-skills-shortage-what-now/

[66] Ibid.

[67] Ibid.

[68] Semiconductor Industry Association. (2023, July). Chipping Away: Assessing and Addressing the Labor Market Gap Facing the US Semiconductor Industry. https://www.semiconductors.org/chipping-away-assessing-and-addressing-the-labor-market-gap-facing-the-u-s-semiconductor-industry/

[69] The White House. (2022, August). FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China. https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/

[70] McKinsey & Company. (2022, October). The CHIPS and Science Act: Here's what's in it. https://www.mckinsey.com/industries/public-sector/our-insights/the-chips-and-science-act-heres-whats-in-it

[71] Semiconductor Industry Association. (2022, December). The CHIPS Act Has Already Sparked $200 Billion in Private Investments for U.S. Semiconductor Production. https://www.semiconductors.org/the-chips-act-has-already-sparked-200-billion-in-private-investments-for-u-s-semiconductor-production/

[72] Government of Ontario. (2023). Powering Ontario's Growth - Ontario's Plan for a Clean Energy Future. https://www.ontario.ca/files/2023-07/energy-powering-ontarios-growth-report-en-2023-07-07.pdf

[73] OVIN. (n.d.). Programs. Government of Ontario. https://www.ovinhub.ca/programs/

[74] NSERC. (2022). NSERC's Awards Database. https://www.nserc-crsng.gc.ca/ase-oro/index_eng.asp

[75] Invest in Canada. (2021. October). Why Canada is the solution to the global semiconductor shortage. https://www.investcanada.ca/news/why-canada-solution-global-semiconductor

[76] Government of Canada. (2023). Canada-Korea Free Trade Agreement. https://www.international.gc.ca/trade-commerce/trade-agreements-accords-commerciaux/agr-acc/korea-coree/index.aspx?lang=eng

[77] Government of Canada. (2023). Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP). https://www.international.gc.ca/trade-commerce/trade-agreements-accords-commerciaux/agr-acc/cptpp-ptpgp/index.aspx?lang=eng

[78] Jenna Sudds. (2023, March). Investing in Ranovus to further advance Canada's semiconductor industry. Government of Canada. https://jennasuddsmp.ca/news/ranovus

[79] Ibid.

[80] Ontario Geological Survey. (2022). An introduction to Ontario's critical minerals, with highlights from the Ontario Mineral Inventory. https://www.geologyontario.mndm.gov.on.ca/mines/ogs/rgp/Ontarios_Critical_Minerals_Introduction.pdf

[81] Ontario Mining Association. (2022). Facts and Figures. https://oma.on.ca/en/ontario-mining/facts_figures.aspx

[82] Statistics Canada. (2023). Table 36-10-0402-01 Gross domestic product (GDP) at basic prices, by industry, provinces and territories (x1,000,000). https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610040201

[83] Statista. (2023). Semiconductors – Canada. https://www.statista.com/outlook/tmo/semiconductors/canada?currency=CAD

[84] Statista. (2023). Semiconductors - United Kingdom. https://www.statista.com/outlook/tmo/semiconductors/united-kingdom?currency=CAD

[85] Government of Canada. (2022). Search by industry (NAICS codes) – Trade Data Online. https://www.ic.gc.ca/app/scr/tdst/tdo/crtr.html?&productType=NAICS&lang=eng

[86] Ibid.

[87] Ibid.

[88] Ibid.

[89] Ibid.

[90] Ibid.

[91] Government of Canada. (2021, June). Minister Ng reinforces importance of made-in-Canada hardware and semiconductor products at ventureLAB's HardTech conference. https://www.canada.ca/en/economic-development-southern-ontario/news/2021/06/minister-ng-reinforces-importance-of-made-in-canada-hardware-and-semiconductor-products-at-venturelabs-hardtech-conference.html

[92] Statistics Canada. (2023). Table 14-10-0202-01 Employment by industry, annual. https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=1410020201

[93] Ibid.

[94] Ibid.

[95] Government of Canada. (2023, March). Government of Canada invests in Ranovus to further advance Canada's semiconductor industry. https://www.canada.ca/en/innovation-science-economic-development/news/2023/03/government-of-canada-invests-in-ranovus-to-further-advance-canadas-semiconductor-industry.html

[96] ventureLAB. (n.d.). About. https://www.venturelab.ca/about

[97] OVIN. (n.d.). Regional Technology Development Sites. https://www.ovinhub.ca/ecosystem/regional-technology-development-sites/

[98] ventureLAB. (n.d.). Hardware Catalyst Initiative. https://www.venturelab.ca/programs/hardware-catalyst-initiative

[99] Ibid.

[100] Invest Ottawa. (2021, February). TSMC: Doubling down on Ottawa. https://www.investottawa.ca/blog/tsmc-doubling-down-on-ottawa/

[101] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[102] Teledyne DALSA. (n.d.). Company Profile. https://www.teledynedalsa.com/en/company/company-profile/

[103] Onsemi. (n.d.). About onsemi. https://www.onsemi.com/company/about-onsemi

[104] Celestica. (n.d.). Unlock the potential of the future. https://www.celestica.com/about-us/who-we-are

[105] IBM. (n.d.). About IBM. https://www.ibm.com/about?lnk=flathl

[106] NSERC. (2022). NSERC's Awards Database. https://www.nserc-crsng.gc.ca/ase-oro/index_eng.asp

[107] Carleton University. (n.d.). Research Areas. https://carleton.ca/doe/research-areas/

[108] McMaster University. (n.d.). Microelectronics & VLSI. https://www.eng.mcmaster.ca/ece/research/areas-of-specialization/microelectronics-vlsi/

[109] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[110] Government of Canada. (n.d.). Canada and the G20. https://www.international.gc.ca/world-monde/international_relations-relations_internationales/g20/index.aspx?lang=eng#a1

[111] Invest in Canada. (2021. October). Why Canada is the solution to the global semiconductor shortage. https://www.investcanada.ca/news/why-canada-solution-global-semiconductor

[112] Government of Canada. (2022, February). Government of Canada announces significant investment in the Canadian semiconductor and photonics industries. https://www.canada.ca/en/innovation-science-economic-development/news/2022/02/government-of-canada-announces-significant-investment-in-the-canadian-semiconductor-and-photonics-industries.html

[113] Government of Canada. (2013). Foreign Trade Zone. https://www.canada.ca/en/department-finance/programs/international-trade-finance-policy/foreign-trade-zone.html#a2

[114] The White House. (2023, March). FACT SHEET: Strengthening the United States-Canada Partnership. https://www.whitehouse.gov/briefing-room/statements-releases/2023/03/24/fact-sheet-strengthening-the-united-states-canada-partnership/

[115] Ibid.

[116] CIFAR. (n.d.). The Pan-Canadian AI Strategy. https://cifar.ca/ai/#topskipToContent

[117] Center for Strategic & International Studies, CSIS. (2023, May). Can North America Become a Semiconductor Powerhouse? https://www.csis.org/analysis/can-north-america-become-semiconductor-powerhouse

[118] Government of Canada. (2022, September). Semiconductor Challenge Callout. https://www.ic.gc.ca/eic/site/125.nsf/frm-eng/LCOE-CBXKRY

[119] Government of Ontario. (2023, March). Northern Energy Advantage Program. https://www.ontario.ca/page/northern-energy-advantage-program

[120] Government of Ontario. (2022, January). Ontario Businesses To See Full Impact of 2021 Electricity Rate Reductions. https://news.ontario.ca/en/release/1001459/ontario-businesses-to-see-full-impact-of-2021-electricity-rate-reductions

[121] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[122] Ibid.

[123] Ibid.

[124] Government of Canada. (2019, November). Canada's Innovation Strengths and Priorities. https://www.tradecommissioner.gc.ca/innovators-innovateurs/strategies.aspx?lang=eng

[125] Government of Canada. (n.d.). Canada and the G7. https://www.international.gc.ca/world-monde/international_relations-relations_internationales/g7/index.aspx?lang=eng

[126] SILICAN. (2023, October). First steps for Canada. https://www.slideshare.net/CouncilofCanadianInn1/first-steps-for-canada-silican

[127] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[128] Ontario Mining Association. (2022). Facts and Figures. https://oma.on.ca/en/ontario-mining/facts_figures.aspx

[129] Ontario Geological Survey. (2022). An introduction to Ontario's critical minerals, with highlights from the Ontario Mineral Inventory. https://www.geologyontario.mndm.gov.on.ca/mines/ogs/rgp/Ontarios_Critical_Minerals_Introduction.pdf

[130] Natural Resources Canada. (2023, April). Mineral exploration Ontario 2023. https://files.ontario.ca/mines-mineral-exploration-ontario-2023-en-2023-05-29.pdf

[131] CRM Alliance. (n.d.). Germanium. https://www.crmalliance.eu/germanium

[132] CRM Alliance. (n.d.). Gallium. https://www.crmalliance.eu/gallium

[133] Clement Tan. (2023, July). China slaps export curbs on chipmaking metals in tech war warning to U.S., Europe. CNBC. https://www.cnbc.com/2023/07/04/china-imposes-export-curbs-on-chipmaking-metals-in-tech-war-with-the-us.html

[134] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[135] Ibid.

[136] University of Windsor. (n.d.). Centre for Hybrid Automotive Research and Green Energy (CHARGE) Lab. https://www.uwindsor.ca/engineering/research/383/test

[137] University of Waterloo. (n.d.). Welcome to the Waterloo Centre for Electrochemical Energy. https://uwaterloo.ca/centre-electrochemical-energy/

[138] OVIN. (n.d.). R&D Partnership Fund – Electric Vehicle (EV) Stream 1. https://www.ovinhub.ca/programs/rd-partnership-fund-electric-vehicle-ev-stream-1/

[139] OVIN. (n.d.). Project Arrow. https://www.ovinhub.ca/project-arrow/

[140] Ibid.

[141] Canada Semiconductor Council. (2021, November). Roadmap to 2050: Canada's Semiconductor Action Plan. https://canadassemiconductorcouncil.com/news/

[142] Ibid.

[143] University of Waterloo. (n.d.). Welcome to Sensors and Integrated Microsystems Laboratory. https://uwaterloo.ca/sensors-integrated-microsystems-lab/

[144] University of Waterloo. (n.d.). Nano and Micro Systems Lab. https://uwaterloo.ca/nano-micro-systems-lab

[145] Caterina Favino. (2022, October). The Role of Semiconductors in the Renewable Energy Transition. https://earth.org/semiconductors/

[146] Environment Journal. (2023, March). Ontario launches Hydrogen Innovation Fund to kickstart opportunities. https://environmentjournal.ca/ontario-launches-hydrogen-innovation-fund-to-kickstart-opportunities/

[147] Invest in Ontario. (n.d.). CLEANTECH. Government of Ontario. https://www.investontario.ca/cleantech#related