LIGHT Technologies

A STRATEGIC ECONOMIC ASSET

PHOTONSCANADA

A Report by the Canadian Photonic Industry Consortium – 2016

THANKS TO OUR PARTNERS

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The Canadian Photonic Industry Consortium (CPIC)

The mission of CPIC, also known as Photons Canada, is to assist Canadian companies to optimize operations and to improve profits by facilitating and accelerating the application of photonic technologies that improve quality, productivity and profitability. For more information: **http://photonscanada.ca/en**/

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EXECUTIVE SUMMARY

Photonics is the science of light — how to produce it, detect it, manipulate it, employ it and analyze it. Photons (particles of light) have properties such as colour, polarization and directionality that multiply their uses by an order of magnitude compared to electrons in microelectronic circuits. In fact, photons provide our most precise link to the matter around us and present us with an invaluable opportunity for probing and energizing materials with extraordinary finesse. The technological world is just beginning to tap into this complexity.

Making Light Work for Canada, 2008

PHOTONICS – A STRATEGIC ECONOMIC ASSET

For 20 years, the Canadian Photonic Industry Consortium (CPIC) and its predecessors have helped Canada's Photonics Sector to develop, mature, and serve as an important engine of high-technology economic growth. During these years, CPIC has attracted, on a pro bono basis, the brightest and most experienced minds to this task, with impressive results. In carrying out this work, CPIC has also completed a series of impartial expert studies focussed on developing the Canadian photonics sector. These studies have provided a beacon for technology investments, both public and private. This intelligence has not only served our emergent photonics industry well, it has ensured that Canada remains globally recognized as a player in this increasingly important industrial sector.

Photonics has become a $CDN 650 billion global industry that impacts every sector of Canada's economy and the daily lives of every Canadian. Yet photonics-based technologies still have a relatively low profile among our leaders and decision-makers.

Canada's approximately 400 photonics companies employ more than 25,000 people and collectively generate close to $4.6 billion annually, with an average growth of 10%, of which approximately 65% comes from exports. Most of these companies are sub-system or system-level integrators of photonics components. Imports of photonic goods reached $CDN 6.4B in 2015, indicating the increased potential for today's Canadian domestic photonics industry.

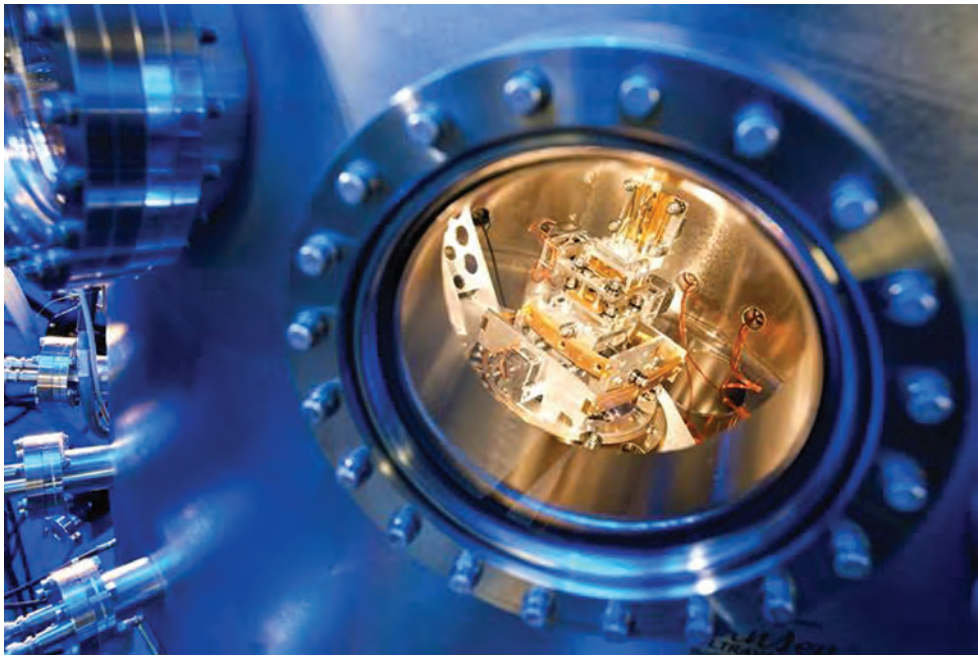


Photo: Canadian Light Source

Although Canada's photonics sector includes a small number of larger companies or divisions, the nation's core photonics producer-sector is firmly rooted in small and medium enterprises (SMEs), plus start-ups with revenues in the $1–10 million range and up to 50 employees. These companies vary from developers and components manufacturers (e.g., lasers, fibre optics) to complete photonics-based instruments (fibre lasers, sensors, cameras, projectors, scanning microscopes, etc.).

Meanwhile, the USA and Europe are developing targeted photonics strategies, focussed on their own economies. Consequently, it is becoming critical for Canada to develop its own strategy, not only to ensure the growth of our photonics industry, but to accelerate the use of photonics by companies in the many industrial sectors that are key to our economy.

Currently, Canada annually invests about $CDN150 million in photonics R&D centres and universities, employing 1000 photonic researchers. However, the research is often untargeted and translation of the outcomes into commercial success must be increased.

Furthermore, although Canada creates world-class photonics physicists and engineers at the PhD level, it neglects to address the shortage of photonics technicians and applications engineers, thereby hampering the industry's growth. More broadly still, most engineers graduating from Canadian universities have had little exposure to photonics, impeding the industry's ability to benefit from photonic solutions in all sectors.

During the past 20 years, Canadian industry has evolved from not knowing what photonics was, to realizing that photonics pervades all aspects of our society. Consequently, the Canadian photonics sector has reached a tipping-point: It can maintain the status quo or pursue all opportunities to play an important role in the future of both Canadian and global photonics development and manufacture.

To do so, the sector must take a more-strategic view of the whole photonics domain. As the sector's consortium, CPIC is uniquely positioned, both in expertise and impartiality, to assist in this mission. If we are to enjoy maximum advantage from the continued growth of global photonics opportunities, we need an up-to-date, balanced view of, and influence on, all sectors.

Recommendations

1. Improve Photonics Education and Awareness

Given that the level of photonics education and awareness in Canada is still inadequate for meeting the ongoing demands of photonics users, photonics courses should become a core part of all undergraduate science and engineering training. Colleges must also increase the number of photonics courses for technicians. In addition, the photonics community needs to proactively engage educators and professional communicators to popularize the photonics world to the general public.

2. Engage the User Community Domestically and Abroad

As demonstrated by the workshops that we held on the various application sectors, the photonics community should engage with the user community to develop solutions that provide leadership to key Canadian industries and exporters. Initiatives such as the Horizon 2020 Program in Europe have demonstrated the value of partnerships between different economic sectors. Canada's photonics leaders should encourage multi-national enterprises to participate in our photonics community. Such outreach will ensure that both national and international user communities will have an informed view of Canada's photonics capabilities, open up opportunities for local system integrators, and raise awareness of our process knowledge.

3. Increase Commercialization of Canadian Technology

Despite the investment in photonics partnership R&D, technology flow and transfer between the academic and industrial sectors is inadequate. We recommend establishing programs that encourage stronger participation and leadership from industrial and university partners. Two proven models are the Horizon 2020 Program in the European Union and the recent creation of the Integrated Photonics Manufacturing Institute in the United States.

4. Focus R&D on Strategic Sectors

Many other countries have focussed investments in photonics: the Integrated Photonics Manufacturing Institute at the State University of New York (SUNY); flat-panel displays in Korea; high-power laser processing in Germany; photonics electronics systems convergence technologies in Japan; and the Association of Industrial Laser Users (AILU) in the UK.

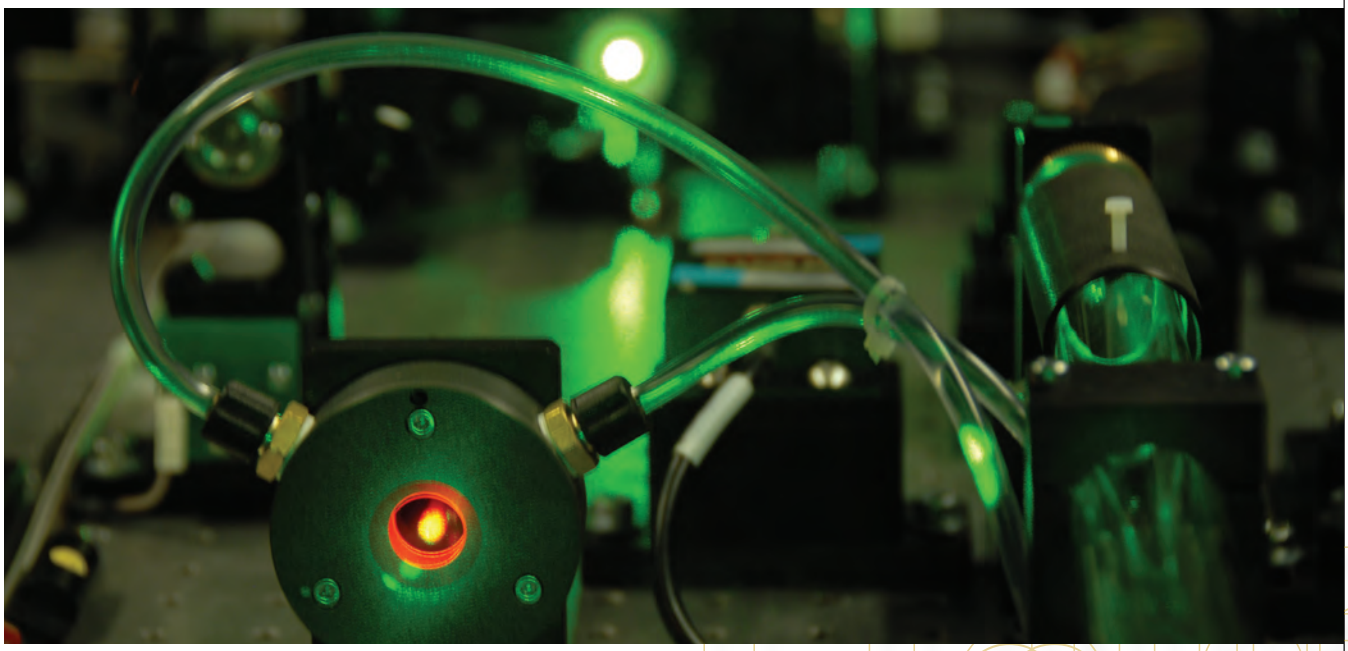


Photo: Defence Research and Development Canada

Photo: National Research Council Canada

Canada's investment in photonics is still broad-brush and relatively unfocussed. We recommend establishing a photonics strategy group that includes industry and academics. Their role: to focus investment on a few key sectors judged to be of global significance during the next ten years, and where Canada has the photonics skills to make a difference.

5. Expand the Cluster Model

Due to Canada's size, two levels of clusters are important for Canada:

1. A national cluster to develop partnership between the clusters and to organize national and international activities.
2. Regional clusters to organize local activities and networking opportunities.

Strong cluster activity encourages the incubation and development of a balanced distribution of photonics companies. The Quebec cluster is very active, while those in Ontario and the western provinces need to strengthen.

INTRODUCTION

On December 20, 2013, the UN General Assembly 68th Session proclaimed 2015 as the International Year of Light and Light-based Technologies (IYL 2015). In proclaiming an International Year focusing on the topic of light science and its applications, the UN has recognized the importance of raising global awareness about how light-based technologies promote sustainable development and provide solutions to global challenges in energy, education, agriculture and health. Light plays a vital role in our daily lives and is an imperative cross-cutting discipline of science in the 21st century. It has revolutionized medicine, opened up international communication via the Internet, and continues to be central to linking cultural, economic and political aspects of the global society. (Ref: http://www.light2015.org/Home/About.html)

PUTTING LIGHT TO WORK

INTERNATIONAL YEAR OF LIGHT 2015

Since their discovery, lasers have launched entirely new fields of science and technology, all classified under the general label of "photonics." The new fields include advanced and additive laser manufacturing; laser micro-processing; non-linear optics; photo-chemistry; and bio-photonics. These applications have developed and transformed whole areas of technology, from the ubiquity of the bar code, to defence systems and entertainment technologies. Unquestionably, photonics will have equally significant effects on health care, manufacturing, energy and the environment.

Photonics enables us to generate, transmit, measure and use light in a myriad of applications that have already enhanced our daily lives. While the late 20th century was the age of electronics, the early 21st century will belong to photonics.

Canada has always played a major role in the world-wide photonics community. We've invested strongly in photonics research; have made a number of important contributions to photonics technology; and are now home to several clusters of photonics companies and research institutions distributed across the country.

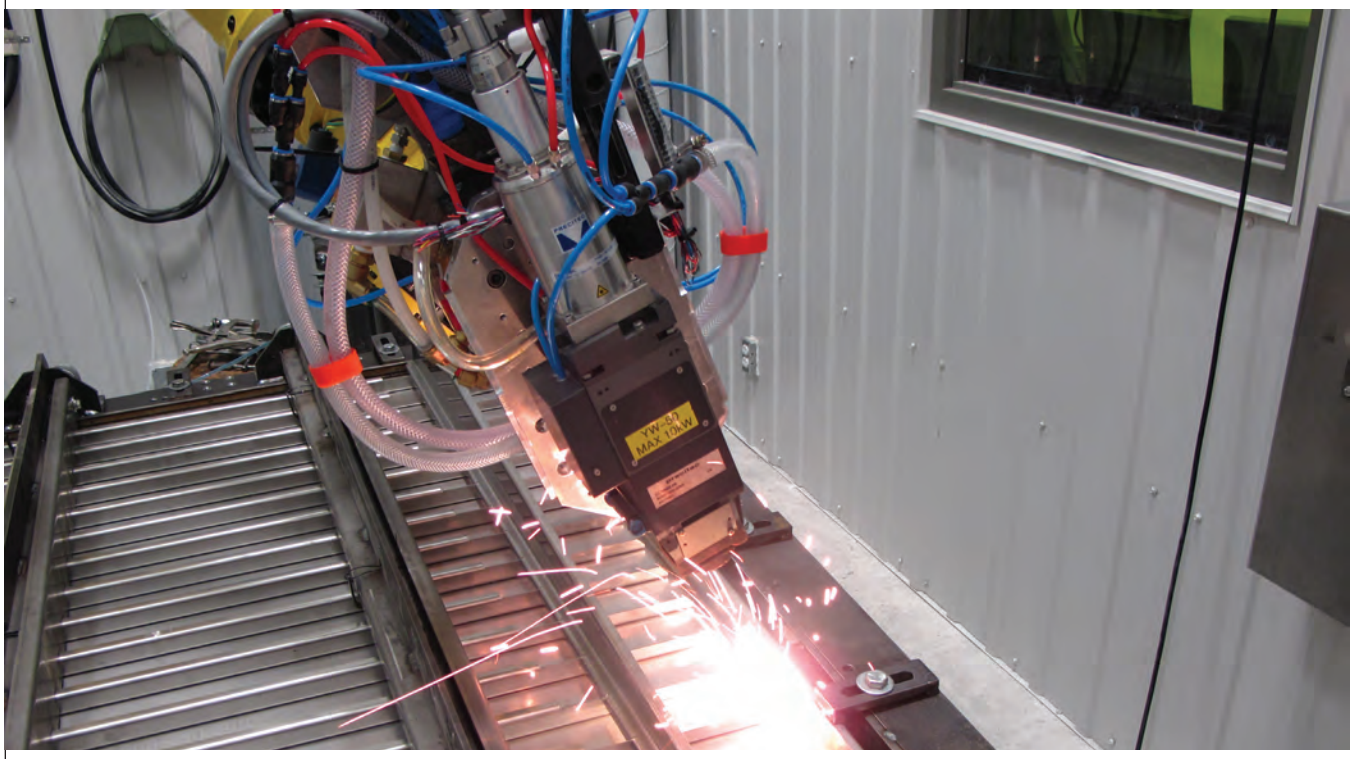


Photo: Novika Solutions

What would increase the economic impact of photonics on the Canadian economy? This report answers that question by examining four areas:

- The status of photonics in Canada, from its science base to its current producers;
- The extent of its application in major sectors of the economy;
- The impact of training and education in creating a highly qualified workforce; and
- How Canada can improve its standing in the photonics arena – for which we make recommendations.

Ironically, despite its ubiquity in a vast array of consumer products, the photonics revolution is virtually invisible to the very consumers who have embraced its rapid assimilation into their daily lives. Nowhere do Canadians benefit more from photonics than in the consumer goods market, where the photonics toolbox has helped power a revolution in the entertainment and computing industries. For example:

- Old-fashioned, bulky cathode-ray (CRT) television sets and computer monitors have been replaced with amazing rapidity by the elegant and compact flat-screen with liquid crystal and LED, computers and tablets that beckon so temptingly from the shelves of Canada's electronics stores.
- CDs and DVDs are still the norm for flexible, temporary and permanent data storage, music, and video – thanks to inexpensive semiconductor lasers and precision optical engineering.
- Photonics has also contributed to reducing the size of the microelectronic components that significantly increased computer capabilities and hardware memory components.
- Meanwhile, low-cost light-emitting diodes and liquid crystal displays have revolutionized portable devices such as cell phones and PDAs, as well as enabling incorporation of cameras and full-colour displays suitable for high-definition video.
- Even the digital camera is a result of enormous advances in solid-state image sensors.
- Internet and wireless mobility brings us virtually free access to instant information and entertainment — wherever we happen to be: in our homes, offices or en route to travel destinations. This information reaches us via the global fibre-optic backbone that connects most cities and towns in the developed world.

While cable and wireless companies have been using optical networks for some time to carry their backbone traffic, they are now racing to meet the seemingly insatiable demand for more bandwidth by targeting optical-fibre-to-the-home.

None of these applications would have been possible without the significant technical advances that have made high-performance photonic components widely available.

Improved Health Services

Light is an efficient and non-invasive tool for medical diagnosis and treatment. Laser-based systems are now commonly used for both internal and external surgery. Lasers are more selective than conventional techniques and cause less bleeding, resulting in faster recovery. Photonic treatments are also increasingly in demand for procedures such as sight correction, removal of skin and pigment irregularities, and hair removal.

Photodynamic therapy — the use of light-activated drugs that are selectively absorbed by malignant cells — is faster, more precise and less traumatic than conventional treatments for many cancers.

For example, biopsies are among the many optical applications that now routinely rely on photonics-based instruments to analyze tissue samples. Furthermore, compact photonic analytical devices are moving diagnosis from the hospital to the physician's office. Eventually, these technologies will enable us to monitor our health from home and to communicate directly with our physician.

In dentistry, optically cured resins have replaced amalgam as filler, and dentists are not only replacing conventional high-speed drills with laser-based devices, but also using 3D imagers to produce high-precision implants.

Energy and Transport

While today's reliance on replacing incandescent light bulbs with low-energy bulbs is a priority for many governments wanting to reduce energy consumption and carbon dioxide emissions, these bulbs are merely a stopgap. High-brightness light-emitting diodes (LEDs) are now the preferred source of all lighting. Solid-state lighting is extensively used for signage, architectural and security applications. LEDs — already used extensively in North America's traffic signals — also glow from the dashboards, tail lights and head lamps of vehicles, and have become common in the cabins of most trains and planes.

Meanwhile, photonics-based advances that make solar cells more efficient are contributing to the move from fossil fuels to renewable energy sources. With its Feed-in-Tariff Program, Ontario is leading the way in building solar plants in Canada, while Alberta is also seriously constructing photovoltaic factories.

Vehicles now include laser-based devices such as lidars and imagers as components in their collision-avoidance and rear-view systems. And, for both terrestrial and avionic entertainment and monitoring systems, plastic optical fibres are increasingly displacing traditional copper wiring — resulting in significant savings in both cost and weight.

Security

Thanks to their compactness and immunity to electromagnetic interference, photonic sensors are ideal for applications in difficult-to-reach locations. That's why they have also become popular for monitoring hot spots on electrical transmission cables and measuring temperature in oil wells.

Photonic sensors offer important safety applications too. Embedded in structures such as bridges, they can give early warnings of potential failures. Security applications are another area with great commercial potential. For example, a single optical fibre installed around the multi-kilometre perimeter of a sensitive site can pinpoint intrusion to within a few metres, making such systems ideal as sensitive and easily deployable security monitoring.

The Defence sector invests heavily in photonics-enabled equipment, from advanced sensing technologies such as infrared night vision systems to laser guidance and weaponry. In fact, fibre optic data busses connecting a host of optical sensors have become the standard for leading-edge military aircraft. Equipped with fibre optic gyroscopes that are not only more compact, accurate and less power-hungry than conventional devices, these newest optical systems are widely used in both military aircraft and weapons. The "fly-by-light" concept is becoming a reality.

Governments invest hundreds of millions of dollars annually in advanced optical sensing technologies, including hand-held, laser-based optical spectrometers capable of detecting and measuring gases and airborne agents from distances of hundreds of metres.

Advanced Manufacturing

Advances in the semiconductor industry have depended in part on the ever-decreasing size enabled by improvements in optical lithography using ultraviolet lasers. The next generation of lithography systems will use laser-produced soft x-ray sources. Laser repair of memory chips and flat-panel displays are keys to keeping yields high and prices affordable. The use of ultrashort pulse lasers for micro-processing and the introduction of photonics at the chip level will increase the capacity of electronic systems while reducing their footprint and power consumption.

Another major advance has been the use of lasers for cutting precision shapes in materials as diverse as metals and clothing fabrics. Similarly, laser-positioning and welding have become standard on many of today's automobile-production lines. Additive laser manufacturing and 3D-printing are new technologies for producing tailored and corrosion-resistant materials while also enabling faster production and reducing both weight and the amount of material required. The lumber industry uses computer-aided laser measurement to maximize the output from each log. In fact, sophisticated laser-vision systems are rapidly becoming the norm to monitor online production processes and quality control. One application familiar to us all: Most of the goods we buy are identified and tracked by laser marking and bar-code scanning.

2 PHOTONICS – ENABLING YOUR WORLD

In 2015, the Canadian Photonic Industry Consortium organized a series of market-focused workshops across the country on photonics technologies of key economic importance to Canada. These workshops were designed to hold group discussions between representatives from industry, university and R&D Centres. The workshops included discussions on business and technology trends in each application sector and how photonics-based technology will likely be used to enhance each industry sector's competitiveness. Detailed SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) of photonics-enhanced solutions is included for each application domain.

2.1 AEROSPACE SECTOR

With more than 700 companies, 180,000 employees and $28 billion in revenues, Canada's aerospace sector is critical to the Canadian economy. The Aerospace Industries Association of Canada indicates that 73% of the industry's activity is dedicated to manufacturing. The Association forecasts that Canada's civil aircraft production will grow by 22% between 2014 and 2021.

For the Aerospace Sector, relevant photonics applications include optical fibres for light-guiding, communications and sensing; lasers for illuminating and processing; 2D and 3D imaging systems; heads-up displays; large-screen projection systems; light-emitting diodes; and solar-energy harvesting. In future, photonics will be a strategic element and a key enabling technology – even more so than today. With tools using light in the form of high-power lasers, processes can be handled automatically and flexibly, producing components and products with extraordinary quality.

That said, the trend towards customization, and the growing importance of industrial design, will continue to require novel methods to enable new product-shape capabilities. Also becoming ever-more important will be novel manufacturing processes with extraordinary quality that will allow mass customization, rapid manufacturing and zero-fault production. This trend in the advanced manufacturing sector was made possible by the recent development of high-power fibre lasers that replaced large-footprint inefficient lasers for processing and advanced manufacturing. Both light-emitting diodes (LEDs) – which have now become a commodity – and lasers that cover the whole visible spectrum are now used in displays, as well as in lighting. Resolution of

OPTIWAVE SYSTEMS INC.

Optiwave Systems Inc. is a committed leader in the development of innovative software tools for the design, simulation, and optimization of components, links, systems and networks for photonics, nanotechnology, optoelectronics and optical communications. Since its inception in 1994, Optiwave's software has been licensed to more than 1000 industry-leading corporations and universities in over 70 countries worldwide. Today, Optiwave's cutting-edge photonic design automation software and customized engineering design services offer its customers a distinct competitive advantage, by vastly shortening their time to market while dramatically improving quality, productivity and cost-effectiveness.

Our products include finite difference time domain and beam propagation software for optical component design, and time/frequency domain block sampling and circuit-level analog simulators for photonic sub-systems and systems.

Optiwave's team of scientists, engineers and software developers is headquartered in Ottawa, Ontario and has an established distribution network throughout the Americas, Europe, and Asia. Optiwave's roots as an R&D company and close ties to the Canadian academic and research community are its key strengths and have enabled Optiwave to maintain its international status as one of the benchmarks for photonic systems design.

electro-optic systems and multi spectral imagers will continue to improve with the use of image-processing. New applications are already developing with the improvement of 3D displays and information-processing. Novel aerospace applications of light-weight fibre sensors, hyper spectral imagers, silicon photonics and solar panels are also being developed. Although the Canadian photonic industry is mainly composed of SMEs, they cover most of these applicable technologies.

2.1.1 Trends

The Aerospace industry faces many needs. These include strong demand to reduce weight and power consumption of air vehicles for fuel economy; and advanced sensors for real-time monitoring of aircraft systems for optimizing flight parameters. Advanced cockpits require high-resolution displays and efficient lighting. Furthermore, photonics-based advanced manufacturing should reduce manufacturing cost, and new photonics-enabled technologies for inspection and maintenance will undoubtedly play a dominant role in improving reliability and safety.

Other aspects, such as countermeasures for security, are of growing importance due to terrorist threats. Robotic technology is already in use and should grow as technology improves. The use of lasers for cutting, welding and surface treatment will also continue to grow as well as for additive manufacturing. The industry expects to use immersive tools for simulation and training, with electro-optic systems simulation and displays for virtual maintenance and manufacturing. In addition, composite materials and the replacement of electric wiring by optical fibres will greatly reduce weight. New technologies such as photo-darkening windows and fly-by-light concepts are already being introduced in airplanes.

2.1.2 SWOT Analysis

The Canadian aerospace ecosystem is well integrated vertically, from fundamental research originating in academia and training of highly qualified personnel, to mature technology development from R&D Centres, Small and Medium Enterprises (SMEs) and government organizations. These factors help Canada to ensure smooth knowledge transfer from research to field use.

Not only in Canada but world-wide, the aerospace sector's large companies need full-scale service delivery at a high Technology Readiness Level (TRL). In Canada, photonic companies are mainly small custom-producers and Small-to- Medium-Enterprises (SMEs). Canada does not have an organization like the USA's Defence Advanced Research Projects (DARPA), which supports new technology developments. Furthermore, the rules of the International Traffic in Arms Regulations (ITARS) are challenging for Canadian companies. Both our aerospace industry and photonic companies should take advantage of currently available programs that support the development of solutions.

In summary, although the major weakness to Canada's SMEs for the aerospace sector is their small footprints, these companies provide solutions to reduce weight and lower power consumption. The photonic community should take every opportunity to advertise this capability to end-user associations and companies. Photonic industries should also strive to increase their Technology Readiness Levels (TRLs) to better-link with the needs of major international aerospace companies.

The greatest threat to the Canadian photonic industry is worldwide technology competition for low cost and added value. Canadian photonic companies should develop specialized niches to respond to the specific needs in aerospace. To do so, they must develop knowledge and expertise in the entire aerospace supply chain.

TABLE 2.1 *Photonics for the Aerospace Sector*

Business Trends
Advanced Manufacturing
Reduced weight and power consumption
Optimization of flight parameters
Inspection and maintenance
More-efficient lighting
High-resolution displays
Flight passenger experience (entertainment, connectivity, etc.)

Technology Trends	Photonic Technology Trends
Increased use of composite materials	Increased resolution of electro-optic systems such as imagers, fibre sensors and lidars.
Wider use of robotic technologies	Laser-additive manufacturing
Use of lasers for welding, cutting, surface treatment, etc.	LEDs and lasers for display and illumination
Laser-additive manufacturing and 3D printing	Improved 3D displays
Electro-optic systems simulations	Increased use of fibre lasers

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
Both sectors have developed strong skills in diverse markets	While the SR&ED program supports the development of new technologies, there is little support for commercialization.
Have accumulated many years of aerospace and photonics expertise and technology development	Unlike Europe and the USA, Canada does not recognize photonics as a key industry capability.
Aerospace ecosystem is very well structured, training HQPs and transferring new technologies to industry is effective.	Lack of communication links between the aerospace sector and the photonics world
Efficient networking between universities, R&D Centres, private sector and Government	The needed key technologies are from Germany for manufacturing, and from Asia for displays.
Opportunities for Canada	**Threats to Canada**
Many existing photonic technologies can already respond to the aerospace sector's needs.	If not available in Canada, aerospace industries will find their photonic solutions from outside the Country.
Photonics capabilities should be advertised to end-user associations and companies.	Strong world-wide competition for cost and added value
Photonics provides excellent technologies to reduce power requirement and weight.	If photonics is not recognized as important, Canada will lose the global market and the Canadian HQPs will move to USA and Europe.
The explosion of Unmanned Arial Vehicles (UAVs) is an opportunity to test light-weight and low-power photonic technologies.	

2.2 AUTOMOTIVE SECTOR

Canada's Automotive Manufacturing Sector is also critical to the Canadian economy. According to Canadian industry statistics, motor-vehicle manufacturing employs about 37,000 persons for a total production of $53 billion. In addition to that, there are about 64,000 employees in the motor vehicle parts manufacturing community, with a production of $24 billion. Their productivity is very high with material and supplies representing between 64% and 83% of the production (source: Canadian Industry Statistics, **www.ic.gc.ca**). With the trend toward autonomous cars recently demonstrated by Tesla, Apple and Google, the car of the future will include a mix of sensors, radars, cameras and lidars — technologies that have all been developed from the photonics sectors and will likely provide interesting future opportunities for the photonics industry.

Many photonic domains are applicable to the automotive sector: Information and communication technologies (ICT); advanced manufacturing; imaging; sensing; monitoring; signage; and lighting. Although Canada's photonic industries are mainly SMEs, they have developed their niche by producing components, equipment, software and photonic integrated circuits for optical communications that could be used for vehicles. One of the most important recent advances made in the automotive sector has been the use of high-power fibre lasers for cutting, welding, additive manufacturing and other advanced manufacturing processes. Ever-newer processes with extraordinary quality will enable mass customization, rapid manufacturing and zero-fault production to become even more important as new light-weight composite materials are developed for improved fuel consumption. Innovative laser processes will bring additional major competitive advantages to the automotive manufacturing industry. Fibre-optic and distributed sensors complete the Canadian offer. Other photonics applications are underway in process improvement and environmental monitoring, as well as LED signage and lighting solutions. The Canadian photonic industry therefore presents excellent opportunities for the automobile sector.

2.2.1 Trends

In addition to using advanced manufacturing with robots and lasers for cutting, welding and surface treatment, the trend towards customization and the growing importance of industrial design will require novel methods to enable new product-shapes capabilities. Looking ahead, new manufacturing processes with extraordinary quality that will allow mass customization, rapid manufacturing and zero-fault production will become important. The car industries will be seeking technologies for improved safety and environmental protection. Driver assistance, enhanced lighting, pedestrian protection and adaptive cruise control will help to develop safer automobiles. Car-to-car and car-to-infrastructure will require photonics-based connectivity, wireless links, human-machine interface and navigation data. More broadly, photonic applications will contribute to protecting the environment through emission-reduction, alternative energy and weight reduction.

Photonics will also help address expectations regarding "the car of the future." Enhanced, more-efficient and effective lighting will be important – expectations most likely to be met by novel materials, more-sophisticated optical elements and new tooling. Given, too, the amount of data generated by the numerous sensors, rapid information-gathering and situation-awareness will be critical, and will require intelligent vision systems and advanced microelectronics. The automobile will also need new technology for energy storage.

Turning to the manufacturing industry, lasers – with their 35% electrical efficiency and high power – are becoming the main manufacturing tool in the automobile sector. With today's 2D/3D capability, laser cutting is more flexible than stamping for thin-metal cutting. Remote spot welding is nine times faster than the standard welding machine. For heavy transport (which needs to weld thick material), hybrid laser welding is four times faster than the standard process. The automotive sector also uses lasers for brazing, cladding, heat treatment, drilling and marking. Micro-lenses and holographic inserts are technologies suitable for mass production, which complements the use of solid-state lighting. Improved fibre sensors, imagers, and advanced displays complete the photonic technologies applicable to the automobile.

2.2.2 SWOT Analysis

Canada has laser-processing centres such as Novika, INO and a number of universities with capability and expertise to develop high-power laser processes. Government support to the industry is efficient with its NRC-IRAP, SR&ED, and Made-in-Canada programs and research centres. With the number of universities now involved in photonics, a strong and highly skilled workforce is available to the industry.

For auto and auto parts manufacturers to use laser processing, they need to analyse the economic value of modifying their manufacturing process and to obtain support for process development. SMEs must still meet significant overhead with Government programs. Although training students in manufacturing processes and mechanical engineering is adequate, their knowledge of photonics is limited – or even nonexistent. In addition, there is no efficient link between the automobile sector

and photonic clusters. Furthermore, universities and industries should work more closely, as they do in other countries.

It is important to improve and increase communication with the automobile sector about the benefits of using photonics and laser processing. The photonic industries should develop lower-cost photonic solutions to facilitate their use by the automobile sector. Since the car of the future will need a significant number of sensors and imaging systems, the photonics community has a golden opportunity to support this sector and to develop strong links between the two clusters. By working closely with industries, university researchers will develop an "industry mind" approach, and conversely, industry will better understand and appreciate the researchers' input.

Another consideration: Since it is much easier for start-ups to find investment capital in the USA, talented Canadian students may be inclined to move there to create a company. We need more students in photonics to respond to future growth. Global competition for people and technologies is very strong and Canada must rapidly develop solutions to maintain its global share in photonics.

TABLE 2.2 *Photonics for the Automotive Sector*

Business Trends
Advanced manufacturing of light-weight composite material
Secure, connected vehicles for navigation and car-to-car communications
Vehicle-to-vehicle direct-sight communications
Automobile lighting with new, more-efficient sources
Laser welding for efficiency and faster production
Green technologies for energy, weight reduction and low fuel consumption

Technology Trends	Photonic Technology Trends
Real-time environmental monitoring	Improved image sensors and vision systems
Processing at very high bandwidth	Much higher accuracy of manufacturing systems through photonic technologies
Intelligent vision systems	5-Axes manufacturing equipment guiding laser processing
Dynamic lighting with nano/micro technology, novel materials and optical elements	Advanced manufacturing with an improved quality factor
More-efficient technology to make automobile components	High-power, high-frequency and short-pulse lasers

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
The use of laser processing to improve productivity in large companies	Lack of effective communications between industry and universities. (Germany's Fraunhofer-Gesellschaft would be a good model for Canada.)
Novika: a good example to follow for accelerating use of laser-processing by SMEs	Lack of opportunities to link photonics community with end-user industries
Highly skilled workforce with photonic grad students	Lack of training on photonics for undergrad and technical students
Well-equipped research infrastructure	Slow transfer from research to development and innovation
Government support for industry research through IRAP and SR&ED	Government programs require large overhead that SMEs can't afford

Opportunities for Canada	Threats to Canada
Use of ultra-short pulses to manufacture light-weight composite material	International partnership agreements that could accelerate skilled personnels' move elsewhere
Development of regional clusters to link the photonic community with local end-users	Need to offset strong global competition by anchoring Canada-based companies and trained people
Creation of problem-solving approach between end-user associations and the photonic community	Shrinking of Canada's photonics talent pool due to fewer students' interest in pursuing a career in photonics
Development of an "industry mind" in universities	If Canada is unable to attract capital, it may result in exodus of talent and intellectual property.
Education of undergraduate and technical students in the basics of photonics and its opportunities	Competing technologies and perceived high cost of photonic solutions
Improved industry-university collaboration using Germany's Fraunhofer Gesellschaft model	

2.3 COMMUNICATIONS AND MICROELECTRONICS SECTORS

Numerous Canadian companies are involved in optical communications. Currently, many Tier-1 multinational network-equipment manufacturers undertake a significant proportion of their R&D in technical centres here, including Ciena, Alcatel-Lucent, Huawei, Cisco, and Ericsson. In addition, many other companies offer components and subsystems to these giants, or occupy a complementary market niche in the optics-enabled communications and microelectronics sector. These companies include Viavi Solutions (formerly JDS Uniphase); and Lumentum (recently split from JDSU); as well as EXFO and TeraXion, to name only a few.

In 2013, Statistics Canada indicated that Canada's information technology and communication (ITC) manufacturing sub-sector exported 81% of its production, representing a total of more than $10B in 2013 (a drop of 39% compared to 2007). Currently, our domestic communications industry faces substantial headwinds arising from low-cost commoditization of telecommunication devices – a secular trend reinforced with the on-going explosive growth of large-scale data centres. That said, many Canadian-based companies have successfully leveraged their in-house expertise and innovative capabilities to develop, patent-protect, and market high-value-added components and subsystems, which, at least for the time being, are less susceptible to offshore commoditization. Nonetheless, the long-term sustainability of these companies would be greatly enhanced if Canada were to develop suitable photonics-related technology strategies on two fronts: on one, to facilitate the growth of our photonics telecommunications industry; on the other, to accelerate our domestic firms' own use of photonics in the many (non-ITC) industrial sectors that are key to our economy.

2.3.1 Trends

Although R&D and innovation are carried out in North America, there is a still-continuing tendency to move services and manufacturing to Asia (although the USA has been moderately successful at repatriating some manufacturing operations). Bandwidth growth and security requirements are driven by several principal factors, including data communications; increasing use of cloud and data centres; increasing transfer of HD videos to the customers and "the Internet of Things."

These business trends have consequences for technology development. The growth of data centres requires short-reach interconnects. Content providers, meanwhile, exert strong pressure in three areas: to reduce cost-per-bit; to address strong cost sensitivity to "last-mile" deployment; and to mitigate additional pressure for an ever-more-shortening product cycle. With 100 Gigabits per second, (per narrow optical channel) already deployed, and 400 Gbps on the horizon, there is ever-increasing pressure to fully exploit low-attenuation spectral windows of optical fibres.

One technology trend is rapid network reconfiguration via programmability: for example, with Software Defined Networks (SDN) and Network Function Virtualization (NFV). New opportunities are arising from advanced modulation of optical carriers, which permit transmission of more information per bandwidth than traditional on/off switching schemes, routing and switching schemes (such as micro-electronics and optics), and laser sources with programmable logic controllers. Examples of advanced modulation are multi-level signaling formats such as Pulse Amplitude Modulation (PAM-N), an enabling technology for 400G implementation. However, the revolutionary switch from non-return-to-zero (NRZ) to PAM-4 presents many new challenges related to design, measurement, and testing. The use of advanced modulation techniques underpins the development of next-generation single-carrier bandwidth transmission in the 400 Gb/s and 1Tb/s arena. In addition, WDM with much tighter inter-carrier spacing will be developed achieving high-scale integration by using silicon photonics and Indium Phosphide technologies.

2.3.2 SWOT Analysis

In Canada, Government support has helped ensure a strong research capacity through research grants and programs provided by such sources as the Canada Foundation for Innovation (CFI); the Natural Sciences and Engineering Research Council (NSERC) partnership programs; Scientific Research and Experimental Development (SR&ED); and programs to support the hiring of Highly Qualified Personnel (HQP).

Furthermore, Canadian industry can access a skilled workforce and a large talent pool. A good model is the Silicon Electronic-Photonic Integrated Circuits (SiEPIC) organization, which trains students to design and model silicon photonics. In addition, Canada has good links among industry, university and R&D centres, collectively resulting in a quite robust "photonics eco-system."

The Canadian photonics industry, however, is fragmented. There are no plans or strategies to develop a critical mass in high-value sectors. Since Canada is a small player facing strong international competition, we need to select our niches. Industry should be more proactive in "outreach" and other initiatives to entice more students to study science, technology, engineering and mathematics (STEM). We should also leverage our diverse multicultural workforce to help SMEs reach more international and emerging markets. Many new opportunities are created through advanced technologies. The industrial sector should make greater use of our available photonic skill sets and talent pool.

OPTEL VISION

Optel Vision is the #1 global provider of solutions for traceability of pharmaceuticals, specifically in terms of optical-electronic-IT solutions integrated in production lines.

With nearly 400 highly skilled employees, including 300 in Quebec City, Optel Vision is an important player for wealth creation for Quebec and Canada. With over 90% of its income from exports, exceptional profitability and a network of local suppliers, Optel Vision contributes greatly to Canadian economic development.

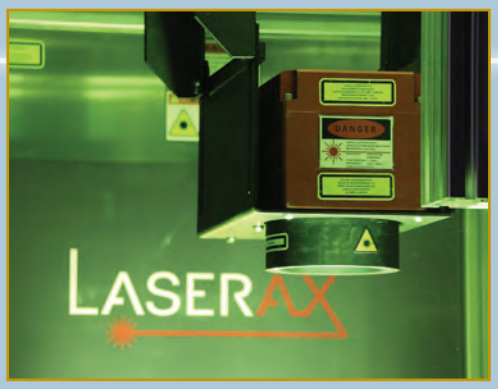
TABLE 2.3 *Photonics for the Communications and Microelectronics Sectors*

Business Trends
Strong pressure on power and cost reduction at all levels (joules/bit and $/bit)
Dramatic increased requirement for bandwidth with datacom, HD video and Internet of Things
Short-reach interconnects for data centres
Security: critical for data communications

Technology Trends	Photonic Technology Trends
Packaging to reduce cost and increase performance for deployment	Integrated photonics with Silicon Photonics and Indium Phosphide technologies (PICs)
Chip level integration (PIC)	More accessible nano-photonics
Network programmability with Software-Defined Networks and Network Function Virtualization	Quantum dot-based lasers and amplifiers
Advanced modulation schemes and Spatial Mode Multiplexing	High-power, short-pulse lasers applied to micro-fabrication
	Moving toward mid-infrared and Terahertz spectral windows

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
Skilled and talented workforce	Not enough critical mass in certain areas; too thinly distributed; no comprehensive photonics marketing strategy
Good connections and collaborations between Industry and Universities	Lack of Canadian-based multi-national companies
Government support for research and infrastructure in Universities	Difficulty of retaining talent
Well-developed eco-system	Limited ability to address global markets
Opportunities for Canada	**Threats to Canada**
Many new emerging markets which should be addressed	Strong international competition from countries with lower entry barriers and offshore manufacturing
Need to promote and “sell” Canada’s “brand”	Slowly losing manufacturing-aware engineering skills
Need to leverage our multicultural workforce	Losing valuable and well-trained talent
Need to attract multinational enterprises with our lower R&D cost and low carbon footprint	Need to address Intellectual property theft

LASERAX



Created in 2010, LASERAX is a manufacturer who supplies "innovative, robust and safe" laser solutions for most demanding industrial applications. With its team of experts in laser technology, LASERAX offers a full range of products, services, and applications for cutting, marking and welding different materials.

Over the last five years, we have provided solutions to various industrial sectors, including personal hygiene, agriculture, automotive and processing of aluminum. Whether by doubling the speed of a production line, drastically improving the quality of a manufacturing process or allowing the production of new products using an innovative laser method, LASERAX creates manufacturing wealth. Continually pushing the boundaries of lasers, our solutions generate value-added and improve the competitiveness of our industrial customers.

2.4 DEFENCE AND SECURITY SECTOR

The Defence and Security Sector is important for Canada, both for safety issues and Canada's economy. The federal Government has a major acquisition program for the Military, and the Defence and Security industry employs about 109,000 people for manufacturing, maintenance and repair. Fifty percent of the Sector's annual sales of $13B is exported (**www.defenceandsecurity.ca**). The prime industry associations for this sector are CADSI-Canadian Association of Defence & Security; the CANASA-Canadian Security Association; and AIAC-Aerospace Industry Association of Canada. Photonic research within Defence Research and Development Canada is located in Valcartier, Quebec.

Many photonic domains can be applied in the Defence and Security sector, including information technologies and communications (ITC); manufacturing; imaging; sensing; monitoring; signage; and lighting. As demonstrated during the presentations at the workshop, the Canadian photonic industries are mainly small and medium enterprises (SMEs) that have developed their niches by producing components, equipment, software and photonic integrated circuits (including "light-on-a-chip" based on indium phosphide and silicon photonics). Quantum technologies to ensure secure communication links also have potential for sensing. The sector includes many industries offering spectroscopic solutions; spectral imagers; and tunable lasers for spectroscopy to detect gases in chemical warfare. The Sector also markets fibre lasers for cutting, welding, additive manufacturing and other advanced manufacturing processes. Fibre-optic and distributed sensors complete Canada's offer for imaging sensors. A few companies are involved in process- and environmental monitoring, while others offer LED signage and lighting solutions. The Canadian photonics industry therefore presents excellent opportunities for the Defence and Security sector.

2.4.2 Trends

Integrating information from different sensors is challenging, as is management of large amounts of information to establish situational awareness. Consequently, Defence and Security customers are looking for pervasive and extreme-performance solutions. These become very attractive for industries that are looking for complementary solutions which could be applicable to many other customers.

For this sector, the technologies that are highly attractive are those that can provide not only adaptive systems, but also information about the environment and potential threats. Consequently, smart sensing and autonomous systems are of critical and growing importance, as are technologies for human safety and health monitoring.

Photonic technologies are highly suitable for sensing, detecting and identifying environments and threats. Spectroscopic sensors and imagers, and fibre sensors have widespread applications for defence and security, so the association of a variety of sensors (visible, infrared, THz, hyperspectral and multispectral, etc.) provides more-accurate information. Silicon photonics is becoming the approach to miniaturization of systems, and quantum sensing is of growing interest. For remote sites, advances in photovoltaics are also important, since energy harvesting remains an important issue for the military.

2.4.2 SWOT Analysis

The Canadian photonic community is diverse and spread throughout the nation. Canada has more than 36 universities producing a highly skilled workforce in photonics. We also have R&D Centres that translate the technology through technology-readiness levels from TRL-3 to TRL-6, and we have a strong "photonic corridor" linking Quebec, Montreal, Ottawa and Toronto. Canada's industries have also developed equipment and systems that are not affected by the US ITAR regulations. The "Made in Canada" program is an excellent approach for bringing technologies to market.

The federal government supports the Defence industry for R&D through its federal scientific research and development programs, but funding has been reduced significantly just when Defence R&D needs more support. The Canadian defence market is not strong, and our

industries must rely on exports. There is no local multinational enterprise (MNE) that could integrate our Canadian photonics technologies. Most – if not all – of these MNEs are foreign-owned, with headquarters outside Canada. Furthermore, some companies find it difficult to deal with the Government's procurement system. In addition, the Goverment does not recognize photonics as an important technology for Canada – which limits the development of a Canadian photonic strategy.

Since Canadian industries have developed equipment and systems that are not affected by the US ITAR regulations, they are in a good position to market their products in Europe and Asia within the Canadian regulations. The need for border surveillance is a strong opportunity for the photonic industry. Photonics provides solutions to complement human surveillance capability in urban areas for rapidly detecting potential threats. The Industrial Regional Benefits program has been modified to become an Industrial Technology Benefits program, which should offer new opportunities to our photonics industries.

The status quo is a significant threat to the Canadian photonics industry. The industry must increase industrial R&D and maintain Canada's manufacturing capability. Many Canadian defence industries are foreign-owned, which affects critical business decisions. To ensure future industry growth, the sector needs to increase both the general public's and students' interest in technology.

TABLE 2.4 *Photonics for the Defence and Security Sector*

Business Trends
This sector needs pervasive technologies such as photonics.
Cyber security is of growing importance.
Information overload and data integration are becoming problematic.
Alliances are necessary, since security is a global concern.
They need better, faster, smaller and lower cost equipment.

Technology Trends	Photonic Technology Trends
Situation awareness	Rapid increase of photovoltaic capability
Renewable energy	Multi-sensing capability
Soldier-health monitoring	Spectroscopic detection of chemicals
Remote sensing	Hyper-spectral, multi-spectral, polarization-based and quantum sensors
Miniaturization of equipment and Intelligent integration of sensors	Higher-power and wavelength diversification of fibre lasers

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
Highly skilled workforce	Lack of financing to bring a product from TRL 4 to the TRL10 level
Strong photonic cluster in Quebec City around Université Laval and Institut national d'optique; close to Defence Research Development Canada (DRDC)	Canadian market very limited in size
Increased maturity of Canadian photonics companies	No local multinational enterprise to integrate our SMEs' innovations
Capable of offering ITAR-free systems	Weak Government support to the industry (e.g., the reduction of SR&ED credits)
Strong photonic corridor between Quebec, Montreal, Ottawa and Toronto	No photonic strategy within the Government

Opportunities for Canada	Threats to Canada
Border surveillance is a good market for photonics.	Limited investment in photonics R&D could create a Canadian technology gap.
The market for ITAR-free products is open to Canadian industries.	Other countries are investing massively in technology.
The Industrial and Technological Benefits program is a good opportunity for the photonic community.	In some cases, acquisition of Canadian companies by foreign companies results in the loss of employment in Canada.
Remote detection and surveillance is well-suited to photonic devices.	ITAR regulations limit marketing to other countries.
Suitable technology is needed to augment the human capability.	Students' (and the general public's) lack of awareness of photonic technologies.

2.5 ENERGY SECTOR

Canada's energy sector, which includes Oil & Gas, Solar, Wind and Hydro Power, provides an essential commodity for all Canadians. Crude oil represents about half of the Canadian commodity and is our largest export product. However, the Canadian growth of oil and gas production since 2011 is much lower than that of the USA, as well as that of the whole world. Furthermore, with the lower cost of photovoltaic modules, we are seeing a constant growth of solar installations, largely in Ontario (thanks to the Feed-in-Tariff Program), but also in Alberta and other provinces. In addition, the Canadian Government supports the development of efficient and "green" processing technologies to reduce our industries' environmental impact.

Many photonic technologies are applicable to the energy sector, including cameras and sensors, laser-processing systems, monitoring devices, lighting and signage. Although mostly SMEs, the Canadian photonics industry covers most of their technology needs. For example, fibre lasers could be used not only for acoustic detection of leaks, but to cut, weld or manufacture new pieces of material. Optical communications facilitate sensor-fusion and integration, and embedded photonic devices are now feasible using MEMS, nanotechnologies, and silicon photonics. Solid-state illumination increases lighting efficiency and the lower cost of photovoltaic systems is becoming very competitive.

2.5.1 Trends

Now that Canada has committed to the G7 plan to end using fossil fuels by 2100, our industries must reduce their carbon footprint by process-optimization and more-efficient extraction. This commitment means that they must develop new technologies in an environmentally friendly way to use with "clean energy" (such as solar and wind). The energy industry wishes to use new technologies to detect and reduce all gas emissions. Photonics technologies offer the industry many different approaches. In Canada, the cumulative number of installed photovoltaic systems demonstrates a significant annual growth of more than 30%. The Internet of Things and Big Data are also rapidly becoming significant, since real-time monitoring, intelligent analysis and information management are essential to optimize the processes.

2.5.2 SWOT Analysis

Photonic solutions have many benefits, including flexibility, a small foot print, and rapid prototyping. Furthermore, various photonic systems could respond to the needs of more than one application domain, and development of new photonic products does not necessitate high-cost equipment. Canada's large companies in the energy sector need full-scale service delivery, since Canadian photonic companies are mainly SMEs and small-volume specialized product manufacturers (rather than large-volume producers). Consequently, the chasm between technology development and the operational system remains large.

OZ OPTICS

Under the direction of Ömür Sezerman, (the company's founder, CEO, and president), OZ Optics has evolved to become a leading developer and manufacturer of fibre optic components, test equipment, and sensors. Started in 1985, it now boasts vendors in over 30 countries and more than 10,000 customers worldwide. Its three manufacturing facilities, in Canada, Turkey, and China, house nearly 400 employees. More than 200 of those employees can be found at the company's headquarters and R&D facility in Ottawa.

OZ Optics works closely with local universities and research institutions to bring new ideas from the lab to the marketplace. Much of this work has contributed to OZ Optics' broad patent portfolio. From its beginnings as a pioneer in polarization-maintaining components, OZ Optics has always been an early adopter of new technologies. It is one of only a small number of companies in the world using femtosecond lasers, as well as being one of the few companies that has successfully exploited Brillouin sensor technology. With an in-house machine shop, optical coating facilities, and clean rooms, supported by a well-trained staff encompassing all relevant disciplines, OZ Optics is well positioned to continue its expansion in new and exciting directions in the field of fibre optics.

Photonics-based developments in information and communication technologies, micro-electronics, illumination, lasers and sensing could find valuable applications in the energy sector. Furthermore, Canada's new federal regulations on environment will result in an increased need for photonic sensors to monitor the environment, as well as for process efficiency and productivity improvement.

Depressed oil & gas prices limit investments in development of new technologies, making low-cost conventional solutions more attractive. In the case of photonics research, Canada has a limited number of photonics-focussed, multi-national companies with long-term vision that could mature technologies from proof-of-concept to full production. Therefore, the development of efficient links between the energy and the photonic sectors should be beneficial to both industries.

TABLE 2.5 *Photonics for the Energy Sector*

Business Trends
The industry is looking for efficiency improvement.
The energy industries (Oil & Gas; Solar) need better monitoring capabilities at all levels.
The trend is toward sustainable energy and renewable resources.
Solar energy is moving from provincial to municipal support.

Technology Trends	Photonic Technology Trends
A change of mentality: industry is now more open to new technologies.	Reliability improvement
Internet of Things and use of Big Data impacts importance of photonics	Photonic packaging for harsh environments
Increased demand for information processing and analysis	Reduced cost is increasing the availability of photonic solutions.
Technology integration	Wider use of spectrum
Use of multiple-technology input for better decisions	Increasing use of high-power lasers with local laser manufacturers

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
High-quality personnel and critical mass in photonics	Photonics still seen as an enabling technology, but not as a sector.
Flexible and scalable photonic technologies	Photonic industry does not get support similar to that available in Europe or the United States.
Unique photonic capability responding to Oil & Gas needs	Lack of links for collaboration between clusters
Canadian capability in photonic micro-fabrication	Different cultures between technology developers and production industry
Strong expertise in Oil & Gas	Canadian photonic industry still too small and scattered in both location and applications

Opportunities for Canada	Threats to Canada
The energy sector has strong motivation for improving efficiency and productivity.	Difficulty of financing new concept developments within the present investment climate
Government regulation on environmental issues for the energy sector creates strong opportunities for photonic industries.	Depressed Oil & Gas price limits introduction of new technologies.
Photonic industries should make use of the world-class expertise of the energy sector.	Competition from foreign producers
The creation of an Oil & Gas Photonics cluster would improve links between needs and solutions.	Lack of vision to support photonic industry
	Low cost of established technologies limits investment in new ones

2.6 HEALTH AND MEDICAL SECTOR

As in most developed countries, Canada's health and medical sector are very important and represent significant spending of $219B across all levels of Government, representing 11% of GDP. The Provinces reserve, on average, 38% of their budget each year (source: National Health Expenditure Trends, 1975 to 2015, October 2015, Canadian Institute for Health Information). Canadian medical-device production and distribution employs about 35,000 persons, with sales of $7B (source: **www.medec.org**). Eighty percent of the industry is located in Ontario and Quebec, with a strong concentration of 1200 firms in the Greater Toronto Area (source: **www.greatertoronto.org**). Medical devices have many applications, including for diagnostics, patient aids, orthopaedics and dental applications. Canada's most-important medical industry associations are MEDEC (Medical Technology Companies) and CMMA (Canadian Med-Tech Manufacturers Alliance).

According to the Optical Society of America's Industry Development Association, global health-care spending is evaluated at more than $US 8 trillion, which includes spending on medical devices of $US 600 billion, from which US$ 54 billion is for bio-photonics. Therefore, bio-photonics plays an immense role in the health and medical sectors. For example, micro-sensing helps to investigate cells and tissues; cytometry is used to characterize cells; bio-analytics and bio-fluidics develop lab-on-a-chip devices; and in-vivo analysis, equipment for clinical diagnostics and clinical therapeutics are all applications of photonics.

In addition, many photonic domains are applicable to the Health and Medical sector, including Information Technologies and Communications (ITC); manufacturing, imaging, sensing, monitoring, lasers, lighting, spectroscopy, fluorescence, etc. Although Canada's photonic industries are mainly SMEs, they have developed their niche by producing components, equipment, software and photonic integrated circuits for various applications. They also market fibre lasers for cutting and treating. But the Health and Medical sector also benefits from photonic applications that other sectors rely on, such as fibre optic and distributed sensors, and LED lighting solutions. Furthermore, the industry has created a significant international foothold in niche photonic components – in addition to noticeable photonic systems development. The Canadian photonic industry therefore presents excellent opportunities for the Health and Medical sector.

2.6.1 Trends

Although new sophisticated equipment and medical devices have been purchased by Canada's laboratories and medical offices, the amount of new data gathered from various sources is so enormous that storing and analyzing it is a challenge. In addition, Canada's aging population is putting high stress on the health-care sector, resulting in a need for low-cost, high-performance equipment to be distributed widely in the community. These advances in technology, which are accelerating progress towards personalized medicine, are nevertheless becoming a reality that is already highly appreciated.

The medical sector makes as much use as currently possible of the innovations that were or are being developed for other sectors. For example, development of advanced micro-electronics devices for communications now facilitates the miniaturization of bio-sensors. As the medical field progresses, it creates a need for more accurate and safe equipment to replace old technologies.

Photonics – and more specifically, bio-photonics – now plays a tremendous role in the improvement of the health-care system. Smart, miniature and distributed sensors using optical fibres; lasers tuned to more efficiently treat biologic material; and spectral and 3D imagers are new tools now available to medical personnel.

2.6.2 SWOT Analysis

Canada has a world-leading academic team in Toronto and in many universities and research centres. With our proximity to the United-States, our industry has access to a large market to complement the Canadian one. Canada's industry-university link in bio-photonics is strong and facilitates the training of highly qualified personnel.

Both the federal department of Health Canada and Canada's medical personnel have difficulty in accepting new modalities that are optimizing the use of new technologies. Furthermore, no multi-national enterprize on medical devices has headquarters in Canada and therefore, business decisions are made outside of our country. We also need more student entrepreneurship to create companies based on new technologies. Although the industry has access to the federal *Build in Canada Innovation Program* (which financially supports some projects at the last level of development), Canada needs a program similar to the US *Small Business Innovation Research (SBIR)* program, which also supports development at lower levels of readiness.

Canadian industry is well-positioned to make use of today's easy access to the global market in bio-photonics. Our bio-photonic experts are recognized

worldwide, which facilitates our ability to create companies based on these newly developed photonics technologies. Next, we must proactively raise venture capitalists' awareness of the broad opportunities photonics technology offers to address the medical market.

Since the global market is accessible to all countries, we need to be more competitive to access and maintain our market share. Canada's bio-photonics start-ups urgently need more financial support to compete on an international scale.

Bio-photonic research is financed by two funders: the Natural Sciences and Engineering Research Council of Canada (NSERC) funds medical-devices research, and the Canadian Institute for Health Research (CIHR) funds health improvements and clinical trials. It is important to maintain these funding sources to ensure the continuation of bio-photonic research that can translate into medical innovations. We must also access financial support to efficiently translate new innovations into applications.

TABLE 2.6 *Photonics for the Health and Medical Sector*

Business Trends
Emerging Big Data drives the new business models by exploiting the Internet, the cloud, data interpretation, etc.
An aging population requires increased medical technologies and services.
Increased use of wearable systems and tele-medicine
Distributed healthcare delivery
More-efficient equipment through better performance at lower cost

Technology Trends	Photonic Technology Trends
Miniaturization and portable devices	Reduced cost per optical watt, power-per-bit and increased usable bandwidth.
Technology for minimally invasive approaches	Miniaturization of devices
Greater precision of tools	Quantum optics for sources and sensing
Regenerative medicine (replacing, engineering, or regenerating human cells, tissues or organs.)	3D imaging
Safe imaging technology to replace X-Rays	Fibre lasers tuned to diverse applications

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
The ease with which we can export from Canada, and our excellent international reputation	Weak Government funding for industrial research
Solid-based academics with world-leading photonics researchers	No equivalent to the US SBIR (Small Business Innovation Research) program that supports the development of new products
Excellent training of next-generation, well-educated workforce	"IP treatment varies between universities (designation of ownership, royalty awards, etc.)"
Strong knowledge-based electronics from Canada's telecom sector	General public unaware of photonics' potential as an important technology
Development of an efficient eco-system	Lack of Canadian non-Government capital for growth

Opportunities for Canada	Threats to Canada
To educate VCs, "Angels" and politicians about photonics	The global market is available for all countries and therefore Canada needs to be more competitive.
Easy access to the global market	Little understanding of photonics' significance by various governments could result in insufficient support to remain competitive.
Proximity to the USA should facilitate marketing.	Lack of investment capital to exploit new technologies encourages exodus of skills and IP.
Some hospitals are open to demonstrations of new technology.	If Canada does not maintain development of expertise in bio-photonics, we will lose our competitive stance.
Medical personnel should learn more about photonics.	Restrictive research practices limit translational research.

PHOTON CONTROL

Photon Control Inc. designs and manufactures a wide range of optical sensors and instruments to measure temperature, pressure, position, and flow. These products are used by original equipment manufacturers (OEM) as well as end-users in the Semiconductor, Oil and Gas, Power, Life Science, and Manufacturing industries around the world. Photon Control's products provide high accuracy and reliability in extreme conditions and are supported by a team of experts that offer onsite installation, training, and support. Photon Control Inc. also provides engineering services for customized optical measurement systems. Headquartered in an ISO 9001:2008 manufacturing facility in Burnaby, BC, Photon Control Inc. is listed on the TSX Venture Exchange, trading under the symbol PHO.

2.7 NATURAL RESOURCES SECTOR

The Natural Resources Sector contributes to about 20% of the country's GDP and therefore has a significant impact on our economy. The main drivers are Energy, including Oil & Gas; Solar; Wind and Hydro Power; Metals and Mining; and Forestry. Of these, natural resources such as crude oil represent about half of the Canadian commodity and are our largest export product. Energy represents 28% of Canadian exports, and other non-agricultureal natural resources represent 24%. This sector generates direct employment for about 900,000 Canadians, and indirectly leads to an equal number of jobs, representing a total impact of 1.8 million positions.

Photonic technologies applicable to the Natural Resources Sector are often based on those developed for other sectors, such as Information Technologies and Communications (ITC); manufacturing; sensing; monitoring; signage and lighting. Although Canadian photonic industries are mainly SMEs, many excel at developing, producing, and marketing niche high-value-added products, such as components, equipment, software and photonic integrated circuits. In addition, Canadian companies have developed an enviable reputation in fibre-laser technology, producing fibre lasers for use in cutting, welding, additive manufacturing and other advanced manufacturing processes. Fibre-optic and distributed sensors complete the Canadian offer for imagers. A few companies are involved in process and environment monitoring, while others offer LED signage and lighting solutions. The Canadian photonic industry therefore presents excellent opportunities for the Natural Resources Sector.

2.7.1 Trends

Canada is moving from a disproportionately resource-based economy to one that is more diversified. The Natural Resources Sector is under both economic pressure to reduce cost, and under social pressure to develop clean processes. New technologies may be a solution, thereby presenting an opportunity for the photonics industry. For example, the increased use of sensors may soon give rise to a "Big Data" problem to integrate all this information into a usable process. Remote sensing, and autonomous and integrated systems are key to improve processes and to lower cost.

Many new photonic technologies could have a strong impact on such applications as spectroscopy and quantum sensors to differentiate materials and identify potential ore deposits, etc.; and multi-spectral band communications to improve data gathering. Photonic technology also facilitates system integration with its small size, low cost and ruggedized equipment.

2.7.2 SWOT Analysis

The Natural Resources Sector could find solutions to its needs from the Canadian photonic industries. With the strong respective eco-systems in photonics and natural resources, enhanced collaboration between these sectors would have a strong impact on the economy. However, the Canadian photonic industry comprises mainly SMEs that address many markets but the industry

TABLE 2.7 *The Natural Resources Sector*

Business Trends
Strong price pressure for the mining sector
Strong social pressure on environment issues
Many NR industries are traditionally low-tech: they have difficulty investing in new technology.
Lack of technology skills limits introduction of new technology.
Reducing cost by using technology

Technology Trends	Photonic Technology Trends
Big Data for integration information from all sensors	Automated fielded sensors
Looking for autonomous systems for gathering samples	Integration and implementation of software, ruggedized systems, automation and low- cost equipment
Increasing use of satellite-based and drone-based imaging	Multi-band communications improve integration.
Remote connectivity is becoming important.	Fielded spectroscopy systems
This sector is slow in technology adaptation	Quantum sensing to differentiate materials

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
Rich photonic industry and research infrastructure	Canadian conservative culture
Well-established ecosystem in photonics	Lack of seed funding for start-ups
Strong natural resources eco-system looking for new technology	Lack of a clear vision and technology roadmap for the investment community
Low-cost R&D when made in Canada	Little or no national cross pollination between photonics and natural resources
	Difficult to find funding for environment technologies

Opportunities for Canada	Threats to Canada
Natural resources sector is unaware of photonics' capabilities.	Given the present economic downturn, there is no new R&D in the natural resources sector.
Need to improve Government and investors awareness of photonics	Industry tends to look at foreign solutions, even if Canadian-based solutions exist.
Need to develop easy access of natural resources industry to state-of-the-art technologies	Competition is from other technologies that are already demonstrated and at lower cost.
Need to engage community at all levels, from school to public	Natural resources industry would not invest in photonic R&D, but is looking for ready-to-use, ruggedized and good-cost solutions.

lacks "critical mass." Hence the resources industries' natural reflex is to look for solutions outside the country. Improving the network between the photonic and the natural resources communities would strengthen both industry sectors.

The photonics community should listen to the needs of the natural resource community to be able to educate and train them about the potential of photonics to improve processes and efficiency. End-user industry, government, as well as the public, need to be aware of these capabilities.

Although it is important for the industry to improve efficiency through new technologies, the current economic downdraft limits R&D investments. Natural resources industries need low-cost, proven solutions which, up to now, have been usually based on non-photonic technologies. It is up to the photonic industry to develop appropriate solutions which would compete with these technologies.

2.8 PHARMACEUTICAL SECTOR

As shown in Chapter 2.6, the health and medical sector is very important for Canada and represent significant Spending of $219B for all levels of Government. The aging population is a concern, since 45% of health spending is used for the 65-and-older people, who currently represent 15% of the population. Drug spending represents 16% of total spending, and Government accounts for 42% of the expenditures on drugs. Patented drugs represent 62% of total drug sales, but only 30% of the prescription drugs in Canada. The pharmaceutical sector employs 26,300 persons with annual sales of $22B, and $7.7B of domestic manufacturing. About half of the Canadian market is shared by 10 large pharmaceutical companies (source: National Health Expenditure Trends, 1975 to 2015, October 2015, Canadian Institute for Health Information).

Many photonic domains are applicable to the pharmaceutical sector, including advanced manufacturing, spectral imaging, sensing, monitoring, lasers, spectroscopy, fluorescence, and so on. Although Canada's photonic industries are mainly SMEs, they have developed their niches by producing components, equipment, software and photonic integrated circuits for various applications. They also market fibre lasers, which are used for sampling and advanced-manufacturing processes. Nanophotonics, optogenetics, and both fibre-optic and distributed sensors complete the Canadian offer. We also have companies offering specialized LED-based systems. The Canadian photonic industry therefore presents excellent opportunities for the pharmaceutical sector.

2.8.1 Trends

Technologies facilitating precision and personalized medicine are important for the future in health care. Note, however, that R&D spending by Canadian pharmaceutical companies declined from 8% of sales in 2008 to 4.5% of sales in 2013. The trend is to outsource R&D to small companies and universities. There is also a strong trend towards moving diagnostic capabilities directly to point-of-care.Technologies for rapid point-of-care diagnostics are important to improve and reduce health-care costs. New processes are also developing: for example, Biologics (which are manufactured in a living system such as micro-organisms, plants or animals). CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is another recent methodology which attaches foreign genetic elements to DNA. Theranostics connects diagnostics with therapeutics to develop individualized therapies. Hyper-spectral, multispectral imaging, and the use of multi-modal imaging facilitates rapid diagnostics and therapies that are important in drug development. Multi-spectral and broad-band light sources, including LEDs and lasers, can be developed for a specific application. Technologies developed for other applications (such as high-power and ultrafast lasers), are also applicable to the pharmaceutical sector for advanced manufacturing, and for other techniques such as laser-induced breakdown spectroscopy.

2.8.2 SWOT Analysis

Collaborative research between industry and university is slowly proving to be effective and Canada has developed a strong R&D infrastructure to support it. The photonic industry has developed non-destructive and non-contact systems and strong imaging capabilities. Proximity of the United States and strong links with Europe facilitates exports. Photonic companies are close to the two major pharmaceutical/biotechnology clusters in Montreal and Toronto. Canadian photonic industries have demonstrated strong creativity in the development of their niche market.

TABLE 2.8 *The Pharmaceutical Sector*

Business Trends
Globalization of pharmaceutical industry
Growing use of generic drugs
Outsourcing R&D to SMEs and universities
Precision medicine with personalized pathology and genomics
Point-of-care diagnostics

Technology Trends	Photonic Technology Trends
Big data and cross correlation of information from many sources	Multimodal imaging combining many technologies
Biologic-based drugs, optogenetics and targeted drug delivery	Improving light sources, LEDs, broadband, near-infrared, far-infrared, lasers
Theranostics – combining therapeutics with diagnostics	Increased use of integrated optics
Stem cells for regenerative medicine	Imaging spectroscopy with higher spatial and spectral resolution, and near-field imaging
Rapid point-of-care diagnostics	Use of high-power/ultrafast lasers

SWOT ANALYSIS	
Canadian Strengths	**Canadian Weaknesses**
Presence of photonic clusters that facilitate networking	No financial support for commercialization
Collaborative research between industry and universities	Companies are small, which hampers negotiations with large multinational enterprises.
Improved imaging capabilities available from industry	Photonic companies target large pharmaceutical companies instead of addressing the Tier-1 and Tier 2 companies.
Eco-system includes a variety of capabilities and organizations	Canada lacks the eco-system to make use of the entrepreneurship spirit that brings technologies to market.
Large-scale R&D infrastructure	Research priorities for funding limits possibility of discovering game-changing technologies.

Opportunities for Canada	Threats to Canada
We should develop stronger links between end-users and the photonic community.	Lack of capital encourages exodus of companies, skills and intellectual property.
Photonic companies need to be educated about the pharmaceutical companies' supply chain.	Lack of focus to develop critical mass on a few photonic technology sectors instead of a sparsely distributed photonic industry
Photonic companies should show-case their products to end-users.	The imbalance between new emerging technologies and marketable research projects
Research projects needed for new emerging technologies	Restrictive research practices threaten Canada's ability to maintain competitive stance.
	Potential negative influence of international agreements on the intellectual property.

We do not have a national photonic strategy that would identify key areas to strengthen and prioritize research activities. Photonic SMEs are distributed all over Canada (but mainly in Quebec, Ontario, Alberta and British Columbia), and cover almost all aspects of photonics. Industry investment in research is limited and we lack the eco-system covering science-to-market. Ease of transfer of technologies from university to industry varies from one university to another. Photonic companies need to pursue better understanding of the needs of the large biotechnology companies. The Tier-1/2 supply chain partners should be used as a source of market entry for photonic companies. The pharmaceutical companies would be very interested in a photonic technology which could become essential in the manufacturing process and add to their patent-protected status. The Canadian photonic community should use the opportunity of a new Government to educate them and to promote photonics. Photonic companies should be more involved in global trade to protect their market share. Recognizing the SME status of the industry, this may be best achieved through establishing global or remote local partnerships. The photonic community should develop approaches to retain talented international students after graduation. Ultra-fast laser processing should be of high interest to pharmaceutical companies.

The global market is growing and other countries have developed their photonic strategy to ensure their growth. Lack of interest in photonics by students and limited investment capital in photonics will negatively affect the future growth of that community. Continued support for research and for new development is critical to maintain a competitive stance.

UNIVERSITY OF OTTAWA – CENTRE FOR RESEARCH IN PHOTONICS

Advanced Research complex, University of Ottawa

Despite the ubiquitous penetration of photonics, challenges remain, be they at the level of applications where improvements are continuously sought, to optical telecommunications equipment, solar cells, and optical biosensors, or at the level of better understanding how light interacts with matter. To meet such challenges, the University of Ottawa established the world-class Centre for Research in Photonics (CRPuO) founded on strengths within our Faculties of Engineering and Science.

The CRPuO does not recognize disciplinary boundaries, but rather welcomes all who claim optics and photonics as their main area of research. We count electrical, chemical, mechanical and biomedical engineers, along with physicists, chemists and biochemists among our ranks. Of its 20 professors, 15 hold prestigious research chairs, many are Fellows of recognised optical societies , and several have won prestigious research prizes. The CRPuO attracts the best and brightest students and post-doctoral fellows to work alongside top minds in the field – currently over 200 are contributing to advance the field. CRPuO researchers maintain collaborations with many countries around the globe by participating in the exchange of people, material and know-how, and collaborating on common projects.

In addition to human capital, the CRPuO includes state-of-the art research facilities in the new Advanced Research Complex – a building designed and constructed from the ground up with photonics research in mind. In addition to about a dozen individual research labs, the CRPuO includes two core facilities: the Sunlab and the Nanofab, both open for business.

Many large, well-known companies, as well as small and medium enterprises, have partnerships with our researchers and several of our professors have launched companies. This reflects the genesis of a wide range of new applications for photonics and demonstrates that CRPuO is at the forefront of photonics research.

GLOBAL PHOTONICS INITIATIVES

3.1 FOREIGN STRATEGIC INVESTMENTS

Many good examples exist of countries or regions that have identified photonics or its subsectors as areas for strategic investment.

US National Photonics Initiative

Based on the 2012 *Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing*, the United States's National Network for Manufacturing Innovation (NNMI) was created to provide a manufacturing research infrastructure where U.S. industry and academia collaborate to solve industry-relevant problems. The NNMI is a network of Institutes for Manufacturing Innovation in which each Institute has a unique focus – but a common goal – to create, showcase, and deploy new capabilities and new manufacturing processes.

With the strong support of SPIE and OSA, the US National Research Council initiated the National Photonics Initiative (NPI) with the objective of identifying and advancing areas of photonics that are critical to maintaining competitiveness and national security. In their report *Optics and Photonics, Essential Technologies for our Nation*, they identified five key photonic-driven fields:

- Energy
- Biomedicine and Health Care
- Information Technology and Telecommunications
- Advanced Manufacturing, and
- National Defense/Homeland Security

The NPI's active promotion and advocacy resulted in establishment of a new NNMI institute focusing on photonics. In 2015, the USA announced a federal investment of $110 million to create the American Institute for Manufacturing Integrated Photonics (AIM Photonics), with co-investment of more than $500 million by industry, institutions and other government organizations.

Education and Training in the USA

In today's world, it is essential that photonics not only occupy a prominent position in education at all levels, but that it is seen as relevant and interesting for students. There are serious concerns about the decline in student enrollments in science, technology, engineering and mathematics (STEM) and in photonics in particular. Training at the technician level is also key to implement the new developments.

The Society of Photo-Optical Instrumental Engineers (SPIE) and the Optical Society of America (OSA) – two major American professional organizations that promote interdisciplinary pursuit and advancement of photonics science and applications – collectively provide teaching materials, maintain a directory of photonics and optics courses, and support a bi-annual international conference entitled Education and Training in Optics and Photonics (ETOP). Other countries are welcome to join this initiative.

The UK Association of Industrial Laser Users (AILU)

AILU is run by and for the UK laser community. Its membership extends over five continents and is made up of laser users in industry and academia, as well as of manufacturers and suppliers of lasers, and laser-related equipment and services. Their members include many leading players in the UK's laser materials processing community. Formed in 1995 as a not-for-profit organization, the Association enjoys worldwide recognition and membership, thanks to the practical advice it offers on technical and business matters related to laser applications in manufacturing. The Association is a leader in fostering co-operation and collaboration within the laser community, promoting best practices in industrial laser materials processing and allied technologies, and supports the maintenance and improvement of standards for laser safety and performance. (http://www.ailu.org.uk/)

Europe and Photonics21

Effective November 2013, the "Photonics21 Association" became the private contract partner in a contractual Public Private Partnership (PPP) arrangement with the EU Commission in the frame of Horizon 2020, the 8th European Framework Programme for Research & Innovation. Photonics21, (the European Technology Platform (ETP) representing the European Photonics Community since 2005), was invited to form a Photonics Public-Private Partnership back in 2012. As one of six Key Enabling Technologies (KETs) in Europe, Photonics plays a major role for driving growth and employment in Europe and contributes to solving major societal challenges such as an aging society, energy efficiency, inclusion and smart living. (**www.photonics21.org**)

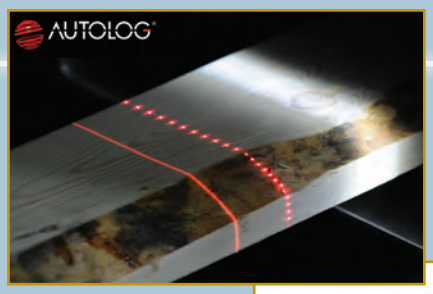
Photonics21 produced the document *Towards 2020 – Photonics Driving Economic Growth in Europe*, which was the basis for Horizon 2020. The latter is the biggest EU Research and Innovation program ever, with nearly $80 billion euros of funding available over seven years (2014 to 2020), in addition to the private investment that this money will attract. It promises more breakthroughs, discoveries and world-firsts by taking great ideas from the lab to the market.

In ASIA

According to their Five-Year Plan, the overall objectives of China's science and technology development is to build China into a knowledge-based innovative nation. China plans to achieve this goal by significantly boosting its strength for indigenous innovation, its international competitiveness in high-tech sectors, and by achieving breakthroughs in priority S&T areas and key technical fields. These fields include high-power lasers, energy efficiency and LED lighting; optical communication networks, flat-panel displays, and new optoelectronic devices, sensors and applications.

Japan invests heavily in research and development to accelerate convergence of photonics and electronics. The nation plans to significantly reduce the size and energy consumption of electronic chips by integrating photonics. Taiwan's major production is flat-panel displays, but the Photonics Industry & Technology Development Association has indicated they wish to diversify by increasing their solid-state lighting and photovoltaics production. Korea, which also produces flat-panel displays and sources, is moving

AUTOLOG



Headquartered in Blainville, Québec, Canada, Autolog is a global leader in optimization and control systems for the wood transformation industry. Since 1987 Autolog has completed more than 700 projects with most major North American and European sawmill operators and mechanical manufacturers. Sawmills around the world use our systems to increase productivity and add value to their end products while reducing their raw material and workforce costs. The average payback time for Autolog systems is often less than one year.

Our team of 90+ professionals is made up of highly dedicated specialists representing the best in their field of expertise. We are proud to define ourselves and live by three strategic principles: Quality, Technology and Customer Experience. Our researchers, engineers, wood process specialists and technicians have proven their capabilities time and time again to utilize and integrate photonics into computerized solutions that work to achieve optimal process performance. We deal in the expertise of optimization, artificial vision, artificial intelligence and optical physics.

We are a technology company. What we "make" is what differentiates us. We customize standard solutions according to our customers' specific needs. Our identity is based on: quality, technology and customer experience.

from unit lighting to system lighting (for example, in intelligent lighting of buildings). In 2014, the Nanyang Technological University of Singapore created a Photonics Institute that encompasses five key photonics centres covering optical fibres, lasers and disruptive photonics technologies.

3.2 INTERNATIONAL PHOTONIC ASSOCIATIONS

European Photonic Industry Association (EPIC)

EPIC is the industry association that promotes the sustainable development of organizations working in the field of photonics in Europe. EPIC fosters a vibrant photonics ecosystem by maintaining a strong network and acting as a catalyst and facilitator for technological and commercial advancement. EPIC is the industry association with the largest network and maintains the European photonics database.

International Optoelectronic Association (IOA)

The IOA is an informal coalition of international optoelectronic/photonic associations. It represents the interests of the industry to national governments, collects information on optoelectronics markets and produces technology roadmaps. The member countries meet each year to discuss optoelectronic markets and trends

OSA Industry Development Associates (OIDA)

OIDA, the former Optoelectronics Industry Development Association, was originally set up in the United States — in part by the Defense Advanced Research Projects Agency (DARPA) — following the 1988 report *Photonics: Maintaining Competitiveness in an Information Age*. In 2014, OIDA merged with the Optical Society of America to become the OSA Industry Development Associates. OIDA plays an important role as the voice of the industry by providing market analysis, road mapping, and government lobbying. The Optical Society's (OSA) mission is to promote the generation, application and archiving of knowledge in optics and photonics and to disseminate this knowledge worldwide.

SPIE

SPIE is an international society advancing an interdisciplinary approach to the science and application of light. The not-for-profit society advances emerging technologies through interdisciplinary information exchange, continuing education, publications, patent precedent, and career and professional growth. SPIE organizes numerous conferences, courses and workshops covering every application of optics and photonics.

3.3 PHOTONICS IN CANADA

At the peak of the telecom boom in 2001, Canada was home to two of the giants of the telecommunications industry: Nortel (which at the time accounted for over 50% of the global revenues for optical network equipment) and JDS Uniphase (which dominated the global market for optical components). Together these companies accounted for over 10,000 photonics jobs in Ottawa alone. Their success and the "buzz" around the sector encouraged a large number of well-funded start-ups, many of which failed in the telecom downturn in the early 2000s. Today Canada has a thriving photonics community that addresses all sectors of the economy.

3.3.1 Photonics Associations in Canada

The Canadian Photonic Industry Consortium (CPIC)

On April 1st 2012, CIPI (Canadian Institute for Photonic Innovations) and CPC (Canadian Photonic Consortium) merged to create the Canadian Photonic Industry Consortium (CPIC), also known as Photons Canada.

CIPI was established in 1999 under the Networks of Centres of Excellence (NCE) Program (a cornerstone of the Government of Canada's innovation strategy). CIPI has had a significant impact on the growth of photonics in Canada. It has done so by fostering collaborative projects between different groups and institutions and initiating many new interactions between industry and university researchers. With the financial support from both the Networks of Centres of Excellence (NCE) and their industrial partners, and through applied research projects focusing on the needs of end-users, the training of highly qualified personnel, and transfer of new technology and knowledge to end users, CPIC has been a tremendous success. Many new products and processes have emerged from these interactions – products that are now available in the market.

UNIVERSITÉ LAVAL – CENTRE FOR OPTICS, PHOTONICS AND LASERS

At the Centre for Optics, Photonics and Lasers (COPL), researchers, technicians and graduate students work in synergy, from the confines of the infinitely small to that of the infinitely fast, to offer society the benefits of photonic technology.

Photos: Louise Leblanc, Université Laval

COPL brings together 23 research teams and roughly 150 graduate students at its Université Laval facilities, where they perform research in photonic materials, optical communications, lasers, optical fibres, biophotonics, optical engineering and instrumentation. They work in a state-of-the-art building inaugurated in 2006 and solely dedicated to optics & photonics research and training. It is the only university-based infrastructure of its kind in Canada and has strengthened COPL's leadership position in the field.

Having benefited from an exceptional training environment, some thirty young scientists graduate each year and join companies or other research organizations where they provide critically needed expertise and know-how. The COPL takes great pride in this accomplishment. In addition, the Centre plays an active role within the innovation chain, contributing technology often developed with industrial partners. Furthermore, since 2005, eight companies have been spun off its research.

Imaging systems for the life sciences; fibre-based components and systems for high-speed communication networks and remote sensing platforms; LED-based solutions for displays and lighting applications; lasers designed for medical as well as industrial use; and a new generation of optical fibres fabricated from novel chemical compounds are all examples of the outcome of research underway at the COPL.

SPIE

SPIE supports an interdisciplinary approach to the science and application of light. Founded in 1955 as an educational charity by engineers and problem-solvers who understood the value of face-to-face connections and information sharing, SPIE has become the leading global advocate for the advancement of optics and photonics technology. The Society serves nearly 264,000 constituents from approximately 166 countries.

SPIE supports scientific achievement, engineering innovation, commercialization of technology, career development, lifelong learning, and industry growth through educational programs, top-ranked technical conferences and industry events including Photonics West, and the SPIE Digital Library – the largest collection of optics and photonics research in the world. SPIE provided more than $5.2 million in support of education and outreach programs in 2015 and is a Founding Partner of the International Year of Light and Light-based Technologies.

CPIC expects numerous further developments to emerge from the seeds planted in these interactions. Building on this success, CPIC was created to assist Canadian companies to optimize operations and improve profits by facilitating and accelerating the application of photonic technologies that improve quality, productivity and profitability. CPIC is now financed by organizing national activities and by membership fees.

Quebec Photonic Network (QPN)-Réseau photonique du Québec (RPQ)

This network is a dynamic enterprise that organizes local and international events. It receives annual financial support from both the Provincial Government and from Economic Development Canada. Complementing this support with membership fees enables QPN to employ full-time administrative staff officers. Nevertheless, it still relies heavily on volunteer efforts.

The Ottawa Photonics Cluster (OPC) and the Ontario Photonics Technology Industry Cluster (OPTIC)

OPC and OPTIC are volunteer organizations whose activities are restricted to networking events and presence at trade shows. For a few years, Ontario provided financial support to the regional network called Ontario Photonics Industry Network (OPIN) but that support ceased a few years ago. OPTIC is the only active cluster in Ontario that organizes site visits and networking events in the Toronto area. Participants in the various workshops have indicated it would be worthwhile to create a regional cluster to link the end-users with the photonic community.

Photonic Clusters in Other Provinces

There is no cluster or similar activity in any other province (the B.C. cluster became inactive several years ago). That said, CPIC's current study has revealed some interest in establishing clusters in both British Columbia and Alberta.

Other National Associations

In addition to the many industry associations focusing on specific sectors, two national associations – CATA (Canadian Advanced Technology Alliance) and CME (Canadian Manufacturers & Exporters) have programs that are closely linked to the photonic community.

CATA (**www.cata.ca**) has the mandate to grow Canadian industries' innovation and competitiveness, and to advocate better support to the industry through improved financing regulations and procurement strategies, two areas important for the photonic industry.

CME (**www.cme-mec.ca**) has created a group called Canada Makes (www.canadamakes.ca) which is focusing on advanced manufacturing that involves photonics technologies.

3.3.2 Government Support Programs to Industry

Canada's photonic industry has access to a few Government programs to support their research and commercialization. The Scientific Research and Experimental Development (SR&ED) is a tax incentive program to support industry R&D. It complements the NRC-Industry Research Assistance Program (IRAP), which provides consulting and research funds.

The Federal Government has recently created the Build in Canada Innovation Program (BCIP), to help companies bridge the pre-commercialization gap by procuring and testing late-stage innovative goods and services within the federal government before taking them to market. This program provides feedback on the performance of a company's goods or services, and facilitates entry to the market place with a successful application. Photonics is included in many of the priority areas identified in this new program.

3.3.3 Research and Development

Canada spends approximately $150 million annually of federal and provincial government money on optics, photonics and laser-related research. Beneficiaries include universities, government laboratories and some support for corporate R&D.

TABLE 3.3.3-1

Canada Excellence and Industrial Chairs in Photonics financed by NSERC

a) Canada Excellence Research Chairs
Quantum Nonlinear Optics
Neurophotonics
Photonic innovations
b) NSERC Industrial Chairs
New Analytical Methods and Technologies for Sample Preparation
Optical Design
Essilor Industrial Research Chair in Visual Function
Coractive-TeraXion-LaserAX-TLCL Industrial Research Chair in femtosecond photo-inscribed photonic components and devices
Chrysler Canada on Solid State Physics and Material Characterization
Chaire de recherche industrielle dans les collèges du CRSNG en procédés et instrumentation optiques

TABLE 3.3.3-2

NSERC CREATE TRAINING PROGRAMS in Photonics

Quantitative Biomedicine
Nanoscience and Nanotechology
Extreme Photonics
Biophotonics
Auditory Cognitive Neuroscience
Next Generation Optical Networks
Silicon Electronic-Photonic Intergrated Circuis (Si-EPIC)
ASPIRE – Applied Science in Photonics and Innovative Research in Engineering
NanoMat – Nanomaterials Science & Technology

Natural Sciences and Engineering Research Council of Canada (NSERC)

Canada has a strong, internationally recognized academic research base in photonics, mainly distributed in more than 36 universities with discrete photonics groups or centres. At the federal level, the majority of research funding is from the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR) and the Canada Foundation for Innovation (FCI).

NSERC research grants in photonics and optics-related topics totalled approximately $81 million in 2014-15, with an average annual growth of 5.6% since 2008. This amount includes $4.7 million distributed to to 43 NSERC Research Chairs in photonics and $2.3 million in CREATE programs (which support students). NSERC investment of $17 million in photonic innovation is done through its partnership programs with an annual growth of 10%. For example, CIHR contributed about $2 million during the same period.

Networks of Centres of Excellence (NCE)

The Networks of Centres of Excellence (NCE) was created to offer a suite of programs that mobilize Canada's best research, development and entrepreneurial expertise, and focus it on specific issues and strategic areas. The NCE annually distributes $130 million in four national programs, bringing together the right mix of people and organizations to address important issues for Canadians:

- Networks of Centres of Excellence
- Centres of Excellence for Commercialization and Research
- Business-Led Networks of Centres of Excellence and
- Industrial Research and Development Internship

Although not focused on photonic technology development like the Canadian Institute for Photonic Innovation (CIPI), many on-going NCE networks are using photonic technologies.

3.3.4 CANADIAN R&D CENTRES

ALLS – Advanced Laser Light Source

ALLS is a unique infrastructure of international caliber located at the Varennes campus of INRS-EMT, where users can work with a variety of intense ultrafast laser sources. This large national laboratory for laser science was financed through the International Joint Ventures Fund of the Canada Foundation for Innovation (CFI) with an investment of 20.95M$. Together with the powerful lasers at the ALLS lab, a series of new ultrafast light sources for revolutionary applications has already been developed.

ALLS has developed a large variety of laser light sources, reaching from THz (300 micron wavelength) to hard X-rays (Angstrom – 0.1 nm wavelength), providing ultra-short pulse durations. Since light pulses of different wavelengths can be spatially and temporally synchronized, they open the door to exploring the potential of dynamic imaging of atomic, molecular and condensed-matter systems, and provide the unique tools to explore the fundamental questions of physics and chemistry. This research leads not only to important outcomes in fundamental science, but also to innovative technological applications and tools. Among these tools: medical high-resolution imaging for mammography; particle acceleration for future proton therapy; micro-machining and material-processing; and applications for security, defence and telecommunications.

C2MI

C2MI is the largest microelectronics research centre and innovation hub in Canada, with state-of-the- art equipment dedicated to advanced packaging, and MEMS innovative products development. With 250 R&D scientists on site, C2MI's goal is to foster its members' growth, within an IP-friendly environment, leveraging its unique 221M$ state-of-the-art infrastructure with capabilities exceeding actual industry standards. C2MI is equipped with 300 mm advanced-packaging and 200 mm MEMS/wafer level packaging lines. Seamless collaboration and synergy among the Centre's members enables the rapid commercialization of next-generation, market-driven prototypes with applications in fields as varied as IT, automotive, aerospace, environment, energy, health and life sciences, and transport.

C2MI's "ecosystem" counts over 100 national and international members, from both industry and academia. It can therefore offer an integrated supply chain for rapid commercialization of market-driven products with on-site technological developments and cost- competitive solutions. Collaboration takes place at partners' sites both in Canada and abroad. Technical support ranges from full services provided by its staff; partners-specific collaborative implication; to direct-use of the infrastructure.

Canadian Advanced Network and Research for Industry and Education (CANARIE)

CANARIE is a government-supported, not-for-profit organization that designs and delivers digital infrastructure and drives digital adoption for Canada's research, education and innovation communities. CANARIE keeps Canada at the forefront of digital research and innovation, fundamental to a vibrant digital economy. The Network continues to evolve Canada's national ultra-high-speed backbone network that enables data-intensive, leading-edge research and "Big Science" across Canada and world-wide. One million researchers, scientists and students at nearly 2,000 Canadian institutions, including universities, colleges, research institutes, hospitals, and government laboratories, have access to the CANARIE Network.

Canadian Light Source (CLS)

The CLS synchrotron is literally the brightest light in Canada — millions of times brighter than even the sun. Scientists use the synchrotron to obtain incredibly detailed information about the structural and chemical properties of materials at the molecular level. Work ranges from mine-tailing remediation, cancer research, and development of cutting-edge materials.

The CLS has hosted over 2,500 researchers from academic institutions, government and industry, and from Canada's 10 provinces and two territories. Since beginning operations in 2005, the CLS has delivered over 40,000 experimental shifts; received over 10,000 user visits; and provided a scientific service essential to over 1,500 scientific publications. The CLS has over 200 full-time employees.

Photo: CMC Microsystems

CMC Microsystems

CMC Microsystems (**www.cmc.ca**), a not-for-profit corporation, manages and operates the facilities of Canada's National Design Network® (NDN). Researchers from over 50 post-secondary institutions and industry have access to the world's best tools, manufacturing technologies, measurement instruments, and training. CMC Microsystems also provides engineering support for designing, making and commercializing innovations in microsystems and nanotechnologies. Over the past fiuve years, CMC delivered $150 million in value to the NDN, including investment from federal and provincial funders and in-kind contributions from industry.

National Design Network® (NDN)

The NDN is a leader in photonics innovation in Canada and around the world. To facilitate commercialization of photonic technologies, NDN annually commits over $1 million in budget, and also leverages significant collaborations with partners. More than 450 photonics projects from academia and industry have been fabricated through CMC, using Canadian and international process technology and packaging expertise.

Defence Research & Development Canada (DRDC)

Defence Research and Development Canada (DRDC) is the primary delivery agent for the Department of National Defence's S&T investment. DRDC operates eight research centres across Canada (each with a unique combination of expertise and facilities) to carry out world-class science and technology research, including the field of optronics.

Within DRDC, it is at the Valcartier Research Centre that thorough expertise was developed over the years in many fields. These fields included understanding, collection and exploitation of spectral data; application and tactical exploitation of active or passive sensors and electro-optical systems; and platform protection against electro-optically guided threats. Research activities carried out at DRDC have resulted in technologies and innovative breakthroughs with strong potential impact on defence and security in Canada, particularly for Canadian Armed Forces operations and for first responders in the field of public security.

DRDC is the centre of an innovation community whose members provide ideas, technology and know-how to support defence and security objectives. In cooperation with the academic community and the defence and security industry, DRDC has spearheaded the completion of numerous innovative projects. In so doing, DRDC enables the transfer and application of scientific knowledge from the broader innovation community to the end users of defence and security S&T at all levels.

Institut national d'optique (INO)

INO is a private, non-profit organization and a leading developer of industrial optics and photonics solutions. INO develops custom, high-tech solutions for Canadian businesses to improve their ability to compete internationally by offering services from design through prototyping and short-run production. Based on light technologies, INO's innovations benefit businesses in a wide range of sectors, including the biomedical, MEMS, energy, and auto industries.

QUANTUM CANADA: BUILDING THE WORLD'S NEXT-GENERATION PHOTONIC TECHNOLOGIES

Canada has been a global photonic powerhouse for more than 50 years, maintaining that position throughout a constantly changing technological landscape. As conventional photonic technologies reach their performance limits, next-generation quantum-enhanced solutions are emerging and will quickly gain ground. The quantum photonic technology platform expands on existing linear technologies in two directions: at low intensity where the quantum nature of light becomes a tool, and at high intensity, where light gains control over the response of any quantum system. In both cases, quantum effects appear that are simply not present in traditional photonics.

New quantum technologies require a complex combination of physical components, including new sources; few-cycle lasers; carrier-envelope-phase stable light pulses; on-demand photon sources; quantum repeaters; optical frequency converters; photon memories and quantum cryptographic key generators; and sensitive detectors. These components will be integrated into ultra-secure communications systems and ultra-precise sensors and measurement devices for time, distance, stress & strain, temperature, and chemical concentration.

The future competitiveness of Canada's photonics industry will depend on nationally coordinated quantum technology R&D and the targeted commercialization efforts undertaken today. The investment required to stay at the forefront is often too high for companies.

However, Canada's combination of federal and provincial support, and world-leading universities and research centres, is balancing the risk with industry and driving productivity and time-to-market. Canada has undertaken a $500 million research effort (over 10 years), with quantum technology hubs being formed to develop and advance the technology-readiness level of critical quantum components. This effort will enable Canada's photonics industry to lead global markets in quantum enhanced photonic technologies.

The direct connection between INO's research activities and industry needs makes INO an important economic driver. In 2014 alone, the direct, indirect, and induced impacts of INO's activities contributed to Canada's GDP to the tune of $344 million, and created and maintained 4,013 jobs. In the same year, the corresponding federal and provincial tax revenue in Canada amounted to $78 million. Since 1988, INO has created 30 companies, including TeraXion, Optel Vision, Pavemetrics, OpSens, LeddarTech, Obzerv, handyem, and Optosecurity, to name a few. These high-tech SMEs are all based in Quebec, yet most of their sales occur outside Canada. INO also realized 60 technology transfers and holds more than 200 patents.

A proven driver of growth, INO's business model has been adopted in other countries as well, for example by Centre Technologie Optique et Lasers ALPhANOV in Bordeaux, France, and the Korea Photonics Technology Institute in Seoul, South Korea. INO's activities are made possible thanks to Canada Economic Development for Quebec Regions and Quebec's Ministry of the Economy, Innovation and Exports.

National Research Council Canada (NRC)

2016 marks the NRC's centennial year as Canada's premier research and technology organization (RTO), home to first-class research infrastructure and world-leading expertise. With an annual operating budget of almost $895 million and approximately 4000 employees, NRC's research and development (R&D) activities are divided into 12 portfolios focused on key industry sectors. Exchanging expertise and ideas among its sectors allows NRC to offer rapid and cost-effective technological advancements in emerging areas such as photonics, as well as to grow and support the Canadian photonics industry.

Photo: National Research Council Canada

- ***Information and Communications Technologies (ICT)***

NRC's ICT portfolio supports the exponentially growing global demand for telecommunications services through its Advanced Photonic Component (APC) program. APC was launched in 2012 to support the development of photonic components and help to de-risk new optical communication technologies being considered by the telecommunication industry. R&D activities include photonic integration, lasers, and photodetectors, as well as packaging and fabrication-process development.

NRC's ICT portfolio has also advanced capabilities in Gallium Nitride (GaN) electronics, leveraging its significant processing know-how and exploiting NRC's competitive advantage as the only Canadian source for GaN electronics.

- ***Security and Disruptive Technologies (SDT)***

NRC's SDT portfolio collaborates with industry, government and universities to develop the quantum photonics technology platform. It also develops and delivers medium-term applications in quantum cyber-security and photonic sensing through its Quantum Photonic Sensing and Security (QPSS) program. Our world-class team explores using femtosecond and attosecond laser pulses and how they interact with matter.

NRC's Fibre Bragg grating prototype service has the industry-leading expertise, fully equipped laboratories and cutting-edge laser systems that make us a world leader in this technical field.

- ***Medical Devices (MD)***

Areas of expertise in NRC's MD portfolio cover such diverse R&TD areas as biosensors and biochips; microfluidics; molecular labels and novel material architectures; medical photonics; radiofrequency (RF) coil and RF/microwave (MW) antennas and electronics; computer simulation; and haptics technologies.

- ***The National Institute for Nanotechnology (NINT)***

Established in 2001 as a partnership between NRC, the University of Alberta and the Government of Alberta, NINT devises nano-enabled solutions that meet scalability, integration, manufacturability and environmental health and safety requirements for product development.

- ***Measurement Science and Standards***

NRC's Measurement Science and Standards (MSS) portfolio encompasses an optical inspection and metrology group that conducts leading research in laser ultrasonics.

NRC also administers the Industrial Research Assistance Program (IRAP), under which Canadian SMEs (defined as fewer than 50 employees) can benefit from technical and business advice as well as funding and other product-development services. IRAP's objective: to build SMEs' innovation capacity and help commercialize their products in the global marketplace. Companies that demonstrate both the desire and potential for

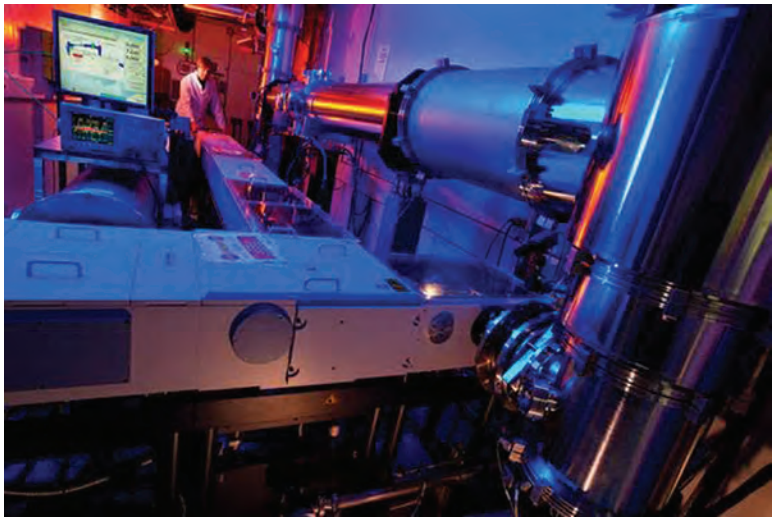


Photo: Canadian Light Source

technology and innovation-based growth can work with NRC-IRAP to create a development plan tailored specifically to their needs. Through IRAP, NRC has benefited the photonics industry by providing assistance and expertise for exciting R&TD projects.

Canadian Photonics Fabrication Centre (CPFC)

The NRC is home to the Canadian Photonic Fabrication Centre (CPFC), the only facility in North America that can fabricate complex III-V semiconductor photonic chips at high yield.

The CPFC provides a "one-stop-shop" for world-class engineering and manufacturing services, commercial-grade prototyping and pilot-run production facilities. Our $150-million, 40 000 square-foot, state-of-the-art facility holds 11 000 square feet of class 1000/100 clean-room space that provides a comprehensive suite of key processes and supporting ancillary activities. With industry-standard tools, and staff with many years of commercial experience, CPFC provides opto-electronic foundry services on a fee-for-service basis, including design and modeling, epitaxy, fabrication and testing, and characterization. The facility can handle anything from prototypes to small-volume runs of photonic devices and photonic integrated circuits.

Optech-CCTT

Optech is an applied research centre in optics that provides services to entrepreneurs, research scientists and students. The centre's mission is to enhance industry competitiveness and support the training of qualified students by actively developing proprietary technologies in optics and photonics.

To reach this goal, the team is developing activities that multiply the impact and potential of optical technologies as key enabling technologies, while bringing together decision makers, industry representatives and university researchers around the topic of innovation. Optech also involves college and university students and teachers in its daily activities and contributes to the development of the next generation of engineers, technicians and researchers. The scope of the 27 employees embraces several industry sectors, including manufacturing, aeronautics, environment, energy, health, arts, and information and communication technologies.

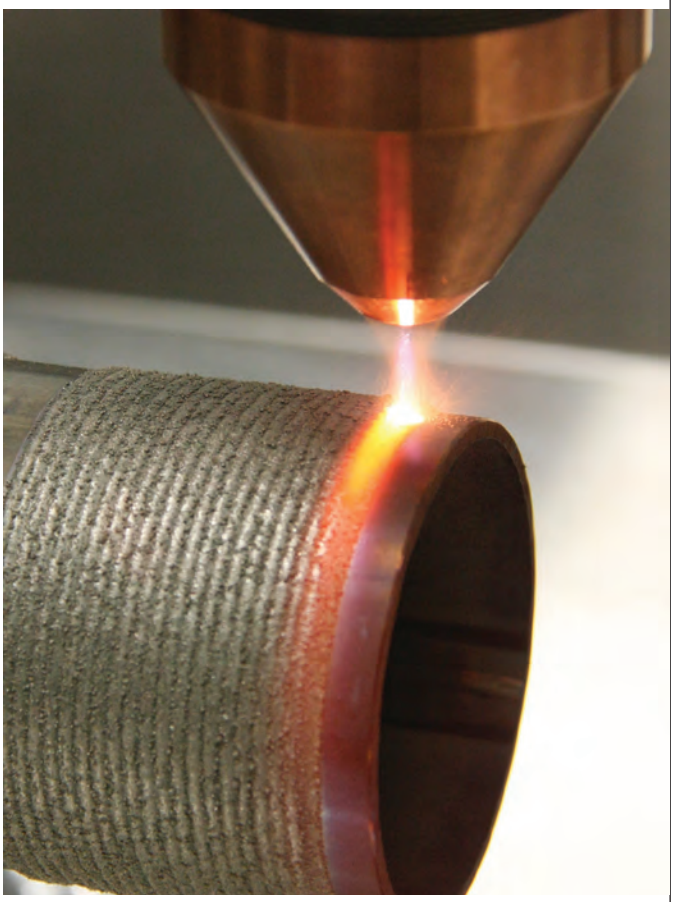


Photo: Novika Solution

Novika Solution

Novika Solution is a not-for-profit organization founded in 1983 under the name "Centre spécialisé de technologie physique du Québec (CSTPQ)." Recognized as a college centre for technology transfer, its multidisciplinary team and its continuously updated research infrastructure allows Novika to effectively complement the expertise of its industrial partners, working with them to improve their competitiveness. Novika offers applied research; development and transfer services in design; software development; and advanced processes; such as laser welding, resurfacing, micro texturing, tempering, and cleaning/stripping. With laboratories equipped with the latest technologies, Novika continually invests in the knowledge and skills of its team, enabling Novika to remain at the forefront of innovation and to meet industrial needs.

Photo: Canadian Light Source

3.4 CONCLUSION

Canada invests heavily in photonics R&D and has a significant number of individual researchers and institutions that have global recognition. It also has many outstanding government and private research facilities that are at the forefront of the technology and have a track record of technology transfer and company incubation. Nevertheless, there is little coordination of this research to focus it on sectors of strategic importance to the country.

Despite significant investment in academic research and some well-publicized success stories, our interviews and workshops revealed widespread concerns about the connections between academic research and industry. Although the number of research partnership projects is growing, there was a feeling that neither industry nor the economy were benefiting as fully as they might from this investment. These disconnects may result in part from the research funding mechanisms, which give research money directly to universities, yet allow companies little influence on the subsequent research.

Another concern is that Canada is failing to educate enough scientists and engineers in photonics. Although we produce a number of very talented PhD-level researchers, there are very few bachelor- or diploma-level courses in Canada that are dedicated to training in the science and application of photonics. Of even greater concern, most engineering degree courses have little or no photonics content. The lack of trained photonics engineers and technicians was highlighted by companies, and this shortfall will impede uptake of the technology. Furthermore, most industries need to be educated about what types of photonic capability are actually available in Canada, and on the powerful impact of using photonic technologies for improving processes and quality.

We have good examples of foreign countries developing their own photonic strategy: what Canada must do now is develop its own strategy to build on its photonic expertise and capability; to facilitate the use of photonics by Canadian industry; and to support the growth of the photonic industry.

CONCLUSIONS AND RECOMMENDATIONS

As demonstrated, photonics offers a rapidly emerging set of technologies that pervade all aspects of society and impact all of Canada's core industrial sectors. Canada has established a strong photonics community that contributes to the global capability base and increasingly adds value by integrating globally available technologies with both systems- and user-applications.

The sector has a number of globally competitive strengths: by focusing on key opportunities, it can play an even bigger role and improve its impact on the Canadian economy.

The core of Canada's photonic producer sector is firmly rooted in SMEs and start-ups with revenues in the $1-10 million range and — at most — 50 employees. These small companies are often under-funded, and are frequently disadvantaged when facing their US competitors, who have access to the *Small Business Innovation & Research* (SBIR) program. Although the *Build in Canada Innovation Program* is an excellent tool to accelerate the development of new products, this program should be extended to cover TRL 4-6 levels by adding financial support to industrial R&D.

In Ontario and Québec, where regional clusters have been encouraged, the distribution of economic activity around this core SME mass shows a balance indicative of healthy growth potential. In other parts of the country, where clusters do not exist, this distribution of economic activity is more scattered, and the comparative size of photonics-related activity is significantly diminished.

During the workshops that were organized in the four main photonic Provinces, participants clearly identified and agreed on the need for regional photonic clusters to provide links with the local end-user industry.

Canadian photonics is already a multi-billion dollar enterprise with a high contribution to exports. However, since Canadian imports in photonics are more than twice the exports, there are opportunities for Canadian photonic industries to better respond to the Canadian domestic market. Some of these opportunities are unique — such as those in the aerospace, defence and security, energy, medical and natural resources sectors — where there could be a strong domestic demand for photonics solutions that can be leveraged to create companies with global opportunities.

Canada excels in photonics at the R&D level. Success in converting this into economic activity to the fullest extent are limited, indicative of a potential weakness in our business infrastructure.

While Canada creates good photonics physicists at the PhD level, we are not producing enough photonics technicians and applications engineers. The average engineer graduating from a Canadian university has very little exposure to photonics, which is a barrier to companies that wish to put photonics in subsystem- and system-level products.

Photonics has great potential to be a significant engine for national economic growth. However, at the strategic level, it is not yet truly recognized as an industrial sector. This limits its visibility at the highest levels of business and government, which may not be in the best national

SWOT for Photonics in Canada

Strengths	Weaknesses
Photonics research capability and infrastructure with R&D Centres (NRC, INO, CLS, CMC, etc.), universities and colleges	No national strategy for photonics
Knowledge base and research infrastructure	Few large receptors for technology
National facilities focused on photonic technology transfer	Limited photonic training of engineers and technicians
Image sensors and vision systems	Large companies are usually subsidiaries of foreign entities.
High-power, short-pulse fibre lasers	Difficulty in raising capital for start-ups
Specialty fibres, remote sensing, spectral imaging, etc.	Lack of domestic suppliers of key photonics components: e.g., high-power lasers and systems

Opportunities	Threats
Growing energy and environment markets	Global competition
Needs in aerospace, defence and security, energy, medical and natural resources sectors	Unfocussed government support of photonics R&D
Green and solar technologies	Too few students in technology
Increased partnering between photonic producers and user communities	Other industries (e.g., resource sector) remain more attractive for investment.
Development of regional photonic clusters	Competition from other technologies
The ITAR-Free market and the use of the Industrial and Technological Benefits Program	

interest. Yet, photonics sits firmly on the global stage. To be successful, Canada's photonics community must have a global perspective, both in expanding its international presence, and in ensuring that Canada's own domestic environment remains open to — and benefits from — the use of photonic technologies.

RECOMMENDATIONS

1. *Improve Photonics Education and Awareness*

Given that the level of photonics education and awareness in Canada is still inadequate for meeting the ongoing demands of photonics users, photonics courses should become a core part of all undergraduate science and engineering training. Colleges must also increase the number of photonics courses for technicians. In addition, the photonics community needs to proactively engage educators and professional communicators to popularize the photonics world to the general public.

2. *Engage the User Community Domestically and Abroad*

As demonstrated by the workshops that we held on the various application sectors, the photonics community should engage with the user community to develop solutions that provide leadership to key Canadian industries and exporters. Initiatives such as the Horizon 2020 Program in Europe have demonstrated the value of partnerships between different economic sectors. Canada's photonics leaders should encourage multi-national enterprises to participate in our photonics community. Such outreach will ensure that both national and international user communities will have an informed view of Canada's photonics capabilities, open up opportunities for local system integrators, and raise awareness of our process knowledge.

3. *Increase Commercialization of Canadian Technology*

Despite the investment in photonics partnership R&D, technology flow and transfer between the academic and industrial sectors is inadequate. We recommend establishing programs that encourage stronger participation and leadership from industrial and university partners. Two proven models are the Horizon 2020 Program in the European Union and the recent creation of the Integrated Photonics Manufacturing Institute in the United States.

4. *Focus R&D on Strategic Sectors*

Many other countries have focussed investments in photonics: the Integrated Photonics Manufacturing Institute at the State University of New York (SUNY); flat-panel displays in Korea; high-power laser processing in Germany; photonics electronics systems convergence technologies in Japan; and the Association of Industrial Laser Users (AILU) in the UK.

Canada's investment in photonics is still broad-brush and relatively unfocussed. We recommend establishing a photonics strategy group that includes industry and academics. Their role: to focus investment on a few key sectors judged to be of global significance during the next ten years, and where Canada has the photonics skills to make a difference.

5. *Expand the Cluster Model*

Due to Canada's size, two levels of clusters are important for Canada:

1. A national cluster to develop partnership between the clusters and to organize national and international activities.
2. Regional clusters to organize local activities and networking opportunities.

Strong cluster activity encourages the incubation and development of a balanced distribution of photonics companies. The Quebec cluster is very active, while those in Ontario and the western provinces need to strengthen.

ANNEX 1 - PHOTONICS IN CANADA

CANADIAN PHOTONIC INDUSTRY

Canada hosts approximately 400 companies whose products rely primarily on photonics: These companies are mainly located in Quebec and Ontario (77%). British Columbia follows with 13%, while 7% are in the Prairies and 3% in the Atlantic Region. Nationwide, the photonic industry employs over 25,000 people. These numbers do not include the significant number of companies that use photonics in some way to achieve an unrelated primary product or service.

In 2014, photonics companies' revenues were about $4.6 billion and the companies expect an annual growth of 10% in the coming years. As seen in Figure A1.1, about 65% of these revenues accrue from exports, with the United States being the dominant market, accounting for 34% of sales. Europe accounts for 17% of the sales and Asia for 12%.

FIGURE A1.1

Distribution of Sales

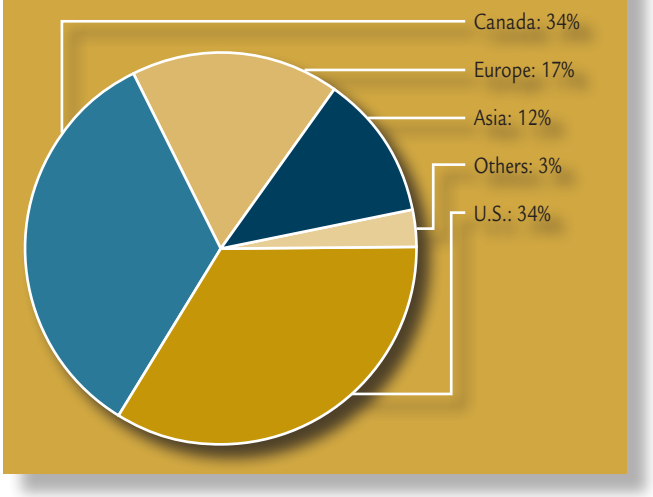


TABLE A1.1

Universities and Colleges with a Photonics Research Team

	Province		Province
Algonquin College	ON	Simon Fraser University	BC
Carleton University	ON	Université de Moncton	NB
Cégep André Laurendeau	QC	Université de Montréal	QC
Cégep Edouard-Montpetit	QC	Université de Sherbrooke	QC
Cégep LaPocatière	QC	Université du Québec à Gatineau	QC
College of New Caledonia	BC	Université Laval	QC
Concordia University	QC	University Health Network	ON
Dalhousie University	NS	University of Alberta	AB
École de technologie supérieure	QC	University of British Columbia	BC
École Polytechnique de Montréal	QC	University of Calgary	AB
George Brown College	ON	University of Ottawa	ON
McGill University	QC	University of Prince Edward Island	PEI
McMaster University	ON	University of Toronto	ON
Mohawk College	ON	University of Victoria	BC
Northern Alberta Institute of Technology	AB	University of Waterloo	ON
OCAD University	ON	University of Western Ontario	ON
Queen's University	ON	University of Windsor	ON
Ryerson University	ON	Wilfrid Laurier University	ON

As for many countries, Canada's photonics industry is dominated by small companies (Figure A1.2). Nearly three quarters of the 400 companies have less than 100 employees, while 30% have fewer than 10 employees. As shown in Figure A1.3, revenues of 50% of the companies are below $10 million, and 20% have revenues below $1 million (or are pre-revenue). Comparing this data to the distribution of sales by size of companies shown in Figure A1.4, we can conclude that 86% of Canadian photonic sales are done by 20% of the companies.

FIGURE A1.2

Distribution of Companies by Number of Employees

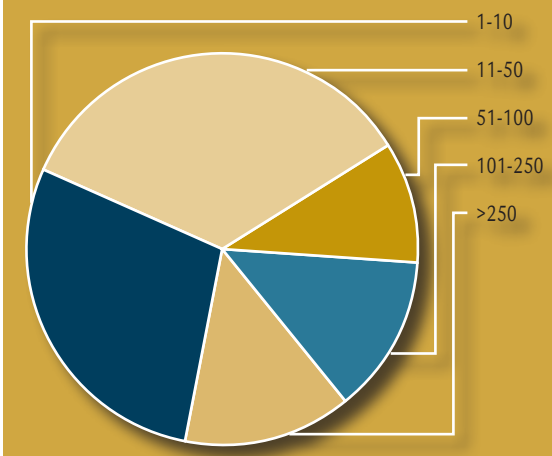


FIGURE A1.3

Distribution of Companies by Size

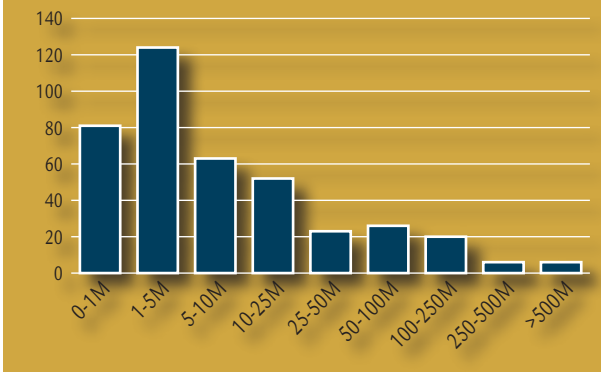
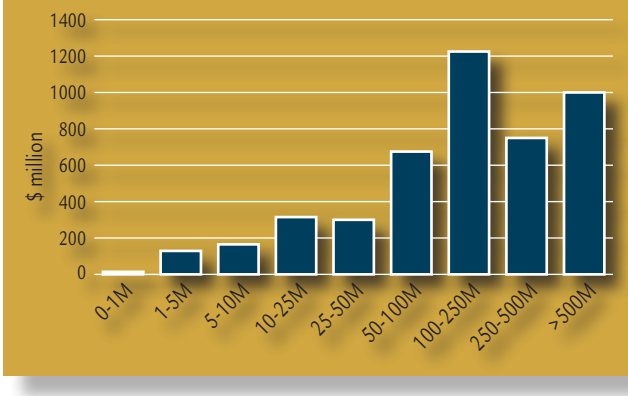


FIGURE A1.4

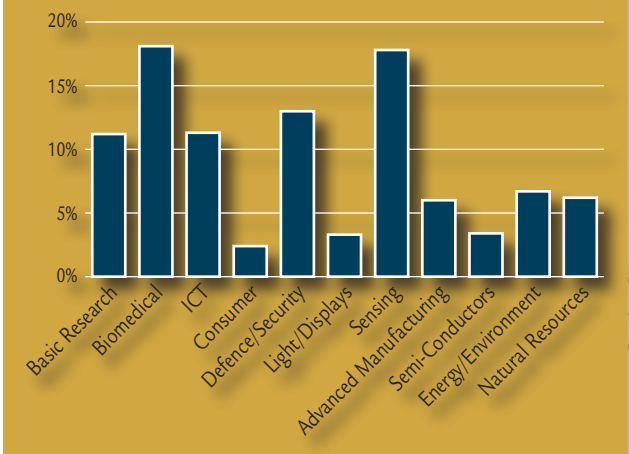
Distribution of Sales by Size of Companies



Since the telecom downturn, the photonics industry in Canada has clearly diversified (Figure A1.5). The biomedical sector and sensing are now the two main drivers of photonic sales. Fewer than 11% of sales are now claimed to address the communications sector, and 13% address the defence and security sectors — historically the two main pillars of Canada's photonics community. It is expected that sales in energy and environment will significantly increase with the trend towards green energy, which represents an opportunity for Canada's photonics companies to build global leadership in an area that is core to Canada's economy. However, consumer, lighting and semiconductor markets are not strong in Canada, as these high-value, cost-sensitive markets are dominated by Asia. Canadian photonics companies address most end-markets and many of them address several: for example, companies that were founded to make devices for telecom now address the life sciences and industrial markets with the same technologies.

FIGURE A1.5

Type of Market Served

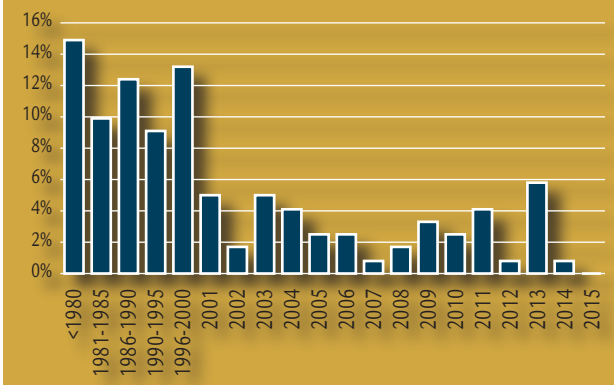


Canadian photonics companies have moved up the "value chain." Only 24% of these companies develop and sell components: those that do, typically have niche positions in specialty devices such as fibres and filters. The majority of the country's photonics companies (63%) provide subsystems or systems and instruments as their end product, many of them using imported optical components to which they add electronics, firmware and software to address a particular application.

Sixty percent of Canada's photonic companies were created prior to year 2000, as shown in Figure A1.6. The survey data does not demonstrate a strong correlation between the age of a company and its turnover.

FIGURE A1.6

Year of Creation of Companies

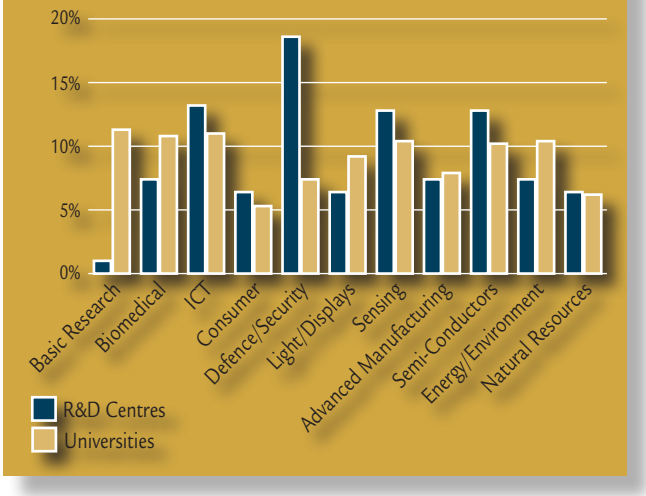


CANADIAN PHOTONICS R&D

The 2015 OECD report indicates that half of gross domestic expenditure in R&D is performed by the industry. In addition, the industries have access to the Canadian R&D capabilities in universities and in R&D centres. Canada spends approximately $150 million annually of federal and provincial government funds on optics, photonics and lasers-related research and development. The 1000 photonics researchers are distributed in the many "photonics" universities and colleges listed in Table A1.1 and within the R&D centres presented in Chapter 3 of the report. Figure A1.7 presenting the markets covered by the R&D community shows that the R&D centres have more activities in defence and security, communications, sensing and semiconductors, while the universities are more evenly distributed between all fields.

FIGURE A1.7

Markets Covered by the Canadian Photonic R&D Community



ANNEX 2 - GLOBAL PHOTONICS

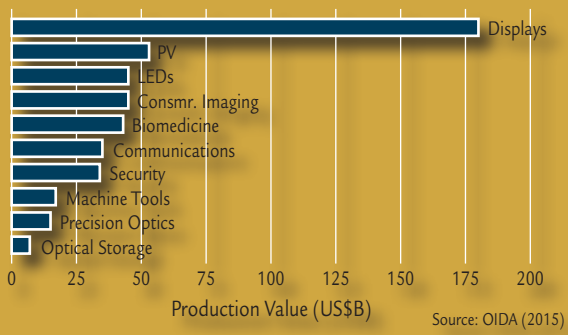
In 2010, the American Physics Society (APS), IEEE Photonics, the Optical Society of America (OSA) and SPIE concluded that the economic impact of lasers was tremendous. They estimated that $3.2 billion sales of diode and fibre lasers were impacting the $4 trillion communications and ICT sector; that $400 million sales of solid-state and excimer lasers were impacting the $2.5 trillion health and biomedical sectors; and that the $1.3 billion sales of CO_2 and fibre lasers were impacting the $1 trillion transportation sector. With its enabling nature, photonics has a strong indirect impact on all sectors of the economy, as evaluated by the OSA Industry Development Associates (OIDA) to $78 trillion.

SPIE and OIDA estimated that the global optics-photonics market would reach US$ 500 billion in 2015, an increase of about 6% from 2014. As shown in Figure A2.1, a significant portion of the global market is on displays, followed by photovoltaics, LEDs, imaging, biomedicine, communications and security.

Figure A2.2 shows that Canada imports CDN$6.7 of photonics products, while the Canadian photonics industry exports 65% of its production of CDN$4.6B.

FIGURE A2.1

Global Photonics Production



Source: OIDA (2015)

FIGURE A2.2

Canada Photonics Imports and Exports

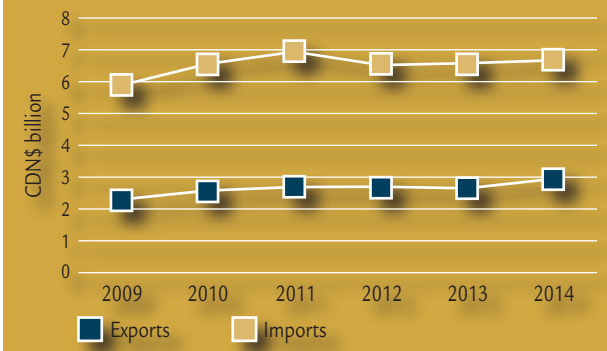
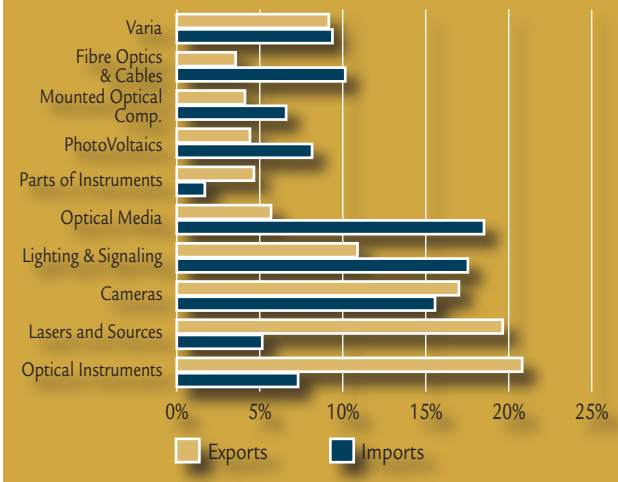


Figure A2.3 shows where products were distributed. More than 60% of Canada's imports are in optical medias; lighting and signage equipment; components; cameras; and optical fibre cables. Optical instruments, lasers and sources, cameras, lighting and signaling correspond to almost 70% of Canada's exports.

FIGURE A2.3

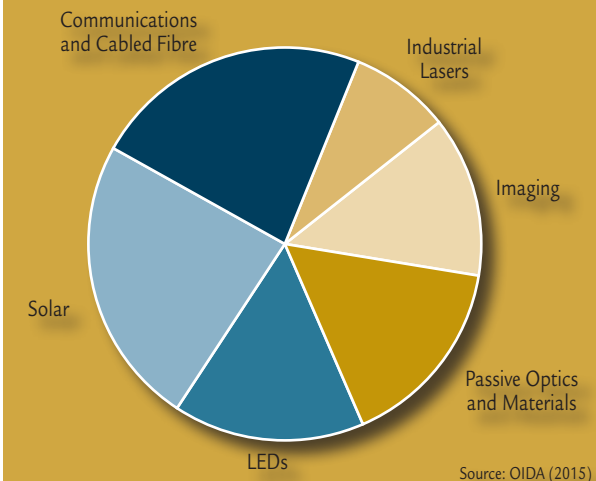
Canada Imports-Exports by Product



The USA's production share is estimated at 18% of the global photonics market (OIDA 2015). The USA's component production is almost evenly distributed among imaging, passive optics, LEDs, solar components, communications, optical fibres, and industrial lasers, as shown in Figure A2.4 from OIDA. The USA supplies 40% of Canada's imports in photonics. More specifically, it provides 60% of Canada's imports in lighting and signage and 46% in fibre cables. In addition, forty-five per cent of imports in optical instruments are from the USA.

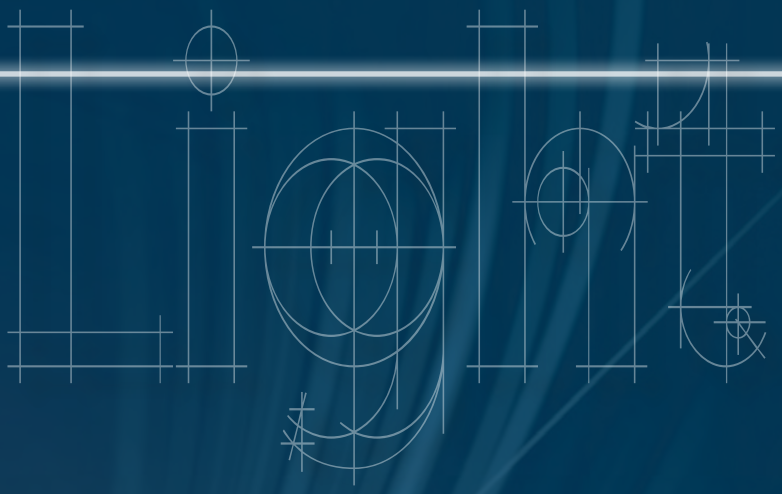
FIGURE A2.4

U.S Component Production



The European global photonics market share is also about 18% (OIDA 2015). Their production covers mainly sensing and imaging, LEDs and laser systems. Germany, France and the United Kingdom are the main producers, but other countries have their own niches. The European industry supplies 11% of Canadian imports: more specifically, 24% of imports in optical components and instruments come from France and Germany.

With its displays production, Asia dominates the global photonics market with 62% (OIDA 2015). Japan's share is 19% and they are strong in displays, solid-state lighting, photovoltaics and input/output equipment. Korea follows with 18% of market share, with its recording media, displays, light sources and solar cells. Taiwan, at a 16% share, is strongly focusing its production on flat-panel displays, and China follows with its 12% share focusing on photovoltaic systems and liquid-crystal displays. About 19% of Canadian imports come from China, 8% from Japan and 4% from Taiwan. Main imports from China are imagers, photovoltaic systems, and optical components. Japan provides cameras and optical components.



The Canadian Photonic Industry Consortium (CPIC)

The mission of CPIC, also known as Photons Canada, is to assist Canadian companies to optimize operations and to improve profits by facilitating and accelerating the application of photonic technologies that improve quality, productivity and profitability. For more information: **http://photonscanada.ca/en**/

PHOTONSCANADA