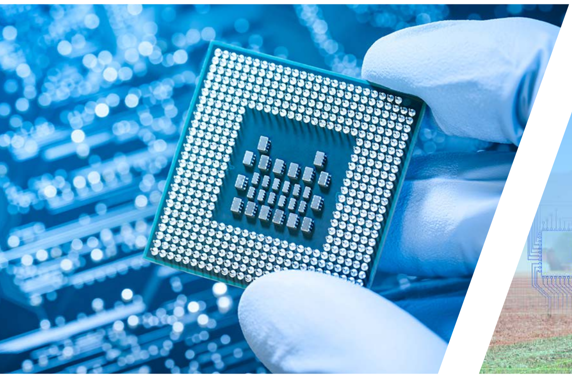
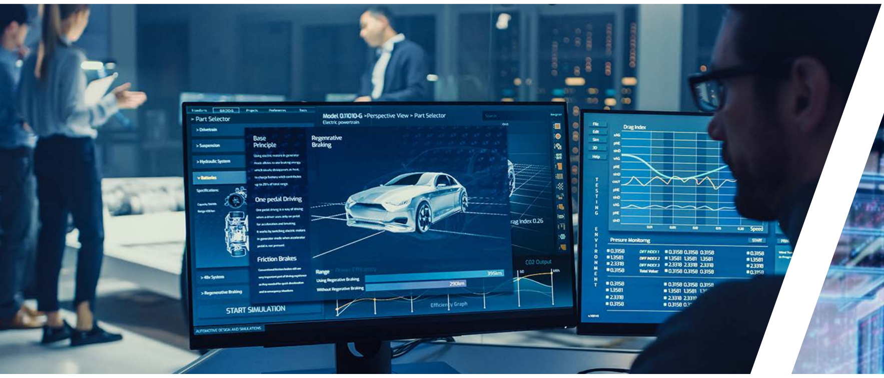
Strategic Plan for CMC Microsystems

Manager of Canada's National Design Network®

Lowering Barriers to Technology Adoption





2020

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CMC Microsystems
www.CMC.ca
June 15, 2020 | IC - 2003

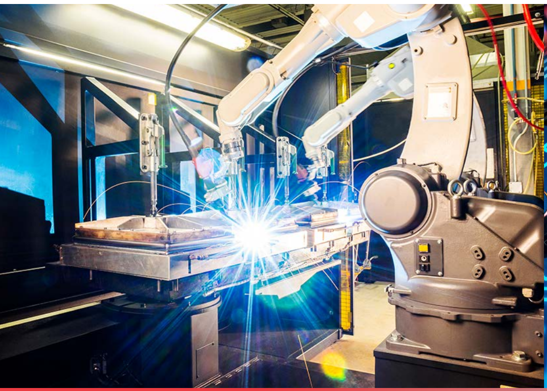
Foreword

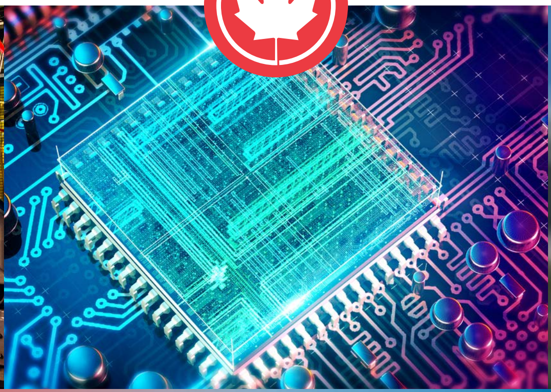
Building on success, a full review of the longer-term strategic direction for Canada's National Design Network® (CNDN) began in August 2019. The Strategic Plan aims to maximize impact on Canadian research, innovation, and economic growth and is aligned with the statement of vision, mission and goals of CMC Microsystems (CMC). The plan summarizes annual stakeholder consultations and the CNDN Technology Roadmap (extended in 2019 from 2020 to 2022), and describes strengths, weaknesses, opportunities, threats, and plans for the years ahead. Directions are presented in foundational technologies – microelectronics, photonics, embedded systems, microelectromechanical systems (MEMS) – technologies critical to enabling Canada's growing digital economy.

Let's work together!

Global partnerships and international technology alliances enable access to CNDN technologies that are used to accelerate innovative research in Canada.

Contact: Gordon Harling, President & CEO, Harling@cmc.ca





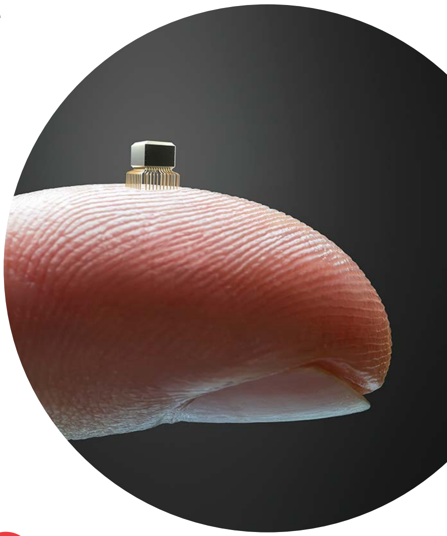
Microsystems

A World of Magic & Invisible Technology

> Arthur C. Clarke, the famous science fiction writer said, "Any sufficiently advanced technology is indistinguishable from magic."

This is true of the world today where we can walk around with our smartphones and talk to someone on the other side of the world without any visible connection, even share video or text. To anyone without the technical expertise, this is an example of the magic we experience every day. Even more, there is much around us that is happening that we do not see. Traffic lights are controlled in a way that smooths our drive home, the thermostat in our home learns our patterns and adjusts the temperature to conserve energy while making us comfortable when we are home, and we can ask a virtual assistant how to cook spaghetti. The most successful microsystems technologies are the ones that we do not even know exist and behind all the invisible things happening around us there are sophisticated microsystems technologies enabling them.

Unfortunately, the more successful we are at developing the microsystems technologies that make our lives easier, the more invisible they become and the easier it is to forget that people had to invent the technologies and people had to figure out how to use those technologies. Also invisible to many Canadians is the fact that we are world leaders at inventing new microsystems technologies, manufacturing those technologies, training people to use them, and developing new products that leverage microsystems technologies. Canada is also a leader in building an organization that enables much of the research and training that is key to our technological strengths and success. CMC Microsystems is a Canadian corporation that was created in a truly Canadian way.



About CMC Microsystems

CMC Microsystems is a not-for-profit collaborative organization founded in 1984 to facilitate access to state-of-the-art design, manufacturing, and testing facilities for microsystems technologies. With headquarters in Montreal and offices in Ottawa and Kingston, Canada, the organization manages CNDN, Canada's National Design Network® – a Canada wide collaboration between over 60 universities and colleges to connect 10,000 academic participants (4,000 researchers and 6,000 student users) with 1,000 companies (Figure 1).

Canada's National Design Network® (CNDN)

A Major Research Facility and one of 16 Canada Foundation for Innovation (CFI) Major Science Initiatives (MSIs). CNDN's mission is to provide research infrastructure for Canada's digital economy, in support of CFI's vision that Canada's researchers lead the world in contributing to competitiveness, prosperity, and quality of life. CNDN is managed by CMC Microsystems (CMC), a not-for-profit organization created to undertake this role.

CMC, through the CNDN, provides access to research and manufacturing infrastructure equally to all universities and colleges across the country and leverages the individual strengths of every institution working with these advanced technologies. Every student in Canada that works in some aspect of microsystems technology will encounter CMC and what it offers. These students, as they move to industry or teaching careers, and the ideas they create, are extremely valuable for driving and enabling the microsystems ecosystem in Canada so that Canada can participate in the magical developments of the modern and future world.

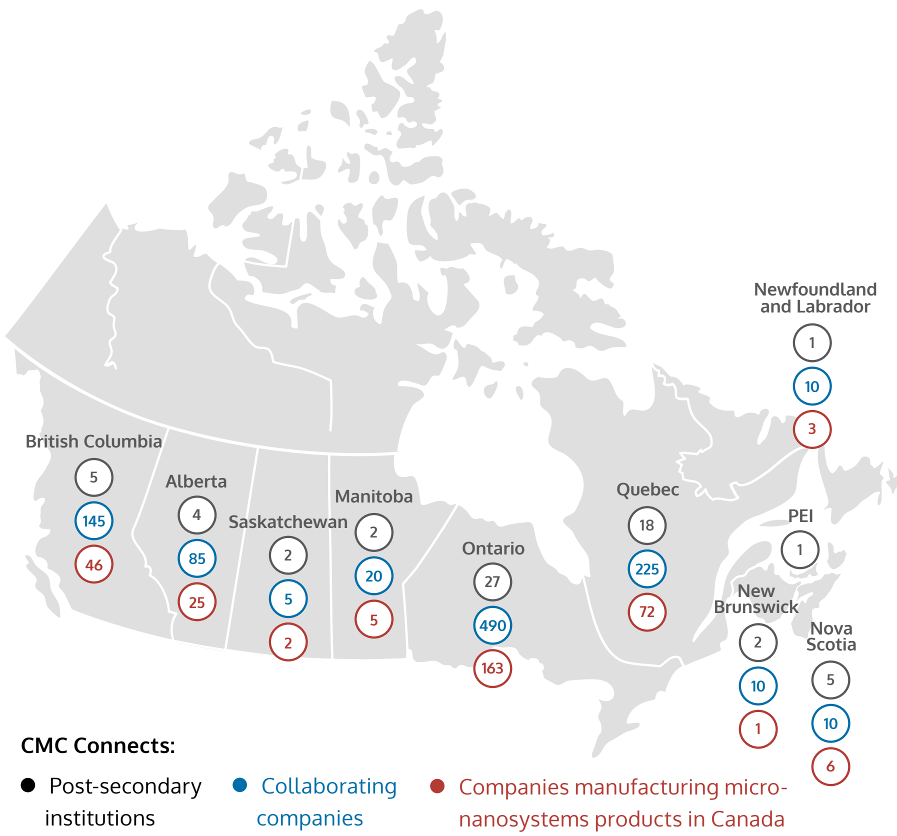


FIGURE 1: **Canada's National Design Network**

Building on Success

CMC's Strategic Plan

CMC's strategic direction aims to maximize impact on Canadian research, innovation, and economic growth. **Microelectronics, photonics, optoelectronics, micromachining, embedded software and nano-scale technologies** are enabling progress in numerous scientific disciplines. These microsystem technologies also contribute to innovative applications in many industrial sectors (Table 1).

TABLE 1: CNDN – Critical in all Aspects of a Modern Digital Economy

CMC's Areas of Technology Application	CNDN Researcher's Interests	Link: Canada's Superclusters	Link: Canada's Economic Strategy Tables
ICT Industries	25%	Advanced Manufacturing, AI	Advanced Manufacturing, Digital Tech
Biomed + Pharma	24%	Digital Tech, Protein Innovation	Health/Bio-sciences
Natural Resources + Energy	11%	AI, Digital Tech, Ocean	Clean Resources
Aerospace	10%	Advanced Manufacturing, AI	Advanced Manufacturing, Digital Tech
Defence + Security	10%	Advanced Manufacturing, AI	Advanced Manufacturing, Digital Tech
Automotive/ Transportation	9%	Advanced Manufacturing, AI	Advanced Manufacturing, Digital Tech
Environment	8%	Digital Tech, Ocean	Clean Tech, Clean Resources
Agri-/Agri-food	3%	Protein Industries	Agri-Food
	100%		

Vision

Research in microsystems and nanotechnology expands knowledge frontiers, enables applications, and contributes to economic prosperity in Canada through advanced technology manufacturing.

Mission

Enable and support the creation and application of microsystems and nanotechnology knowledge and manufacturing capability by:

- Providing a national infrastructure for excellence in research through Canada's National Design Network® (CNDN).
- Establishing and verifying a path to commercialization of related processes, devices, components and systems.

Guiding Values

Research Excellence | "Honest Broker" Benefit to Canada

CMC provides services essential for the research and training required to advance Canada's digital economy, for example, Industry 4.0, autonomous vehicles, big data, Internet of Things (IoT), cyber defence/security, 5G, quantum computing, artificial intelligence (AI) and more.

Strategic Goals

The strategic goals for the CNDN, reviewed annually as part of CMC's planning process, are as follows:

Research: Enable transformative micro-scale and nano-scale research leading to materials, processes, devices, components and integrated microsystems including software.

Commercialization: Accelerate the commercialization of new micro-nano knowledge through joint efforts with Canadian partners.

Manufacturing: Deliver technologies and services, including training, enhanced with manufacturability attributes applicable to research, as well as developments and innovation.

Highly Qualified Personnel: Foster the development of highly qualified personnel (HQP) involved in micro-nano categories of research, encouraging innovation, with emphasis on universities and colleges while including industry, government and others.

Return on Investment: Manage operations and outreach and measure performance to ensure maximum benefits are derived from the significant investments already made in CNDN infrastructure and in particular micro-nano laboratories in post-secondary institutions.

CNDN Impact

CMC is exemplary in supporting research and innovation and the development of highly qualified people where microsystems converge with scientific disciplines that enable Canada's future development.

CMC's strategic direction builds on the corporation's inherent strengths, identifying priorities for delivering best-in class infrastructure to support university and company-based research that depends on microsystem technologies. This strategic direction specifically supports development of highly qualified people to contribute to Canada's economic and social objectives. By providing access to internationally competitive technologies, CMC will enable thousands of highly qualified university researchers to achieve optimal impact on the economy and quality of life of Canadians.

The key intent underlying CMC's strategic direction is to enhance research capability at Canadian universities and young promising companies and to enable the development of highly qualified people in science and technology essential to Canada's competitiveness.

Research Outcomes

1,510	Journal Publications
2,145	Other Publications
85	National Awards
80	International Awards
415	Graduate Student Courses
540	Undergraduate Student Courses

Commercialization Outcomes

20	Start-up Companies
225	Patents (applied for/issued)
40	Licenses
465	Interactions with industry in Canada, valued at **$27.7M**
90	Interactions with foreign industry, valued at **$4.8M**

Impact 2018 (Published annually)
Unless otherwise indicated, all dollar amounts referred to in this Strategic Plan are expressed in Canadian dollars.

CMC's Effectiveness Criteria

CMC's guiding principles for its initiatives and support of client projects are summarized in the Effectiveness Criteria used in selection of projects and resource allocation.

- Realized or potential economic and social benefits to Canada.
- Demonstrated industrial relevance of research.
- Contribution made to maintaining or promoting the standard and status of microsystems research and technology development that has the potential to be exceptional by international standards.
- Contribution to the education of highly trained people for industry, research and education in the field of microsystems.
- Demonstrated need for requested resources (such as fabrication, test access, development hardware, intellectual property (IP), etc.) for microsystems research, technology development and education.
- Demonstrated or potential to demonstrate broad and sustained research and technology development collaboration among researchers, or among research institutions, or across disciplines, or across sectors.

In its commitment to operate optimally within the larger ecosystem in Canada, CMC will:

- Not unduly compete with Canadian commercial entities.
- Undertake projects that will result in a marketable product or service while ensuring it is addressing markets that are not yet commercially viable, but which will support a sector of the CNDN.
- Undertake projects that will result in platform technologies of use to many researchers.
- Encourage multi-disciplinary projects involving multiple institutions.
- Engage in projects that will drive business in the CAD, FAB, or LAB lines of business.

What exactly does CMC do?

CMC offers academic and industrial users services in three categories – CAD, FAB, and LAB. This is made possible by leveraging its world-wide industrial supply chain to enable research and innovation (Figure 2 on page 11).

CMC's internal technical teams support microelectronics, micromechanical sensors (MEMS), photonics, optics and system integration. These are the underlying technologies enabling biomedical devices, autonomous cars, wearable technology, remote health diagnostics, 5G networks, AI-driven data processing, and quantum computing, as examples.

CMC provides royalty-free example designs, design tools to modify and simulate them, and low-cost access to fabrication services to build them, enabling researchers across Canada to lead technology innovation in these areas. Electronic and photonic sensors are finding their way into handheld and mobile devices for point-of-care medical testing, environmental monitoring, and structural monitoring. Getting maximum performance from these sensors requires careful design.

CMC offers access to over 40 university-based fabrication facilities across Canada and the technical know-how to help researchers transfer their knowledge into innovations. Researchers can use industrial-grade software provided by CMC to design their microsystems and use CMC-brokered access to commercial fabrication facilities to build prototypes.

CAD

State-of-the-art environments for successful design

- Selection of high-performance Computer Aided Design (CAD) tools and design environments
- Available via desktop or through CMC Cloud
- User guides, application notes, training materials and courses

www.CMC.ca/CAD

FAB

Services for making working prototypes

- Multi-project wafer services with affordable access to foundries worldwide
- Fabrication and travel assistance to prototype at a university-based lab
- Value-added packaging and assembly services
- In-house expertise for first-time-right prototypes

www.CMC.ca/FAB

LAB

Device validation to system demonstration

- Access to platform-based microsystems design and prototyping environments
- Access to test equipment on loan
- Access to contract engineering services

www.CMC.ca/LAB

Data communications has seen a massive scale-up in volume from text messages, to climate data, to images and video in the areas of health and security. The increase in communication speed would be impossible without photonic circuits. CMC provides training, design and simulation software, and access to fabrication world-wide to facilitate research and product development in photonics. CMC's strategic investments have led Canada to be a global leader in photonics technology.

Global Partners

North America

Canada
14 CAD | 8 Fab | 13 Test
19 Systems & Components
42 University MNT Labs

USA
15 CAD | 5 Fab | 11 Test
8 Systems & Components
1 Co-operative Initiative

Europe

1 European Co-operative Initiative

Ireland
1 Fab

UK
1 CAD
1 Systems & Components

France
2 Fab
1 Co-operative Initiative

Sweden
1 CAD

Netherlands
2 Fab

Belgium
1 Fab

Germany
1 CAD
2 Fab

Austria
1 Fab

FIGURE 2:
Global Supply Chain to Enable Internationally Competitive Research and Innovation

Asia

China
1 Co-operative Initiative

South Korea
1 Co-operative Initiative

Japan
1 Co-operative Initiative

Taiwan
2 Fab
3 Systems & Components
1 Co-operative Initiative

Singapore
3 Fab

Australia

1 Fab

The Return on Investment

Benefits to Canada

Professors have a strong track record of providing researchers and academic institutions in Canada with a competitive advantage in the capital-intensive, industry-dependent microelectronics and photonics domains. Based on strategic and operating plans, this strong national network of researchers will deliver globally competitive, industrially relevant research and innovation. Outcome forecasts, the results coming from the efforts of the researchers, are shown in Table 2.

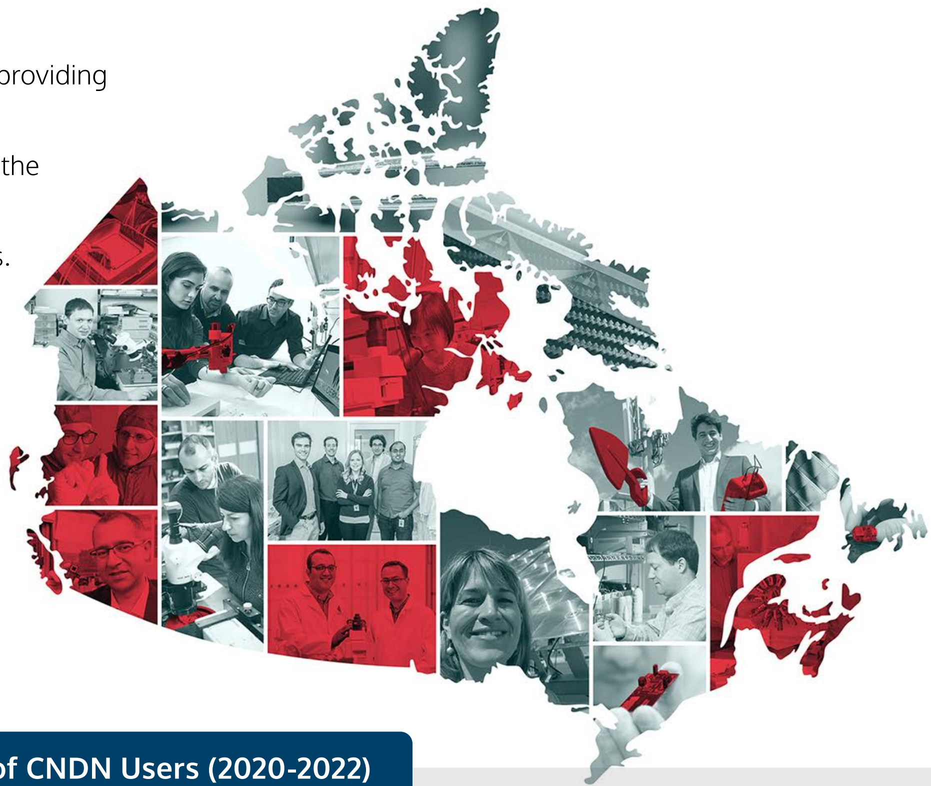


TABLE 2: Projected Impact of CNDN Users (2020-2022)

Outcomes	2020	2021	2022
National and International Awards	135	145	155
Journal and Other Publications	3,630	3,880	4,155
Patents Issued	60	65	70
Start-up Companies	18	18	18
Univ. Collaborations with Industry [#/value]	580 [$30.2M]	620 [$32.2M]	665 [$34.5M]
HQP: Movement to Industry in Canada	795	850	910

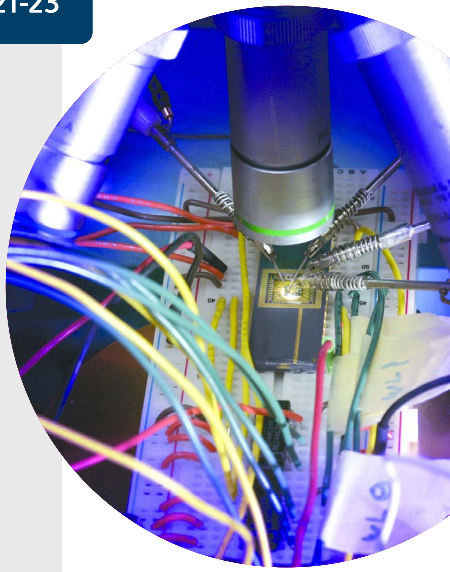
Users	2020	2021	2022
Professors	1,340	1,365	1,385
HQP	9,920	10,595	11,355

Funding the Mission

A high-level view of the operating budget is presented in the following table.

TABLE 3: Sources of funding for O&M Expenditures (in $000), 2021-23

	2021	2022	2023	Total
Federal	900	550	300	**1,750**
Provincial	1,800	1,800	1,500	**5,100**
Institutions	1,263	895	850	**3,008**
Corporations	375	500	750	**1,625**
User Fees	2,775	3,950	4,600	**11,325**
Other	280	435	725	**1,440**
CFI	6,250	6,250	6,300	**18,800**
Total	**13,643**	**14,380**	**15,025**	**43,048**



The following graph illustrates a shift in the distribution of sources of revenues for operations.

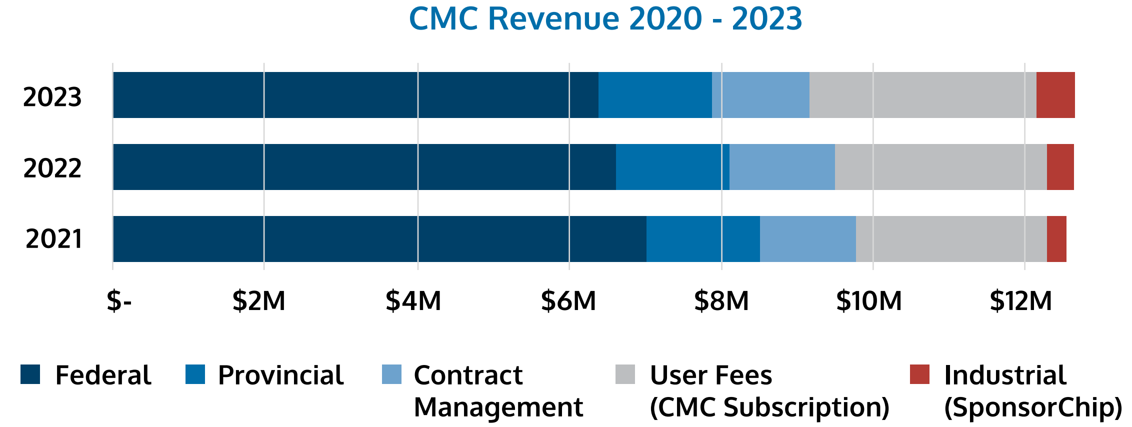


FIGURE 3: Shifting Revenue Sources to Deliver on the Mission

Opportunities & Threats Demand Strategic National Action

Strengths

- Unique research infrastructure delivery model — the envy of programs in other countries
- Respected organization, well-connected on a national scale
- Continued 5% growth of subscriber base. 800 professors/10,000 researchers as of 2020
- Expert domain knowledge and world-wide supply chain

Weaknesses

- Piecemeal funding from multiple sources, each shorter than timescale to obtain a PhD
- Connection with 1,000 companies in CNDN is indirect, through the academic users

Opportunities

- Microsystems increasingly relevant for vibrant digital economy in all Canadian sectors
- Microelectronics and photonics are foundational to quantum computing and AI
- Lower costs, broaden offering by extending services to entities outside of Canada
- Increase impact by enriching offering to start-up companies in Canada

Threats

- Sources of capital (for equipment) insufficient/too few funding competitions
- Increasingly restrictive licensing practices and controlled goods/export controls

Strategic Technology Development

The facility enables users to support innovation in all the sectors identified by the federal government's Economic Strategy Tables (Figure 4) through research and development spanning multiple technology drivers, including the Internet of Things (IoT), 5G, and Artificial Intelligence (AI). CNDN foundational technology areas are critical to enabling Canada's growing digital economy.

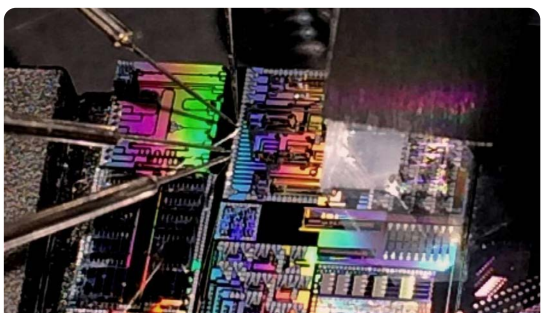
CNDN Technology Drivers	CNDN Technology Areas
IoT	Embedded Systems
5G & Data Centres	Microelectronics, MEMS & NEMS
AI	Photonics: Silicon Photonics, III-V Photonics, Optics
Experiential Tech., Augmented Reality & Virtual Reality	Packaging & Multi-scale Integrations
Energy Management	Nanofabrication: Quantum, Nanotechnology

FIGURE 4: **Fuelling Innovation and Competitiveness Across all Strategic Sectors**

The CNDN technology platforms are underpinned by the following technology areas:

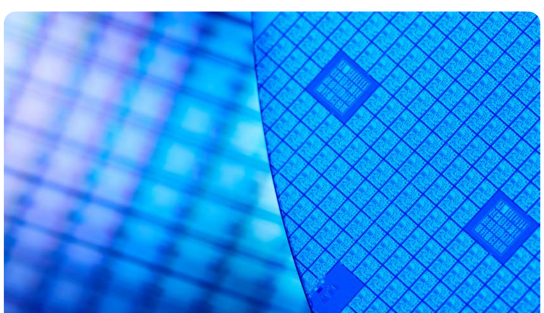
Embedded Systems

Microelectronics, MEMS & NEMS



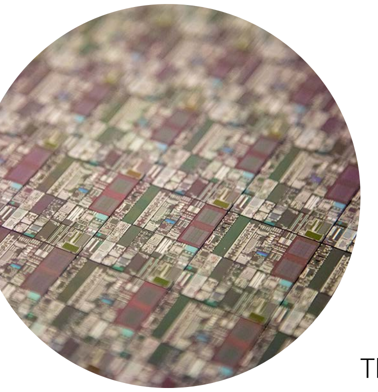
Photonics

Packaging & Multi-scale Integration



Nanofabrication: Quantum, Nanotechnology

Each is addressed in the remaining sections in terms of definition, market opportunities, SWOT (Strengths, Weaknesses, Opportunities, Threats) and plans for the years ahead. The CMC Advisory Committee, a committee of the CMC Board of Directors and with representation from industry, academia, and government, is a key contributor to the formation of this strategy and plans.



Spotlight on Microelectronics

The semiconductor industry is heading toward a collaborative and comprehensive "silicon to services" model that spans from data center to the mobile edge applications. This model builds on the ideas of Platform as a Service (PaaS), open-sourced hardware, and building silicon from disaggregated, pre-verified chiplets to slash costs and reduce time-to-market for heterogeneous designs.

Global semiconductor sales totaled US$481B in 2018. The global semiconductor wafer market size is projected to grow at a CAGR of ~3.8% to reach US$40B by 2022. Demand for chips related to the rapidly growing use of AI will contribute significantly to the industry's overall growth in 2020 and beyond. Every application market is likely to grow through 2022, led by the automotive and data processing markets.

In terms of the technology nodes, the so-called **More Moore** paradigm comes with its set of challenges related to accessibility and affordability of sub-28nm nodes, especially for academic researchers who do not have collaborations with industry. However, there are opportunities to be explored through chiplets and heterogeneous integration of process nodes.

Our strategy will be to lower barriers to technology access by reaching out internationally to customers to help make process runs more affordable and frequent for Canadian clients, enabled by the GLOBALFOUNDRIES (GF) channel partnership and an increased number of dedicated run requests.

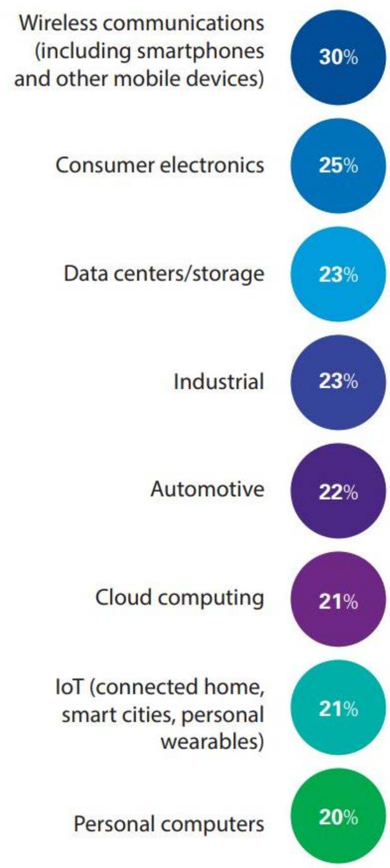
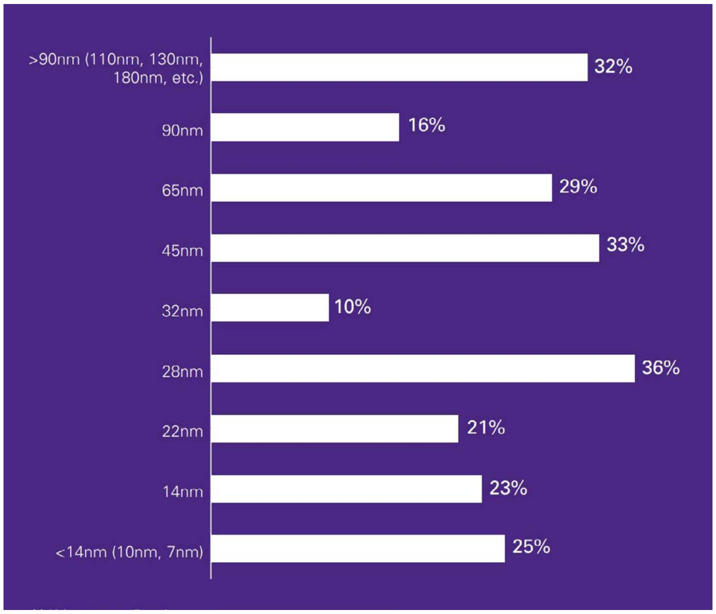


FIGURE 5: **Wireless communications is still expected to provide the highest average percentage of company revenue over the next year**

Source: KPMG Global Semiconductor Industry Survey findings, 2019

Strengths

CMC has access to a variety of technology nodes across various foundries including AMS, GF, STMicroelectronics, and TSMC through global partnerships. The resultant fabrication portfolio supports researchers across a variety of application areas, spanning computing, communication and biomedical applications, while still staying aligned with industry trends as researchers continue to tape out products across a variety of nodes. The reseller agreement with GF positions CMC as the multi-project wafer (MPW) aggregator across North America. Canadian researchers benefit from access to more process technologies from GF's portfolio, including their silicon on insulator (SOI) and silicon photonics technologies - GF45RFSOI, GF22FDSOI and GF9WG, with more frequent runs on CMC's schedule, and lowered fabrication costs. The partnership with OpenHW.org to develop open-sourced RISC-V hardware enables CMC to provide this platform as a service to its research community, the CNDN.



Multiple responses allowed.

FIGURE 6: Companies are still taping out their products across a variety of node sizes

Source: KPMG Global Semiconductor Industry Survey findings, 2019

Weaknesses

Supply chain and access to foundries: In the past year, MOSIS has changed their business model to no longer support MPW aggregation for academics or low volume clients, including CMC, for any foundry. Taiwan-based TSMC, one of the world's largest semiconductor manufacturing firms, has always considered CMC's fabrication business as too low volume to justify a direct relationship. Muse is an established MPW aggregator with process design kit (PDK) distribution rights for TSMC technologies. With few other options for partnerships for TSMC technologies, Muse is currently CMC's only source of access to TSMC technologies; a second source is desirable. Moreover, accessibility, licensing and affordability issues arise with all of GF's and TSMC's sub-40nm nodes, including FinFETs. More than ever, the manufacturing cost reductions available through MPW services such as that from CMC are critical for academics, start-ups, and small and medium-sized companies to access leading-edge technologies.

Opportunities

According to the KPMG's 2019 Global Semiconductor Industry Outlook[1], the top three ranked opportunity sectors from the perspective of types of semiconductors are 1) sensors/MEMS, 2) analog/radio frequency (RF)/mixed signal and 3) GPUs (for example virtual reality (VR) and augmented reality (AR)). In a study by Yole Développement, Quantum as a Service (QaaS) was identified as a market that will grow significantly in the period 2025 and beyond. Growth in RF and 5G markets are also expected to expand the RF Gallium Nitride (GaN) market by 2024. These are potential opportunities for CMC clients to tap into, and support by means of getting involved in R&D activity to develop platform services, fund developmental activity within university labs or by providing access to training.

Growth opportunity sectors	%	Mean
Sensors/MEMS	72%	3.8
Analog/RF/mixed signal	57%	3.6
GPUs	52%	3.5
SoC	46%	3.4
Optoelectronics	40%	3.2
Emerging NVM	35%	3.2
ASIC	34%	3.2
Flash	32%	3.0
MPUs	28%	3.0
Microprocessors	19%	2.9
DRAM	19%	2.7
Discretes	17%	2.6
Other logic	13%	2.7

1=Extremely Low and 5=Extremely high

FIGURE 7: Sensors/MEMS firmly ranked as the top growth opportunity sector for 2019

Source: KPMG Global Semiconductor Industry Survey findings, 2019

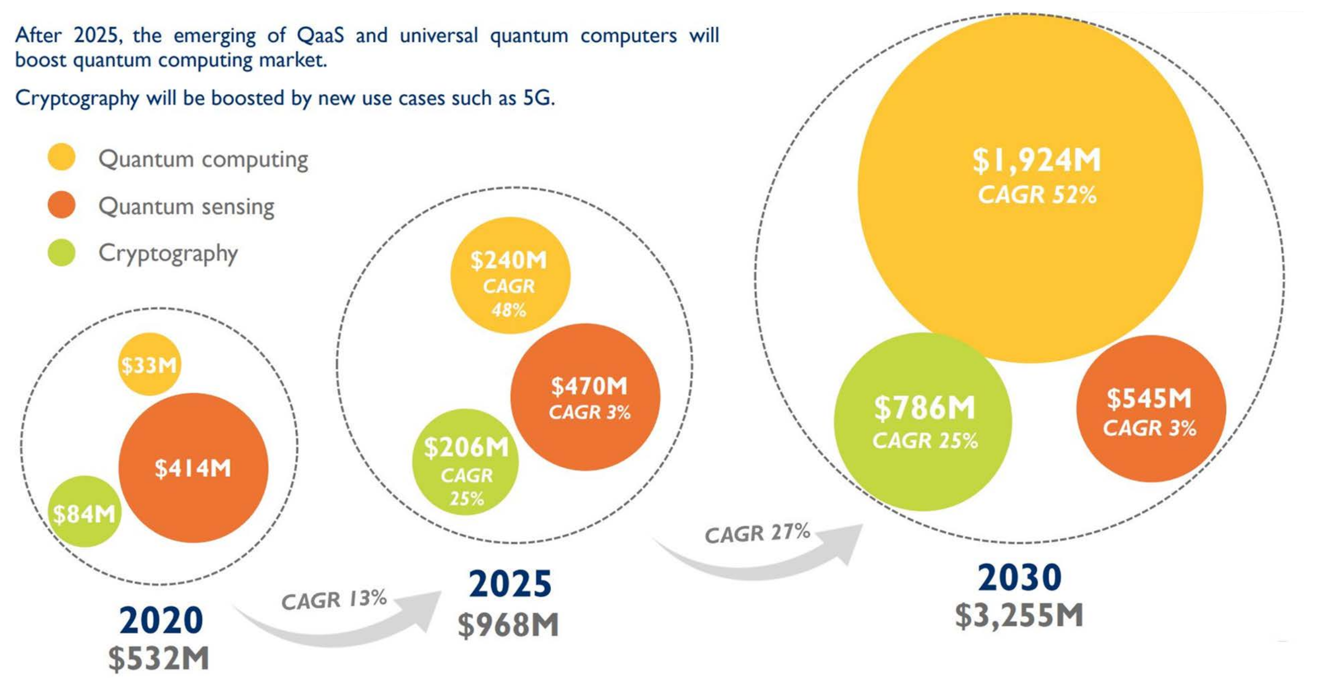


FIGURE 8: 2020 – 2025 – 2030 Quantum Technologies Forecast

Source: Quantum Technologies 2020, Yole Développement, 2020 | www.yole.fr | ©2020

[1] https://home.kpmg/us/en/home/insights/2019/03/semiconductors-the-backbone-of-the-connected-world.html

Threats

Lack of talent is a top concern for the semiconductor industry, as published in the earlier-referenced KPMG study. It's becoming harder to identify means of aligning resources with operations to realize real growth in emerging areas, than it is to identify areas where the opportunities lie. This is true for CMC as well. While several opportunities for growth have presented themselves, finding the right human resources to support and sustain growth may become a challenge as more students either choose the easily accessible and affordable software path or move out of Canada to pursue their hardware career. Supply chain disruption that affect CMC's ability to procure services such as device fabrication, packaging, or testing that leads clients to volume manufacturing is also a threat.

Looking Ahead

CMC will fund research projects with academic partners and matching funding (e.g., Mitacs, Ontario Centres of Excellence (OCE) grants, NSERC Alliance) to lower the barriers to entry and to execute on the following plan:

- Creation of PaaS for RISC-V, quantum (cryogenic CMOS) device development and test, and novel drive and readout electronics for innovative sensor designs.
- Partner with GF and Cadence on training with CAD tools and PDKs, thus increasing the number of students trained to use technologies, increasing awareness about CMC's capabilities in CAD and FAB in the USA, and also promoting our Cadence in the cloud program in the USA and channel partnership with GF.
- Work with peer organizations and suppliers worldwide to mitigate supply chain threats.

Targeted growth of 10% per year in activity and outcomes.

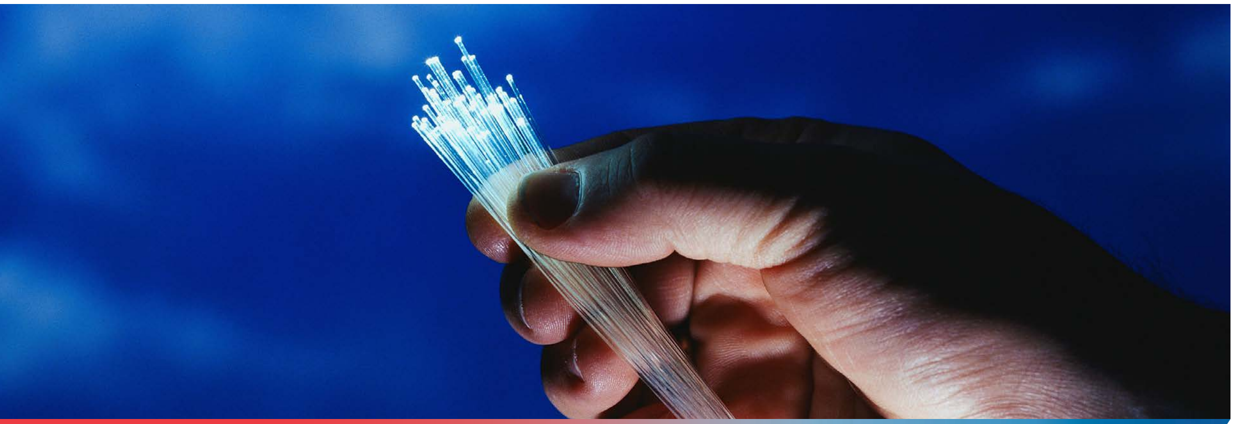
Spotlight on Photonics

Photonics technology is widely used in modern systems, where it delivers many essential functions ranging from data transmission to sensing. The datacenter & telecom photonic components market in 2018 reached a value of US$21B and is forecasted to grow to US$44B by 2025 [2]. This figure includes both discrete and photonic integrated circuit (PIC) components and includes the addition of new PIC based technologies such as polymer photonics and dielectric photonics. Integrated photonics will also be a critical component for IoT sensors and their connectivity. Globally, IoT sensor revenue was estimated at US$10.6B in 2016, and is expected to grow to US$47.8B in 2021 at a CAGR of 35% [3].

We view photonics as a systems-enabling technology, with a strong emphasis on integration, which means putting more photonic functionality onto each chip, as well as integration of photonics with other technologies, particularly microelectronics, using both hybrid and monolithic approaches. As this trend leads naturally to larger and more complex designs, there is a related trend toward greater design automation and verification capability.

The trend toward higher levels of integration naturally favours the adoption of silicon photonics. However, silicon photonics chip volumes are still relatively very small, with current deployments in the high-end market (datacenters, high performance computing (HPC) etc.). Access barriers and costs need to be reduced in order for the use of silicon photonics to become universal and fully integrated with other high-performance technologies.

[2] Lightwave Logic Inc. as quoted in IPSR-I 2019
[3] BCC Research, SENSORS FOR THE INTERNET OF THINGS (IOT): GLOBAL MARKETS March 2017, as quoted in IPSR-I 2019.

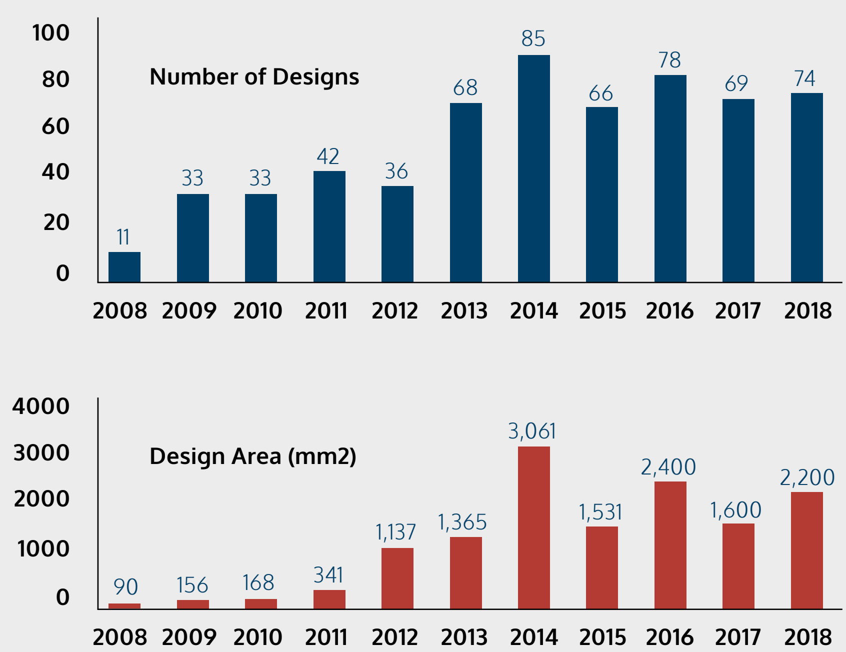


Strengths

Over 850 photonics & optoelectronics designs fabricated; including 600 silicon photonics projects.

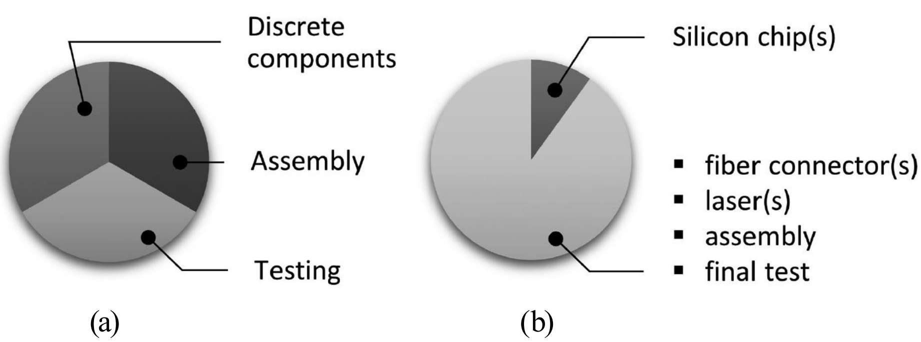
Canada has well-established photonics expertise, dating back to Nortel Networks Corporation, and currently residing in organizations like National Research Council Canada (NRC) and INO, numerous university research groups, and companies including Aeponyx, Ciena, Huawei, NeoPhotonics, Ranovus, and TeraXion. CMC and Canada's National Design Network currently deliver a program that includes (i) fabrication access to silicon photonics platforms for chip-level monolithic integration, (ii) methodologies for scalable integrated photonics design, and (iii) graduate-level training in the design, fabrication and testing of photonic integrated circuits. The recent addition of technologies from GLOBALFOUNDRIES to the CNDN portfolio now allows for enhanced levels of electronic-photonic integration.

CMC-brokered Silicon Photonics



Weaknesses

- The barriers to accessing silicon photonics technology are still considerably high, especially for small companies. MPW access has low barriers, but long cycle times. Furthermore, the silicon photonics PDKs offered by foundries are still under development, which means that some features such as reliability and qualification of PIC building blocks become the end-user's responsibility. As a result, the end-user can use the MPW route only for proof-of-concept or the validation of their ideas. For prototype fabrication targeting their product specs, the end users have to rely on dedicated engineering runs, which are expensive and for which the foundries do not provide a PDK. Currently, there are a small number of research and industrial foundries, which can provide medium-to-high volume access to silicon photonics technology. This thin supplier base with a limited number of players increases the risk for a company to adopt a technology.
- There is a lack of solutions for cheap, automated packaging, particularly for fine-pitch packaging. High coupling losses require on-chip gain.
- Design verification remains a challenge, as it is still a highly manual and labour intensive process, and therefore not easily scalable to larger and more numerous designs. In spite of some recent improvements in automated verification, we still have a long way to go to achieve the levels of automation attained in microelectronics.



Schematic representation of the cost structure of (a) legacy optical devices and (b) silicon photonic devices. The total cost of silicon photonic devices is substantially lower than of legacy devices and is dominated by anything but the Si chips. To fulfill the potential of Si photonics, disruptive improvements in cost and scalability of its packaging are required.

FIGURE 9: A Novel Approach to Photonic Packaging Leveraging Existing High-Throughput Microelectronic Facilities

Source: https://researcher.watson.ibm.com/researcher/files/us-tymon/TBarwicz_Photonic_Packaging_JSTQE2016.pdf

[4] Barwicz et al, IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 22, NO. 6, NOVEMBER/DECEMBER 2016

Opportunities

CMC is well positioned to lower barriers to access, e.g. by developing PDKs and helping to develop re-usable intellectual property through collaborations with foundries and other players in the ecosystem.

Threats

Competition in publication and innovation is fierce. Canada's recognized leadership in photonics is at risk of eroding. There are currently no industrial-class domestic sources of manufacturing. Such manufacturing facilities help build strong innovation ecosystems in their countries. CMC's offerings will need to diversify so that they remain relevant to leading-edge research — a significant challenge. Focusing our existing niche and expertise area of silicon photonics technology may lead to missed opportunities, e.g., the lack of access to III-V materials or devices integrated with silicon photonics. These are currently a gap in the CNDN portfolio. Such a fast-paced environment may preclude CMC from hiring enough talent to pursue all the relevant opportunities.

Looking Ahead

CMC will fund research projects with academic partners and matching funding to lower the barriers to entry and to execute on the following plan:

- Work with partners to develop "made in Canada" solutions for assembly and packaging, which could include optical fibre-to-chip connector assembly at IBM Bromont, and photonic wire bonding using a new machine recently acquired by the University of British Columbia.
- With partners in Canada develop a proposal for "made in Canada" solutions for chip fabrication.
- Work with partners in Canada and Europe to develop hybrid integration techniques.
- Attract international customers to help make MPW runs more affordable and frequent for our Canadian customers.

Targeted growth of 10% per year in activity and outcomes.

Spotlight on Embedded Systems

CMC Microsystems enables critical research in artificial intelligence and machine learning, heterogeneous computing, and 5G for researchers and industry across Canada's National Design Network. This is facilitated by providing access to world-class tools, technologies, expertise and industrial capabilities for designing, prototyping and manufacturing innovations in microsystems and nanotechnologies. CMC lowers the barriers to technology adoption by creating and sharing platform technologies. This includes supporting research excellence in all aspects of embedded systems design, from sensor nodes, and edge nodes, to the cloud including sensor/actuator systems, heterogeneous embedded platforms, and cloud-based heterogeneous computing clusters and providing a rich ecosystem of software tools, methodologies, and high quality data sets.

	2017	2018	2019	2020	2021	2022	2023	2024
Hardware	1,408.54	1,896.55	2,580.82	3,550.51	4,939.76	6,952.60	9,902.87	14,278.94
Software	924.39	1,272.68	1,771.77	2,494.99	3,555.10	5,127.55	7,488.55	11,078.32
Services	516.74	695.69	947.37	1,305.35	1,820.53	2,570.89	3,677.39	5,330.00

FIGURE 10: Global Machine Learning Market, by Component, 2017-2024 (USD Million)

Source: MRFR Analysis

Strengths

- Artificial Intelligence (AI) and machine learning (ML) continue to be hot topics, and Canada has a strong international reputation thanks to institutions such as Toronto's Vector Institute and Next AI, Edmonton's Alberta Machine Learning Institute, and the Institute for Data Valorization in Montreal and the Montreal Institute for Learning Algorithms (MILA). There is resulting strong interest and R&D investment by large, multi-nationals: Advanced Micro Devices (AMD), Intel, Huawei, Google, NVIDIA, Qualcomm, etc.
- Best-in-class tools available already (e.g., Cadence, Mentor, Synopsys university programs) to CNDN. Funds are available for IP purchase through CFI Infrastructure projects: ADEPT (currently), and CADnet (proposed).
- CMC recently deployed an experimental cluster of FPGAs and GPUs in a Compute Canada Federation datacenter at the University of Waterloo. Engineers at CMC are trained to provide user support.
- There is growing availability and interest in open-source processors (RISC-V) in academia and industry enabling technology transfer and commercialization opportunities.

Weaknesses

- Arguably, progress in improving algorithms has become highly competitive due to global research efforts and as a result we may start to see diminishing returns on investment. It is time to investigate custom hardware to accelerate AI and give innovative Canadian researchers and companies a competitive advantage.
- IP blocks that are not open-source, and technology-specific analog/mixed-signal blocks can be expensive or restrictive use/ security requirements and can limit impact and commercialization opportunities.
- Complexity (steep learning curves) and long compile times associated with hardware design tools for creating FPGAs and ASICs is an ongoing challenge for software and algorithm experts.
- While available Open source IP may be difficult to commercialize (verification problem–industry may not trust it or be willing to support it).
- Manufacturing costs are high, design flows complex; getting working silicon first-time is difficult; re-spins and manufacturing delays may extend beyond a student's term of study.

Opportunities

- Large projected growth/opportunities in AI and quantum computing in Canada over the next 5-10 years.
- OpenHW Group has been formed to curate and support verified, silicon-proven RISC-V cores for commercial and academic use. CMC is a founding member and can bring universities in as members.
- System emulator technology provides detailed performance analysis and technology-accurate verification of custom hardware on real-world application workloads, within time/budget of graduate student projects.
- New computation methods and technologies: quantum, neuromorphic photonics. New tools available (Synopsys Quantum ATK).
- New quantum kits and tools via the proposed CADnet CFI Infrastructure project (cryo-CMOS, advanced packaging).

Threats

- Without HQP with relevant skills and experience in prototyping machine learning and embedded systems, Canadian industry will fall behind in a globally competitive market space. We will not be able to build Canadian technologies that will have impact on Canadians' quality of life and relevant market sections (e.g., transportation, ICT, health).
- Cybersecurity is critical.
- The path to scale-up, higher TRLs of novel technologies (quantum, neuromorphics photonics) is uncertain.

Looking Ahead

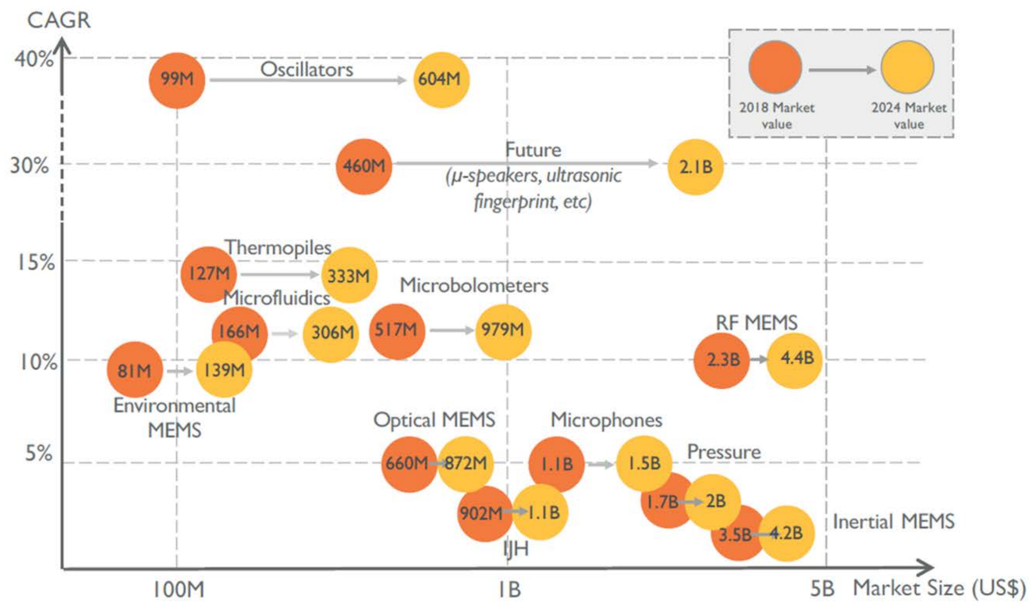
CMC will fund research projects with academic partners and matching funding to lower the barriers to entry and to execute on the following plan:

- Projects to implement RISC-V processor designs in ASICs and FPGAs, IP to be made available as open source to CNDN, industry, etc. via Github.
- Purchasing and installation into compute facility of a hardware emulator for architecture exploration, detailed performance/power estimation, verification prior to manufacturing, early software development.
- Partnering with OpenHW Group to make silicon-verified RISC-V platforms available to academic and industry.
- Leverage Canada's expertise in microelectronics and the CNDN's extensive national reach to augment Canada's reputation in quantum computing, quantum communications, and quantum-enabled sensor technologies.

Spotlight on MicroElectro-Mechanical System (MEMS), Nanofabrication, Integration

The global market for MEMS surpassed US$50B in 2019 with 8% growth in value estimated over the next five years[5]. This significant growth is projected from incumbent sectors of automotive and consumer, and from new applications in medical, machine health, smart buildings, new base stations, and edge computing.

Unlike CMOS technologies, the highly diversified MEMS market typically requires a unique manufacturing process for each product. From 2018 to 2023, 14 new production-volume fabs (200 to 300 mm) will be added for MEMS and sensors in China, Japan, Taiwan, and Europe[6]. For future technologies, strong R&D trends are seeking alternatives to silicon--sensors made on paper, plastics, and textiles. Maintaining relevant technology for CNDN will require agility to access new sources of commercial and R&D fabrication, and heterogeneous integration and packaging.



CAGR: Compound Annual Growth Rate

FIGURE 11: **Evolution of the 2018-2024 MEMS industry: Market value in US$ vs. CAGR**

Source: Status of the MEMS Industry 2019, Yole Développement, 2019 | www.yole.fr | ©2019

[5] Status of the MEMS Industry 2019, Yole Développement [6] MEMS & Sensors Fab Report to 2023, SEMI

Strengths

The collective capability for prototyping and manufacturing in Canada's MEMS community holds strong potential for technology supply to CNDN. The ecosystem is home to two Teledyne MEMS foundries (Teledyne DALSA in Bromont and Teledyne Micralyne in Edmonton), centres for pilot fabrication, packaging, and system development (INO, C2MI - MiQro Innovation Collaborative Centre, and ACAMP – Advanced Technology Development Group), and several NRC research centres (NANO, AFT, XRCC, etc.). Additionally, some 40 nanofabrication facilities at universities are used for research and proof-of-concept demonstrations of new equipment and processes. Design activity is strong; over the last five years, CMC fabricated 387 MEMS designs at commercial and university sources.

CNDN MEMS Design 2016 - 2018	
MEMSCAP (MPW)	79
Teledyne DALSA (MPW)	25
Micralyne (MPW)	6
MNT (university labs)	111

Weaknesses

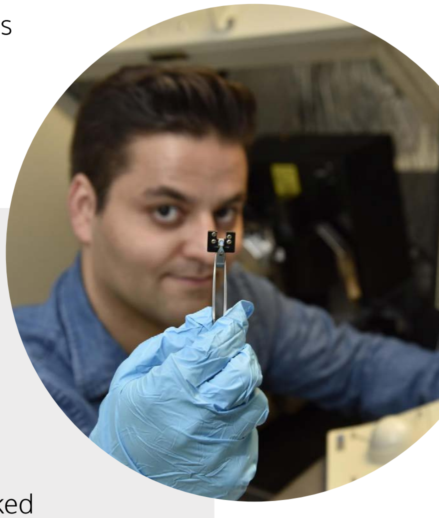
MEMS technologies offer limited platform potential due to one-process, one-product manufacturing, which results in reduced design flexibility and R&D longevity compared to microelectronics. Less frequent manufacturing runs of any given technology translates to greater unpredictability in the cycle time to manufacture a prototype. As an example, the MIDIS offering is interesting for some researchers but it is a complex and high-performance process – a simpler derivative might be of interest to others.

Opportunities

Many small MEMS markets require unique design skills and offer a great opportunity for innovation and HQP receptor capacity. CMC is uniquely positioned to reduce barriers to design by distributing automated design flows (e.g., L-Edit-MEMSPRO-Onscale), reusable design cells, and design-for-X methodologies. Leveraging strong ties to peer organizations around the world, CMC can expand access to in-demand technologies (e.g., pMUT ultrasonic actuators) for Canadian users to build their research programs. Specific needs for heterogeneous integration point to an opportunity for multi-user interposer-type technologies to help researchers demonstrate sensor and actuator systems. Launching a new CNDN training centre will position CMC to deliver new courses (e.g., NSERC CREATE program, summer schools) to address known gaps.

Threats

Growing the quality and number of Canadian HQP in this field is challenged by two gaps in the training and prototyping landscape. Firstly, common postgraduate-level curricula do not cover the topic of microfabrication process integration in any systematic way[7]. Trainees must acquire this knowledge from their research group's apprenticeship culture, and any deficit in this regard directly impacts their relevance to industry. Secondly, in the absence of a suitable MPW process, technology developers frequently prototype in university-based laboratories. Notwithstanding the benefits of such versatile facilities, technology developed there typically lacks rigorous process documentation or a path to scale-up and production. For emerging technology, an accessible small-to-medium-volume partner is essential.



Looking Ahead

Our strategy will be to lower barriers to implementing designs in existing MPW processes by (1) attracting international customers to help make process runs more affordable and frequent, and (2) creating verified cells in the standard MIDIS process (for resonators, gyroscopes and accelerometers) for use as de-risked reference designs. CMC will undertake development projects with academic partners and matching funding (e.g., Mitacs, NSERC Alliance program) to execute on the following plan:

- Pursue additional sources of MEMS MPW and heterogeneous integration for known CNDN needs.
- Create design flows and reusable intellectual property as characterized designs for researchers and industry to use to mitigate risk.
- Create drive and readout electronics for innovative sensor designs.
- Reduce cycle time of MIDIS by transferring fabrication to C2MI and by creating pre-processed 'templates' for design.
- Develop a multi-user silicon interposer technology and a versatile 3D-printed packaging service that can be used to co-package microcircuits with otherwise incompatible technologies (microelectronics, MEMS, photonics, passives).

Targeted growth of 10% per year in activity and outcomes.

[7] CMC consultation with users of XperiDesk, including experienced process developers, 2018.

Glossary & Acronyms

ADEPT: Advanced Design Platform Technology, a CFI Innovation project managed by CMC Microsystems

AMS: ams AG, formerly known as austriamicrosystems AG

ASIC: Application Specific Integrated Circuit

CAD: CMC Microsystems' product line providing Computer Aided Design (CAD) tools

CADnet: (Proposed) CFI Innovation project, an IoT network application from CMC Microsystems (anticipated: 2020)

CFI: Canada Foundation for Innovation

CMOS: Complementary metal–oxide–semiconductor

CNDN: Canada's National Design Network®, managed by CMC Microsystems

FAB: CMC Microsystems' product line providing chip fabrication services

FPGA: Field Programmable Gate Array

GF: GLOBALFOUNDRIES Inc., a semiconductor manufacturer

GPU: Graphic Processing Unit

HQP: Highly Qualified Personnel

LAB: CMC Microsystems' product line provide access to laboratory equipment and R&D services

MEMS: MicroElectroMechanical Systems

MIDIS: MEMS Integrated Design for Inertial Sensors, a fabrication technology from Teledyne DALSA

MPW: Multi-Project Wafer, cost savings via multiple customer designs in one fabrication run

MSI: Major Science Initiatives, a CFI program

NSERC: Natural Sciences and Engineering Research Council of Canada

NRC: National Research Council Canada

PDK: Process Design Kit

PIC: Photonics Integrated Circuit

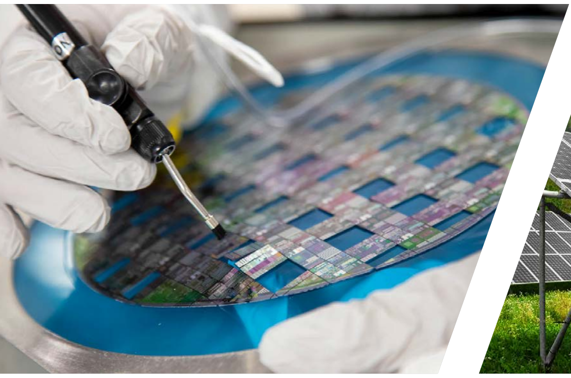
RF: Radio frequency, a wireless electromagnetic signal

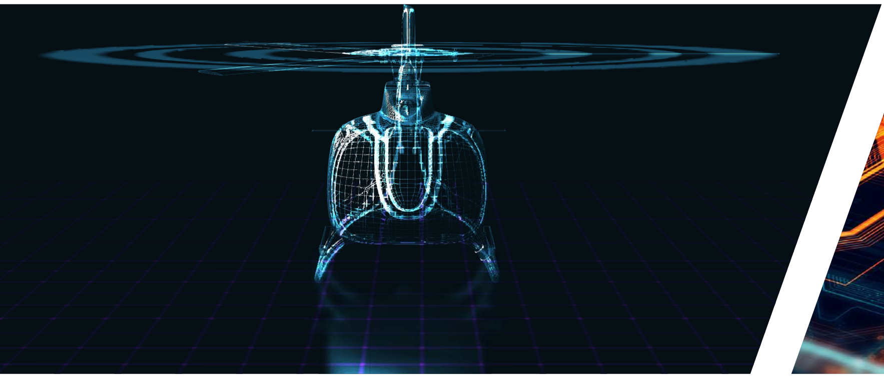
SponsorChip: Industrial support and donation program administered by CMC Microsystems

TRL: Technology Readiness Level

TSMC: Taiwan Semiconductor Manufacturing Company

CMC MICROSYSTEMS





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