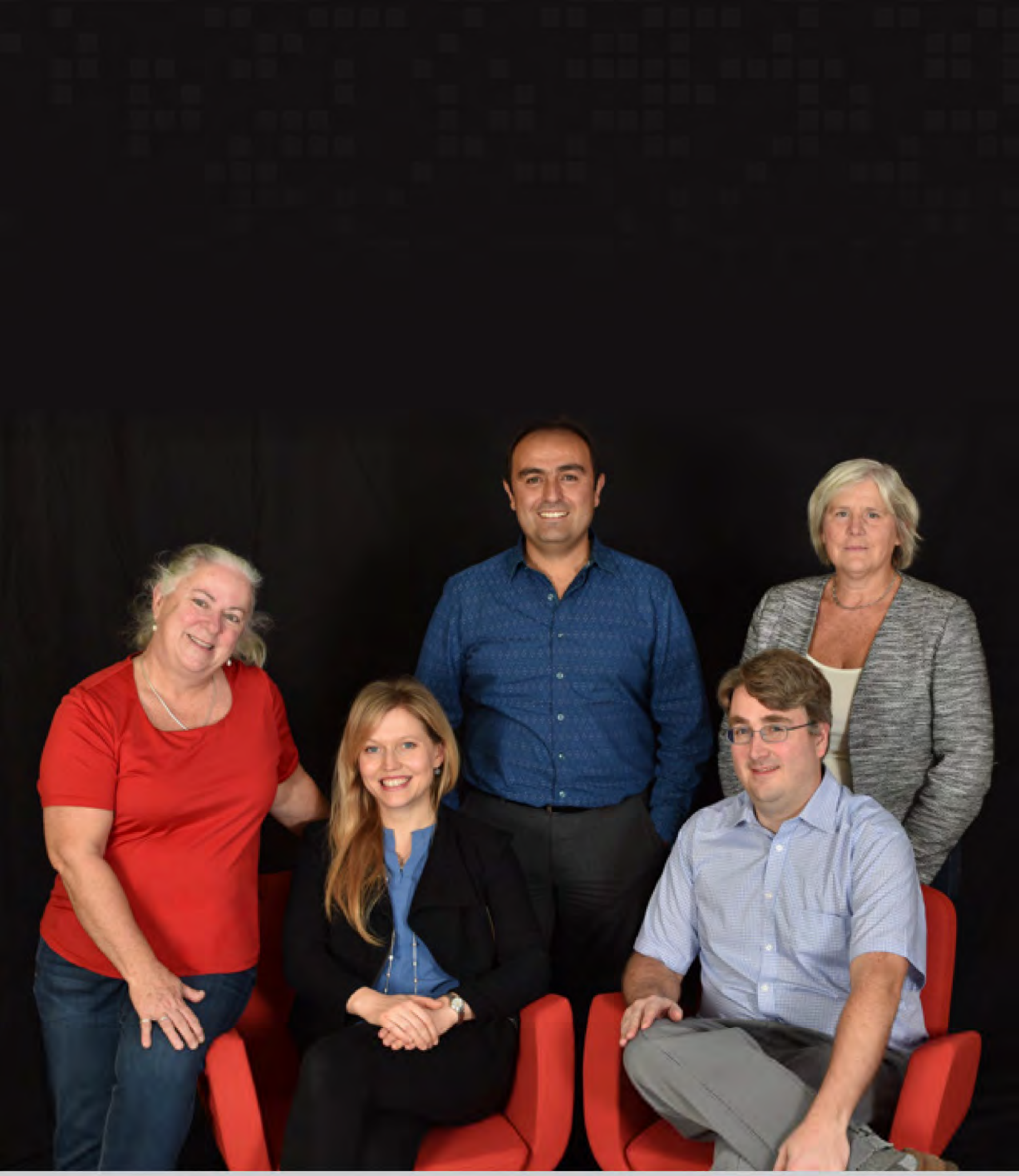
THE CANADA FOUNDATION FOR INNOVATION'S MAJOR SCIENCE INITIATIVES FUND

A report on the advancement of research facilities funded between 2012 and 2017

INNOVATION.CA



Members of the Canada Foundation for Innovation's team responsible for the Major Science Initiatives Fund. Back row: Mohamad Nasser-Eddine, Interim Vice-President, Programs and Planning, and Michèle Beaudry, Senior Programs Officer. Left to right: Sylvie Boucher, Heidi Bandulet and Mark Lagacé, Senior Programs Officers.

FOREWORD

This report tells a powerful story of success for the more than 46,000 researchers and highly qualified personnel who benefit from the facilities funded through the Canada Foundation for Innovation's (CFI) Major Science Initiatives (MSI) Fund. It summarizes recent achievements which offer great promise to the next generation of researchers and which constitute the potential for scientific and technological discoveries as well as strong socioeconomic development for all Canadians.

Highlights include the international recognition received by Nobel Laureate Arthur B. McDonald in physics, by award-winning Yoshua Bengio in neural networks and world record-holder Edward Sargent in chemistry and physics. Facilities and networks have also achieved international recognition with awards from the Royal Astronomical Society (SuperDARN), the American Library Association (Érudit), and a significant U.S. contract for the SuperCDMS experiment at SNOLAB. Collaborative achievements, like the work done between the University of British Columbia and the Vancouver Coastal Health Research Institute to develop a new cancer treatment that will save and improve lives while realizing significant financial gains, are most impressive.

Facilities have universally reached out to collaborate globally. Significant and growing partnerships with business and industry have been noted. Improvements in organizational structures and management have underpinned the success of researchers and constitute in themselves a success, ensuring that facilities are efficient and effective, maintain excellent standards, observe good governance practices and aim for long-term sustainability as well as short-term results.

This report offers a strong foundation for the future — for the students and researchers who will follow in the footsteps of today's dedicated leaders. This text also reveals the intelligent care, concerned stewardship and attention to the unique qualities of each facility as well as the ability to capture the commonalities and overall achievements of these facilities demonstrated by the CFI staff who researched, compiled and wrote this fine report. In particular, I want to recognize Heidi Bandulet, Senior Programs Officer, who, as principal author, worked tirelessly on this project over the summer of 2018 to ensure an outstanding end result.

This story is, above all, a continuing narrative that is being written every day as we work together to share best practices and to meet tomorrow's challenges.

Roseann O'Reilly Runte
President and CEO
Canada Foundation for Innovation

What is the Canada Foundation for Innovation?

The Canada Foundation for Innovation (CFI) makes financial contributions to Canada's universities, colleges, research hospitals and non-profit research organizations to increase their capability to carry out high- quality research.

Research supported by the CFI is helping build communities across Canada. That's because the CFI gives researchers the tools they need to think big and innovate. And a robust innovation system translates into jobs and new enterprises, better health, cleaner environments and, ultimately, vibrant communities. By investing in state-of-the-art facilities and equipment, the CFI also helps to attract and retain the world's top talent, to train the next generation of researchers and to support world- class research that strengthens the economy and improves the quality of life for all Canadians.

This report should be cited as :

The Canada Foundation for Innovation, 2018. *The Canada Foundation for Innovation's Major Science Initiatives Fund: A report on the advancement of research facilities funded between 2012 and 2017*. Ottawa, Ont.

1100-55 Metcalfe Street
Ottawa ON K1P 6L5

Telephone: 613-947-6496
Fax: 613-943-0923
Email: info@innovation.ca

ISBN: 978-1-926485-21-8

INNOVATION.CA

CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

TABLE OF CONTENTS

▲ The Canadian research icebreaker CCGS *Amundsen* is Canada's only dedicated research icebreaker. The ship's facilities and sophisticated pool of equipment make it a versatile research platform for scientists in the natural, health and social sciences along with their partners from government, industry and Northern communities.

EXECUTIVE SUMMARY

The CFI launched the Major Science Initiatives (MSI) Fund in 2011 to enable national science facilities to operate at an optimal level and fully exploit their scientific and technical capabilities. Through this fund, the CFI supports the operating and maintenance (O&M) needs of these facilities and promotes their adoption of best practices in governance and management, including long-term strategic and operational planning.

In 2017, the CFI completed the funding cycles for 12 facilities: four that were funded in the 2012 inaugural competition and eight that were funded in a 2014 special competition. This report, prepared in autumn 2018, presents key findings from the analysis of the final performance and financial reports submitted by these facilities in 2017.

Key observations

Here are key observations for the time period covered by those reports:

- Although each facility had a distinctive funding profile, the eligibility of O&M costs and partner contributions under the MSI Fund were sufficiently broad and flexible to meet each facility's particular operational needs. The CFI tailored its oversight approach to this particular context.
- All facilities achieved gains, even those that received very modest MSI awards. The award size reflected the type and complexity of the facility rather than correlating directly with the facility's level of productivity and success.
- The stability of the operational funding provided through the MSI Fund allowed facilities to optimize their resources and to fully exploit their scientific and technical capabilities, and to improve their long-term sustainability, namely through better preventive infrastructure maintenance.
- All facilities improved their governance and management structures, including the implementation of forward-looking and actionable strategic plans, risk management frameworks and performance measurement strategies, among other things.
- MSI funding contributed to increasing the overall performance of facilities in terms of user access; training and skill development; research excellence and advancement of knowledge; the facility's international stature; and, partnerships with industry and technology transfer.
- Award conditions imposed through the merit-review process drove many of these positive developments.
- A yearly total of 35,000 users and 11,000 highly qualified personnel were supported and 3,300 scientific contributions were enabled by the 12 facilities, averaged over the last three years of the funding cycle (from 2014 to 2017).

Providing support through the MSI Fund

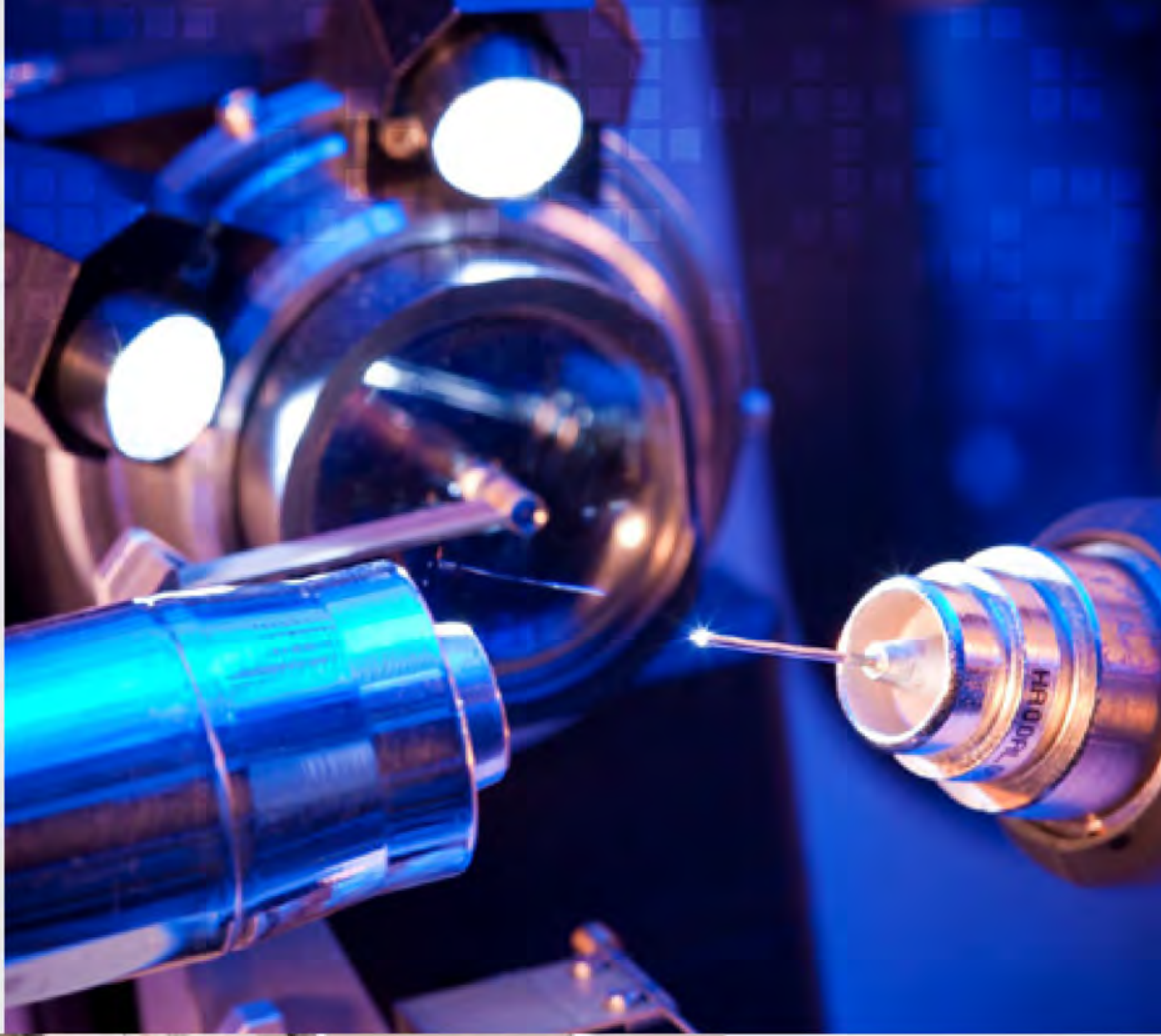
- The assessment of each proposal submitted to the MSI Fund was done through a rigorous merit-review process tailored to the nature and complexity of the facility.
- The process included a review by an Expert Committee and, in the case of the 2014 competition, also a Multidisciplinary Assessment Committee (MAC).
- Award conditions were imposed on eight facilities following review: all four facilities funded in 2012 and four of the eight funded in 2014.
- The total contribution from the MSI Fund to these 12 facilities amounts to close to $211 million, which represents 35 percent of their total operating costs ($594 million). A maximum of 40 percent is allowed, as per the CFI funding formula.
- The estimated total capital investment in those facilities from other CFI funds is about $581 million to date, bringing the total investment from the CFI to nearly $800 million.

Conclusions

- This analysis shows that support through the MSI Fund enabled facilities to deliver outstanding and world-class science and that the CFI met the fund's objectives, an observation that is confirmed by the day-to-day interaction of CFI staff with the facilities. With the development and delivery of the MSI Fund, the CFI has created a model of successful support and oversight for national research facilities.
- Challenges identified through this analysis will inform the planning of the midterm review[1] for the facilities funded in the current funding cycle and will allow the CFI to refine its oversight approach, as well as its reporting framework.
- A "tailored-to-facility" approach ensured that funding decisions and committee recommendations were embraced by facilities. In the best interests of all stakeholders, the same approach will be applied to facilities funded in the current (i.e. 2017–22) and future funding cycles of the MSI Fund.
- The CFI's oversight approach promotes a culture of continuous improvement, factoring in the particular situation and challenges of each facility, and helping facilities think more strategically for the long term.

1 Each facility awarded funding in the 2017 MSI Fund competition will undergo a review by experts near the midpoint of the award cycle, which will determine the CFI contribution to the O&M costs for the remaining period.

The Canadian Light Source (CLS) is Canada's national synchrotron facility located on the grounds of the University of Saskatchewan. Its beamlines are used to study the structural and chemical properties of materials at the molecular level.



The Centre for Phenogenomics (TCP) designs, produces, analyzes and distributes mouse models of human biology and disease. Its resources and research services help academic and industry scientists conduct biomedical discovery research, functional genomic studies, translational research to identify new targets for therapies, proof-of-principle treatment trials and pre-clinical studies to assess drug effectiveness and safety.

INTRODUCTION

The Major Science Initiatives (MSI) Fund provides multi-year support toward the operating and maintenance (O&M) needs of unique national research facilities owned by one or more CFI-eligible institutions. In the 2012 and 2014 competitions for this fund, a total of 12 national facilities received funding from the CFI to cover up to 40 percent of their eligible O&M costs. This report presents key findings from the analysis of the final performance and financial reports submitted by these facilities in 2017.

Purpose of this analysis

The purpose of this analysis is to summarize evidence provided by facilities in support of the attainment of the MSI Fund objectives and, where possible, to identify where CFI funding has had the most impact.

In addition, this report aims to compare the revenue and expenditure profiles of each facility and to provide a snapshot of the investments made by the CFI and other funding partners.

A corollary purpose of this analysis is for the CFI to gain a better understanding of the context of operations of the 12 facilities examined. The last chapter of this report identifies lessons learned. These are expected to be integrated into activities related to the MSI Fund, notably planning the annual workshop for representatives of the MSI-funded facilities and the 2019 midterm review, as well as the reporting framework for the facilities funded in the 2017 competition and the planning of future competitions.

For details on the methodology used for this analysis, as well as some of the inherent challenges and limitations, see Appendix A.

History of the MSI Fund

Since its inception, the CFI has supported the creation of large science facilities that present unique challenges in terms of their O&M needs and their governance and management.

In 2010, the CFI was given the mandate by the Government of Canada to design a systematic approach for evaluating the operational needs and scientific performance of these facilities and for overseeing their governance and management policies and practices.

The CFI launched the MSI Fund in 2011 with the goal of helping to stabilize the operations of these facilities namely through the promotion of governance and management practices of the highest standards including the development of business plans tailored to the Canadian funding model.

The objectives of the MSI Fund are to:

- Secure and strengthen state-of-the-art national research facilities that enable Canadian researchers to undertake world-class research and technology development that lead to social, health, economic, or environmental benefits to Canadians;
- Enable funded facilities to operate at an optimal level and to fully exploit their scientific and technical capabilities; and,
- Promote the adoption of best practices in governance and management, including long-term strategic and operational planning in keeping with the scale and complexity of the facility.

In the first competition, which provided up to $186 million in funding from 2012 to 2017, five facilities satisfied the established set of eligibility requirements: they were unique national facilities, fully operational and had received a minimum of one CFI investment of at least $25 million in capital costs. After the merit-review process, four were recommended and awarded funding[2].

Then, in 2013, the Government of Canada provided an additional $25 million to the CFI to address the needs of other unique national research facilities that were excluded in the original MSI Fund competition (due to the threshold previously imposed on CFI capital investment) but the loss of these facilities would have represented a serious setback for Canada. Among the eligibility criteria were the requirements to demonstrate annual eligible O&M costs exceeding $500,000, and access by a pan-Canadian community of users.

In order to align the funding cycles of the second cohort with the first, successful facilities were awarded funding for three years, from 2014 to 2017. In the end, an additional eight facilities were awarded funding under the second competition, bringing the total number of facilities supported between 2012 and 2017 to12.

In preparation for the renewal of funding to these facilities beyond 2017, the CFI launched a third competition in October 2015. With an available budget of $400 million, the competition was designed to provide continued support to the facilities funded in the 2012–17 cycle, but also to other facilities meeting the eligibility criteria established in the second competition. Seventeen facilities were awarded support through the MSI Fund for either three years (to 2020) or five years (to 2022), among which, 10 had been funded in the previous cycle.

2 The Ocean Tracking Network was not recommended for funding in 2012, largely because it was being managed as a research project, rather than a large national science facility. However, it is being supported in the 2017 MSI funding cycle.

Facilities supported between 2012 and 2017

The 12 facilities funded between 2012 and 2017 represent collective resources for the Canadian research enterprise as they are used by a broad range of researchers from across the country and internationally to conduct world-class research.

Facilities	Awarded through MSI Fund	Awarded through other programs
Funded for five years (2012 – 17)		
Compute Canada (CC), page 47	$60.5M	$211.9M
Canadian Light Source (CLS), page 3	$58.5M	$109.0M
Ocean Networks Canada (ONC), page 41	$37.7M	$51.6M
SNOLAB, page 24	$29.4M	$64.8M
Funded for three years (2014 –17)		
Canadian research icebreaker CCGS *Amundsen*, page vii	$7.6M	$34.0M
The Centre for Phenogenomics (TCP), page 3	$5.6M	$43.2M
Canadian Cancer Trials Group (CCTG), page 7	$3.4M	$0.2M
Genomics Unit of the Biodiversity Institute of Ontario (BIO), page 7	$2.9M	$13.1M
Érudit, page 15	$1.5M	$6.3M
Advanced Laser Light Source (ALLS), page 15	$1.5M	$31.0M
Canadian Centre for Electron Microscopy (CCEM), page 18	$1.5M	$15.4M
Super Dual Auroral Radar Network (SuperDARN), page 18	$0.5M	$0.4M
Grand total from the CFI	**$210.6M**	**$580.6M**

Table 1: Facilities supported through the MSI Fund during the 2012–17 and 2014–17 funding cycles in descending order of the value of the MSI award (not counting awards made in the 2017 competition). Also shown are best estimates of the total CFI contribution awarded to capital infrastructure projects in each facility since CFI's inception (excluding associated contributions, where applicable, from the CFI's Infrastructure Operating Fund).

▲ The Canadian Cancer Trials Group (CCTG) is the only Canadian academic research facility that supports the development and conduction of trials from early phase (e.g., phase I and phase II) studies to large international randomized controlled phase III trials of all treatment modalities across all cancers.

◀ The Genomics Unit of the Biodiversity Institute of Ontario (BIO) runs a world-class facility for high-throughput DNA barcoding, with the capacity for analyzing one million specimens per year, and an active R&D unit.

SUPPORTING FACILITIES' OPERATING AND MAINTENANCE NEEDS

The MSI Fund provided facilities with financial means to help stabilize and optimize their operations to the extent possible within the constraints of the program[3].

Each facility's funding amount was determined on the basis of the merit-review process and reflected a continuation of the actual expenditures in the years preceding the MSI Fund and the proposed management plan for taking full advantage of the facility's capabilities. The eligibility of O&M costs was sufficiently broad to accommodate the vast majority of the needs for running these facilities while recognizing the distinctive characteristics of each.

In the following sections, the actual revenue and expenditure profiles of the cohort are presented as a whole. Individual profiles along with supplementary details are provided in Appendix B. Financial data is also supplemented with contextual information from the reports to show how the facilities were best able to use the funding to optimize their operations, such as through investing in human resources or in the maintenance and upgrades of their equipment.

The CFI also invested in infrastructure projects

As indicated in Table 1, a conservative estimate of the total historical CFI contribution toward infrastructure projects in these facilities (for programs other than the MSI Fund) amounts to close to $581 million. Therefore, without counting commitments made through the 2017 MSI Fund competition, the total CFI investment in the 12 facilities was of the order of $800 million.

Multiple funding partners contributed

Partner contributions for the 12 MSI-funded facilities came primarily from the federal government ($101 million), provincial governments ($80 million) and affiliated institutions, including trust funds and foundations ($77 million) (see Figure 1).

3 CFI's contribution may not exceed 40 percent of a facility's total eligible O&M costs.

As the funding provided by the CFI was intended to complement existing resources to address the operational needs of the successful facilities, it was expected that existing O&M funding partners maintain their support (either as cash or in-kind contributions). Although not shown here, an examination of partner contributions on a yearly basis shows that the level of funding from all major partners remained stable.

CFI was the single largest contributor to the facilities' O&M

The majority of this contribution was awarded to four large facilities funded in 2012

Figure 1: A snapshot of investments made by the CFI and funding partners over the fiscal period 2012–17 to all 12 facilities under the MSI Fund. The total investment amounted to $594 million, $211 million of which came from the CFI, representing 35 percent of the total operating costs of the facilities (less than the maximum 40 percent allowed). Of the $211 million investment from the CFI, $186 million was awarded to the four largest facilities funded in 2012–17 (i.e. ONC, SNOLAB, Compute Canada and CLS), and the remaining $25 million to the eight facilities funded in 2014–17. International contributions are not shown because they are accounted for in the other categories, for example in user fees.

Federal government

The federal government provided 17 percent of the matching funds. The main sources of federal government support were the tri-council federal granting agencies (e.g., $54 million to the CLS from the Canadian Institutes of Health Research (CIHR) and the Natural Sciences and Engineering Research Council of Canada (NSERC)), as well as federal departments such as Transport Canada ($20 million to ONC), the Department of Fisheries and Oceans (close to $1 million to ONC), the Canadian Coast Guard ($3.5 million to CCGS *Amundsen*), the National Research Council ($6.5 million to CLS), Western Diversification ($6 million to CLS and ONC) and Genome Canada ($2.8 million to TCP and BIO).

Provincial governments

Provincial governments provided significant support (13 percent). This support tended to be limited to facilities physically located in their provinces. This indicates alignment with provincial priorities and recognition of the benefits accruing to the provinces. For example, the province of Saskatchewan contributed a portion of the operating budget of the CLS ($11 million or seven percent of the budget) and SuperDARN ($632,000 or 43 percent), two facilities owned by the University of Saskatchewan. SNOLAB, which is located in Sudbury, Ont., and ONC, located off the coast of British Columbia, received contributions from their respective provinces representing 22 percent and 31 percent of their operating budgets respectively.

Institutions and affiliate foundations

Universities contributed to nearly 13 percent of the budget which is at par with provincial sources. They also provided much more than financial support. Most facilities reported that their relationship with their affiliated institutions was stronger because they had obtained support through the MSI Fund. (CFI contributions were made exclusively via eligible institutions[4], which guaranteed some level of engagement.)

For some facilities, obtaining this funding affirmed their status as a national facility and their priority over other laboratories and facilities at their institution. For others, the application of CFI conditions prompted greater involvement from institutions who acknowledged their shared responsibility in meeting those conditions.

The end result was that facilities were provided additional access to Institutional resources. This included dedicated administrative support, project management and business development expertise and help in developing a communication and outreach plan. The facilities were also better supported in their activities (e.g., through release of teaching requirements for facility staff and management). They also benefitted from more oversight and closer lines of communication with the senior management at their institutions.

For example, CCTG reported that significant support from Queen's University was an important factor in increasing the number and efficiency of clinical trials. The university investment of $3 million in faculty positions strengthened capacity for bioinformatics, molecular oncology, biomedical research and imaging. Its support also "led to improvement in timeliness of contract execution, submission of recent grants, Group rebranding, development of a communications plan and recent philanthropic success, including a $100,000 donation toward CCTG's studentship program."

Corporations and firms

Corporations and firms were also key supporters of these national facilities, contributing nearly 10 percent of the overall budget. One example is Vale's Creighton nickel mine which provided essential services (estimated at $40 million for the five-year period), such as the year-round operation of the mining shaft, for SNOLAB to efficiently exploit its underground cleanroom laboratory. Another example is the funding and other resources provided to CCTG by pharmaceutical companies for clinical trials (estimated at $5.6 million).

International and other sources

Funding from the United States' National Institutes of Health (NIH) was the only international source of funding named in the reports from the facilities ($4.5 million to CCTG as cost recovery for the facility's support of clinical trials by American collaborators and to TCP in user fees for research services).

Although not explicitly reflected in the reporting, several international organizations shared the research costs of the programs and projects conducted at the facilities. Facilities also reported that they were able to leverage their MSI award for more funding from Canadian granting organizations, including the CFI, as well as from international sources.

4 Facilities supported through the MSI Fund are owned or operated by academic institutions. They are not eligible to receive CFI funds directly, rather the funds are received through the institution.

Other sources of funding included user fees, non-profit organizations (e.g., health and environmental organizations) and other groups such as private donors.

There are five categories of operating and maintenance costs

There are five categories of operating and maintenance expenses eligible for support through the MSI Fund:

- **Human resources**, including salaries of non-academic managers, professionals, technicians, administrative personnel and consultants directly involved in the governance, management, operation and maintenance of the facility and who provide services which benefit the pan-Canadian user community
- **Services**, including those that directly support the facility (e.g., utilities, security, cleaning, internet), consultants, insurance, fees, permits, telecommunications, etc.
- **Maintenance and repairs**, including replacement of parts, minor upgrades to maintain operational capacity of the facility, extended warranties and service contracts, software upgrades, etc.
- **General administration**, including costs associated with meetings of Boards of Directors and governance committees and related travel, communication and outreach activities, professional services, audits, contingencies, etc.
- **Facility supplies**, including consumables, required to keep the facility in a state of readiness for research (e.g., general lab supplies such as staff protective equipment, cleaning supplies, cleanroom supplies, gases for equipment, supplies related to animal care)

Human resources was the largest O&M expenditure category

Figure 2: O&M expenditures by category for the entire cohort of facilities (sum totals over 2012–17 or 2014–17, as applicable). Dollar amounts do not necessarily reflect how CFI money is distributed among the categories, as matching funds from partners are often earmarked for specific expenses.

As shown in Figure 2, of the five categories, the largest was human resources, which accounted for 47 percent ($278 million) of all expenditures. As these facilities are highly specialized and technically advanced, 80 percent of this amount supported the salaries of highly skilled scientific and technical support staff. The remaining 20 percent supported administrative staff. The next largest categories of expenditures were services, which accounted for 25 percent, followed by maintenance and repairs at 22 percent.

Expenditures grew over the funding period

The overall O&M expenditures of both the three- and five-year cohorts increased over the funding period (see Figure 3):

- From $81 million in year one to $129 million in year five (60 percent increase) for the five-year cohort;
- From $31 million in year one to $38 million in year three (22 percent increase) for the three-year cohort.

An examination of the yearly expenditures by category for the three- and five-year cohorts of facilities indicate that this growth was in part the result of increases in services costs and inflation applied to a baseline of expenditures, but mostly resulted from targeted investments made by the facilities in human resources and maintenance and repairs. Growth in the human resources category was 14 percent and 39 percent for the three- and five-year cohorts respectively. Growth in the maintenance and repairs category is even more significant at 58 percent and 144 percent, respectively.

Overall O&M expenditures increased over the funding period

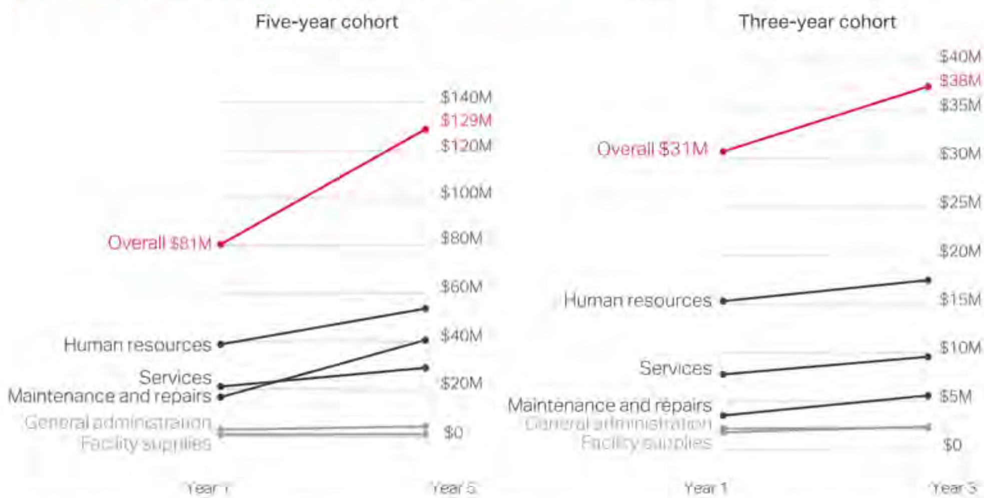


Figure 3: Total expenditures in each category are compared at years one and five for the first cohort of facilities (left) and at years one and three for the second (right).

Investments in human resources for optimal use and improved services

All facilities have used MSI funding to increase or stabilize their staffing levels as a way to evolve their capacity to operate at an optimal level and improve services to their users. The level of increase varies from a few additional staff up to a 35 percent increase in five years for SNOLAB. For most facilities, the new additions were either technical or scientific staff necessary to: provide services in highly specialized areas such as ocean instrumentation and animal model production; support new areas of research such as life sciences and humanities using high performance computing; increase the efficiency of user services or to diversify those services such as data analysis and visualization tools; and, maintain the leading edge in quickly evolving areas such as software development and maintenance and data management.

Several facilities, for example SNOLAB, CCTG, and Érudit, also acquired expertise in administrative functions such as project management, human resources management, business development, technology transfer and contracts coordination.

Érudit also reported that strengthening human resources dedicated to developing new user services and research activities has relieved its small team of senior managers from assuming operational and technical tasks, which in turn has allowed a stronger focus on strategic planning.

All facilities reported professional development activities to ensure that their highly specialized staff have the necessary skills to provide the best services to users (see the section called "Funding enhanced training and skill development for highly qualified personnel, staff and users" on page 31).

Adequate resources to maintain infrastructure for its long-term sustainability

Funded facilities aspire to remain at the forefront of infrastructure developments in their respective fields. MSI funding was reported to be critical for most facilities for maintaining infrastructure at the level required to deliver internationally competitive research and technology development. During the funding period, there were numerous minor upgrades and changes to the portfolio of equipment managed and operated by the facilities. Examples of maintenance activities that were reported mainly relate to incremental upgrades and facility additions to improve efficiency and uptime, such as the retirement of unreliable older systems, the addition of uninterrupted power supplies, the replacement of outdated hardware and software resulting in more advanced programming features, and infrastructure adaptations for compliance with changing regulatory and security requirements.

For a few facilities, significant improvements were also made, for example to their digital infrastructure to improve their capabilities, efficiency and user access to data. Five facilities worked in collaboration with Compute Canada to improve their access to digital infrastructure and processes (ONC, SNOLAB, CLS, SuperDARN and Érudit).

The stability provided by support through the MSI Fund also allowed facilities to give more consideration to their sustainability. Several facilities developed a long-term (multi-year) maintenance and refit/replacement plan for equipment to ensure a state of operational readiness. For example, the CCGS *Amundsen* implemented an improved maintenance cycle of its equipment as a way to maximize the scientific return of its sea operations.

Its maintenance procedures were completely revised and the technical team restructured.

Similarly, ONC refined all aspects of the at-sea and shore-based maintenance of its infrastructure. It also developed standardized procedures for instrument testing protocols, to enable successful instrument deployments. In general, better preventive maintenance has helped several facilities improve their operational efficiency in terms of capabilities ("capacity availability") offered to the research community, and in terms of optimal use of the infrastructure with minimal downtime.

Support through the MSI Fund also allowed facilities to negotiate longer-term service contracts with suppliers for specialized equipment often in need of timely repairs and part replacements, thus improving the reliability of the infrastructure by minimizing hardware downtime and delays on time-sensitive projects. In other cases, such as ONC and the CCGS *Amundsen*, MSI funding allowed the facility to forego such contracts and instead develop the required core competencies and knowledge base within its staff to support its own maintenance needs.

Each facility was unique

There was no typical facility supported through the MSI Fund. To start with, nearly two orders of magnitude separate the smallest and largest O&M budgets (see Figure 4). The size of each facility's annual O&M budget reflected the type and complexity of the facility. In addition, each facility had a distinctive funding profile and O&M needs. As the overall O&M budget for the entire cohort largely reflected contributions to the four facilities funded in 2012 (SNOLAB, CLS, Compute Canada and ONC), the facilities' individual profiles, namely their needs on an annual basis, were examined (see Appendix B).

Nearly two orders of magnitude separate the largest and smallest annual O&M budgets

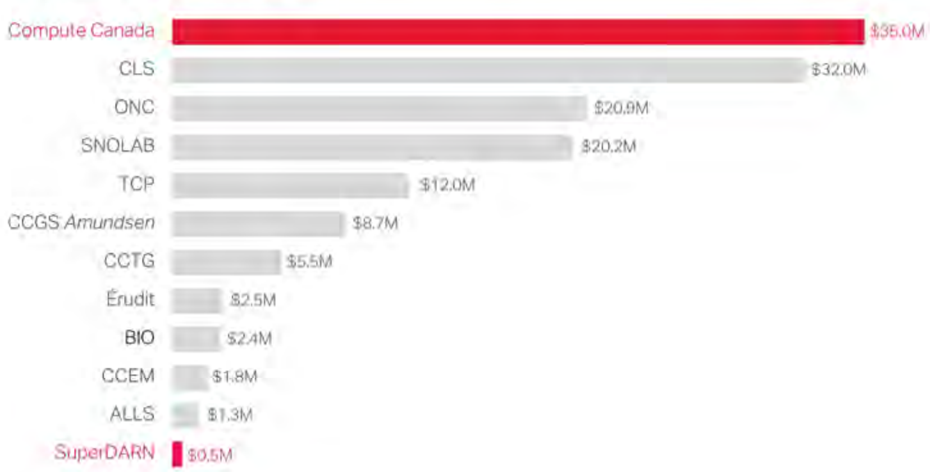
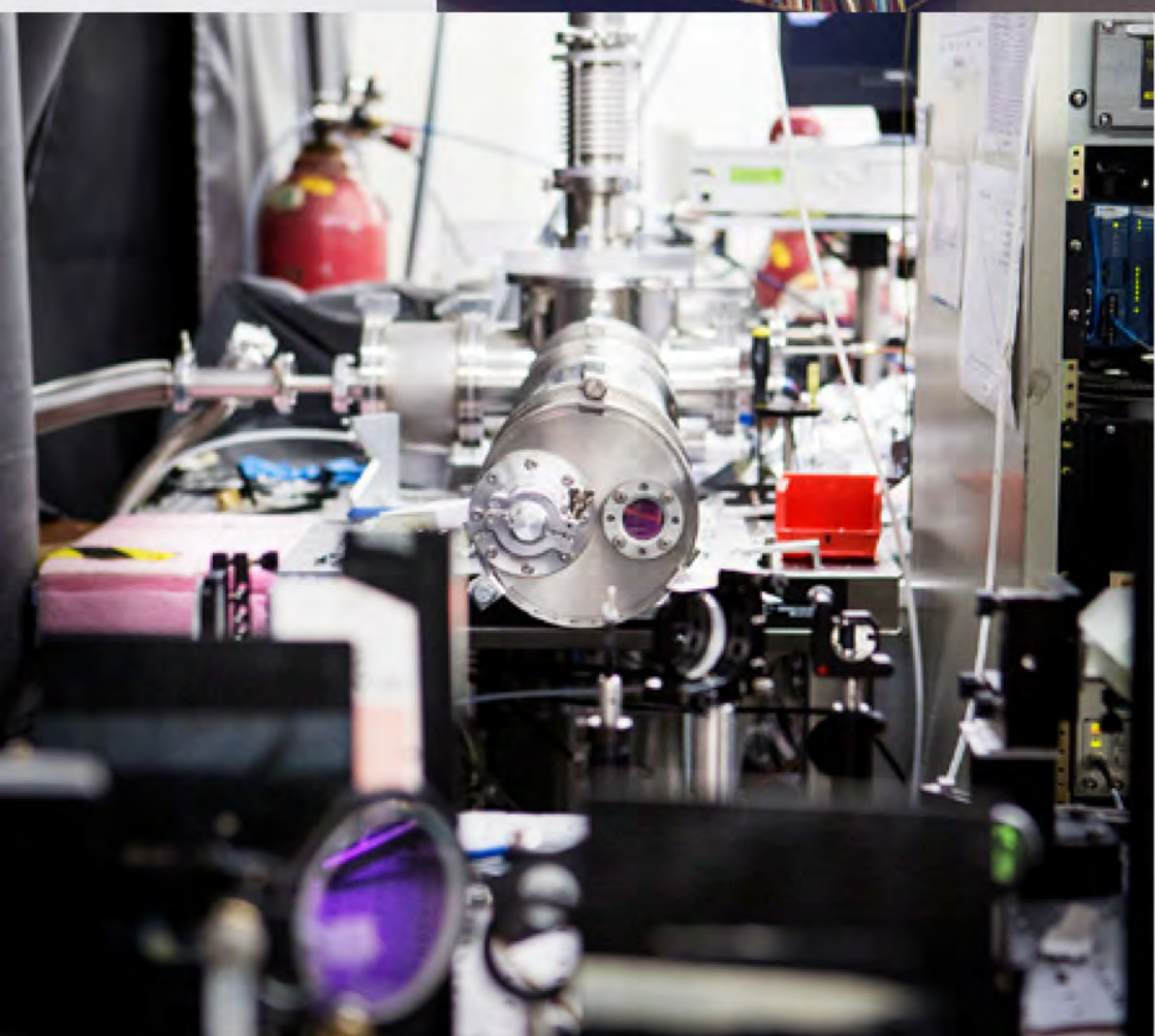


Figure 4: Annual O&M budget of each facility averaged over the last three fiscal years of the funding cycle (2014 to 2017). (Note that SuperDARN's operating budget is for radars located in Canada. The total annual cost to operate all 36 radars of the international SuperDARN collaboration was estimated at $5.4 million in 2017.)

Érudit is a platform for the production and dissemination of French-language research results, giving users access to vast collections of scientific documents and data, mainly in the humanities, social sciences and arts.



The Advanced Laser Light Source (ALLS) regroups a unique variety of ultrashort pulsed laser systems allowing for time-resolved experiments and dynamic imaging in physics, chemistry and biology.

DRIVING POSITIVE CHANGE THROUGH AWARD CONDITIONS

The assessment of each proposal to the MSI Fund was done through a rigorous merit-review process tailored to the nature and complexity of the proposal and included a review by an Expert Committee and, in the case of the 2014 competition, also a review by a Multidisciplinary Assessment Committee (MAC). Members of these committees were selected for their capacity to assess proposals based on the assessment criteria of the fund and their extensive knowledge of facility management, operations and governance. One outcome of the merit-review process was the imposition of conditions on several of the MSI awards to address gaps or weaknesses in the facilities' oversight and operations.

Conditions reflected a facility's key issues

To explore the main challenges that were identified through the merit-review process, an analysis of the conditions in the 2012 and 2014 competitions was conducted. The conditions were coded into 12 categories to enable the identification of the key issues to be remedied by the facilities. Note that many conditions were multifaceted with aspects that could be coded under two or more groups. The conditions were broken down into as many groups as necessary. In total, eight of the 12 facilities had conditions: all four facilities funded in 2012 and four of the eight funded in 2014.

Appendix C provides details on the frequency of each type of condition as well as examples of the key actions taken to address conditions, as reported by the facilities at the end of the funding period. Using their responses, whether, and how, the conditions were met was explored. Further, the conditions applied to these facilities in the 2017 competition (nearly all facilities renewed for funding had conditional awards), were compared to the 2012 or 2014 conditions to establish if the same issues persist after three or five years of support through the MSI Fund.

The most frequently identified gaps in the oversight capabilities of the facilities were related to governance and management structures and practices. The conditions for five of the eight facilities with conditional funding were in either or both those categories. Other recurrent conditions were related to the facilities' ability to track outcomes and their user access processes.

While the conditions were grouped into high-level categories, the specific conditions varied across the facilities, reflecting the diverse context and operations of these installations and networks. There was a wide array of conditions for the eight conditional awards that varied depending on the size, scope, maturity and nature of the facility.

Conditions evolved with the context of each facility

Although responses to a few conditions were not fully outlined in the final reports, CFI staff confirmed that all facilities made satisfactory progress toward meeting their set of conditions. A few examples of actions taken to respond to the conditions are outlined in Appendix C and in other sections of this report (e.g., see the chapter called "Promoting best practices in governance and management" on page 19). All facilities, regardless of conditions, evolved their oversight practices and structures over the course of funding. The conditions appear to have helped facilities address areas for remediation to be in keeping with national research facilities as well as to improve how they report on their progress to the CFI.

All facilities made satisfactory progress toward meeting their set of conditions.

Except for ALLS and BIO, which were unable to demonstrate their status as national facilities, the funding for the other ten facilities was renewed in 2017. Conditions were imposed on nearly all facilities that renewed funding through the 2017 competition (with the exception of CCGS *Amundsen* and SuperDARN), and in most cases these fell into the same group of conditions as the ones from 2012 and 2014. However, the conditions imposed by the MAC in 2017 clearly indicated that significant progress had been made. For example, ONC's condition for tracking outcomes stated: "Although the facility has established metrics, it still needs to enhance the tracking of scientific outputs, outcomes and other metrics to capture the real impact of the facility and its success in light of its mission and objectives."

Many other conditions imposed in 2017 were to prompt facilities to continue to evolve their governance to be more reflective of a national facility.

CFI award conditions, as drivers for positive change, are meant to evolve with the context of each facility. This was noted in particular for SNOLAB and CLS, which, despite good progress and having fully met the previous conditions, were both considered to be at critical crossroads in their lifecycle by the 2017 MAC. In turn, stringent conditions were imposed to the effect that their funding was renewed for only three of the five years of the cycle. The newly applied conditions do not relate to the same issues but instead have shifted to address the emerging challenges facing each facility: delivery of competitive scientific results for SNOLAB and long-term strategy and sustainability for CLS.

The Canadian Centre for Electron Microscopy (CCEM) provides access to a suite of instruments to characterize the structure and composition of materials at the highest spatial resolution, across diverse applications ranging from structural biology, and biomaterials to fuel cell catalysts, nuclear reactor materials and quantum dots for photovoltaics and cancer imaging.

The Super Dual Auroral Radar Network (SuperDARN) is a global network of scientific radars monitoring conditions in the near-Earth space environment. SuperDARN Canada, headquartered at the University of Saskatchewan, is the Canadian contribution to the international SuperDARN program.

PROMOTING BEST PRACTICES IN GOVERNANCE AND MANAGEMENT

In addition to contributing financially to stabilize operations, the CFI was also mandated with overseeing the governance and management policies and practices of MSI-funded facilities to ensure responsible stewardship of public investments and optimal performance.

The CFI developed an oversight framework

With the help of an international advisory committee, the CFI developed its first oversight framework in 2011 — meant as an evergreen document and last updated in 2017 — which outlines requirements and expectations regarding governance and management, ongoing performance monitoring, risk assessment and mitigation, etc. As existing funding partners were invited to participate in this exercise, the result was the elaboration of a common oversight and reporting framework which not only reduces the administrative load on both facilities and funders but also maintains transparency and communication among all stakeholders.

From the beginning, the framework accounted for the fact that facilities are all different, whether in their mandate or mission, stakeholders, culture of the research community or the lifecycle stage of the facility. The CFI recognized from the outset that it must implement a customized oversight plan tailored to the specificities of each facility. Its approach to funding large-scale facilities balances general principles of scientific excellence, responsible stewardship and accountability, factoring in the particular situation of each facility.

CFI's approach to funding large-scale facilities is one that balances general principles of scientific excellence, responsible stewardship and accountability, factoring in the particular situation of each facility.

The CFI facilitated progress according to each facility's stage of development

Implementation and operations of national research facilities are multi-faceted undertakings with several lifecycle stages. A facility's governance and management approach is expected to evolve as the facility matures. As evident from SNOLAB (see pages 24 and 25) and observed for all facilities, evolution of practices, policies, internal structures, etc., is part of the fabric of such installations.

At the start of the funding period, these national facilities were at different stages of operational maturity as related to a facility's stage of development (e.g., R&D design, construction, commissioning, utilization, decommissioning or a mix of those) as well as the facility's relationship with its user base and approach to providing access. Although the operational maturity of the facilities was not benchmarked, the CFI recognizes that several were operational for a number of years (e.g., Érudit, CCEM) while others were in earlier stages of operations as national facilities (e.g., SNOLAB, Compute Canada).

As noted in the previous chapter on award conditions, all 12 facilities evolved aspects of their governance and management structures and practices over the award period, even in instances where no governance or management conditions were set. While the CFI cannot be credited for these transformations, CFI staff worked closely with facilities from the onset, as per the oversight framework, to identify possible areas for improvement based on internationally recognized good practices[5], such as the appointment of a governing body whose composition mirrors that of a national research facility. In addition to sharing these best practices via updates to the oversight framework and in various other documents[6], the CFI hosts regular workshops (six editions by the fall of 2018 including a kickoff meeting in 2011) in which these topics are presented and discussed with representatives of the MSI-funded facilities. The workshops bring together key representatives of each funded facility and establish a forum for sharing knowledge, experience and best practices, and for building relationships across the MSI community, including with the CFI and other funding partners. The workshops also include guest speakers with experience in the management and funding of large-scale facilities from Canada and the United States to bring different perspectives and practices to the group that could be implemented in their own facilities.

The CFI's guidance was acknowledged in several of the performance reports; for example, it was noted that "with advice and input from the MSI program officers, the CCEM developed a detailed

5 These practices were identified and compiled from the knowledge gained from CFI staff site visits at international facilities, collaborations with the United States' National Science Foundation's Large Facilities Office and the European Commission, as well as direct input from the International Advisory Committee for the MSI Fund and the MSI-funded facilities themselves.

6 "Lessons learned on governance, management and operations" presented to the CFI Board in June 2012; Three documents posted on the MSI Fund section of the CFI website since 2016: "Managing user access for large initiatives or facilities," "Developing a strategic plan for large initiatives or facilities" and "Managing risk in large initiatives or facilities."

Management plan focused on the achievement of the CCEM strategic goals set in the CCEM's strategic plan."

The key changes to governance and management structures and practices during the funding period are summarized here. Improvements to the facilities' performance monitoring framework are discussed in the next chapter along with the facilities' achievements, impacts and benefits.

All facilities improved their governance and management structures

Most facilities underwent internal or external reviews of their governance and management during the award period. This brought changes to structures and processes. For example, both Compute Canada and SNOLAB transitioned to governance structures offering greater independence from the facility's stakeholders. As a consequence, these two facilities revised the membership of their Board of Directors to comprise a majority of independent members while still retaining adequate representation from academic institutions or links to those institutions' governing bodies.

Several facilities also developed or refined their governing body's required competency matrix to ensure that it had the appropriate set of combined experience and skills to make informed and efficient decisions for the success of the facility. Both the independence of members and the development of such a matrix are examples of best practices highlighted in CFI's oversight framework.

Other reported improvements include the creation of new committees or the streamlining of existing ones that spanned advisory, finance, user group and planning committees.

The CCGS *Amundsen*, for example, established four new standing committees following its incorporation. These committees support the Board and senior management in overseeing the performance of the facility. They include a User Advisory Committee to provide a rigorous and impartial assessment of requests for access to the ship and an Infrastructure Development Committee to advise on strategy, priorities and costs related to the upgrade and development of the facility's equipment. The CCGS *Amundsen* reported that "these committees are essential for the effective functioning of the Board and to enable informed decision-making."

Some facilities also created or restructured committees to advance knowledge and technology transfer and commercialization endeavours (e.g., ONC's Commercialization and Engagement Committee).

A number of facilities also made changes to their leadership. This included the appointment of CEOs at Compute Canada and BIO (a newly created position at the latter). Other facilities developed and integrated succession plans into their strategic plans (e.g., CCEM, ONC, SNOLAB).

Many facilities created new management positions or modified their management structure to better respond to the needs of the facility and its users. For example, ALLS hired a scientific coordinator to work with users (academic, government and industrial) and the technical team to ensure technical specifications were optimized for the intended application.

Organizational changes included streamlining management positions and defining or redefining roles. The CLS, for example, in implementing changes to senior and middle management positions, commented that the revised management structure "enabled the identification and subsequent focus on strategic priorities."

All facilities developed forward-looking and actionable strategic plans

Several facilities did not have a fully developed governance structure at the start of the award period, nor did they have a formal strategic plan in place with well-defined strategic goals (e.g., CCTG, BIO). During the MSI funding cycle, and to meet CFI's expectations, all facilities developed forward-looking and actionable strategic plans.

SuperDARN reported that "based on lessons learned from involvement in MSI and University of Saskatchewan research facilitators, SuperDARN Canada initiated a strategic planning process for the International consortium." In addition to the update of the strategic planning for the Canadian operations, the process informed the international SuperDARN Executive Council.

Strategic planning also contributed to integrating facility staff in the identification of strategic objectives. Érudit reported that [translated from French] "This exercise involved all of Érudit's staff. It reinforced the team's involvement in achieving Érudit's mission at the same time as the participation of the members of the Board of Directors in its activities."

CCTG explained that it was the recommendations resulting from the development of both strategic and business plans during the award period that were at the heart of its success in increasing the speed at which drug clinical trials are conducted and a subsequent decrease in their associated costs.

All facilities implemented a risk management framework

As one of the best practices promoted by the CFI, facilities were encouraged to develop and implement a risk management framework during the award period to identify key risks (based on exposure and impact), and a strategy to mitigate them. With the exception of a few (CLS, SNOLAB, BIO), most facilities did not have a formal framework in place prior to the MSI award, but all reported having one in place at the end of the funding cycle. Facilities that already had a risk registry reported that they enhanced or refined their framework over this period.

To help facilities develop their framework, CFI staff provided assistance and shared examples taken from the first cohort of facilities. The MSI workshops also provided opportunities through dedicated sessions focused on risk management for facilities to gain helpful knowledge and learn through examples of real-life situations the value of implementing this kind of framework. Some facilities also engaged consultants to develop their framework.

Facilities reported referencing the risk framework on a regular basis and integrating it into the facility's activities once it was in place. For most, the framework is revisited annually to identify emerging risks and to ensure active management of very high and/or likely risks. Some facilities reported having made certain actions specifically to mitigate risks or described having put in place a longer-term strategy to solve or face key issues.

The top three risks reported by the 12 facilities were associated with:

- Human resources (e.g., difficulty in hiring or retaining staff, loss of critical skills, succession planning);
- Financial viability of the facility (e.g., ensuring sufficient O&M revenues, loss of CFI funding or funding from other key partner);
- Operational efficiency and reliability (e.g., issues causing disruption of services or collection of data, system failures, cybersecurity issues).

Other key risks depend largely on the nature and complexity of the infrastructure. For example, the risk with the most serious negative impact for the CCGS *Amundsen* is the possible rerouting of its entire operation by the Canadian Coast Guard (the owner of the vessel) for search and rescue activities or to deliver goods to remote communities, for example, thus deferring all planned scientific activities.

Other risks which are more frequent include:

- Maintaining the infrastructure at the leading edge is a key risk for facilities relying on rapidly evolving technology (CCEM, ALLS, BIO and TCP).
- Risks related to governance, legal and liability issues were often key to facilities with identified weaknesses in their governance or management structures.
- Risks related to health and safety, hazards and regulatory compliance were prevalent among larger and more complex or highly regulated facilities such as CLS, SNOLAB, ONC, TCP and CCGS *Amundsen*. For example, TCP must comply with various sets of laws and regulations (e.g., Canadian Council on Animal Care guidelines and compliance certification) to maintain its operation, which necessitates robust oversight by all of its stakeholders including by domain experts.
- For service-oriented facilities with significant support from user fees, a decrease in engagement or interest of users was often raised as a key risk.

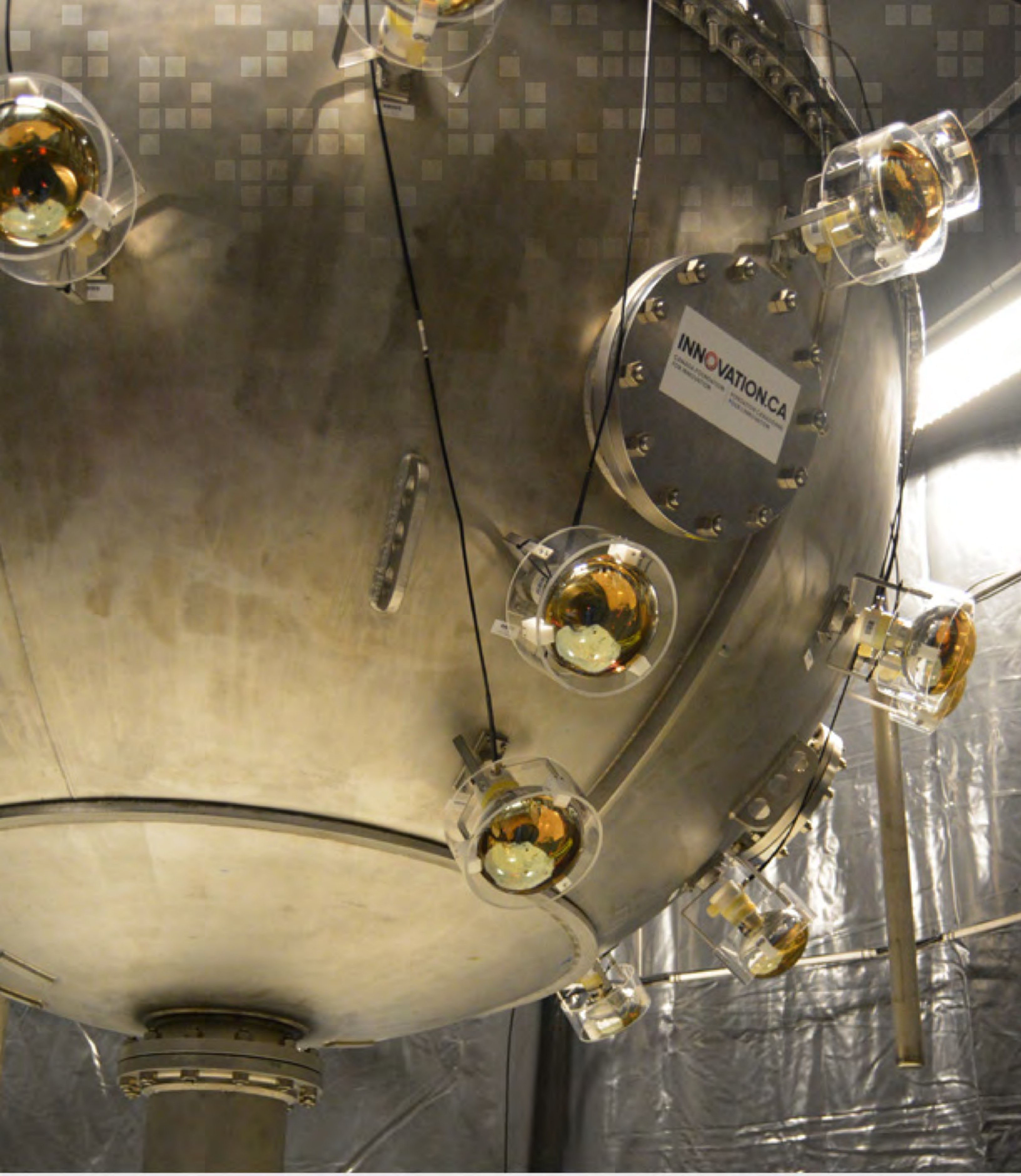
The CFI promotes a culture of continuous improvement

Several facilities initially expressed reservations about the necessity and benefits of implementing "corporate-style" governance and management practices. The belief that it "doesn't apply" came from a view that it is costly to implement in terms of resources, is too bureaucratic in that it slows decision-making, and that it cannot be tailored to reflect the values of research-focused organizations.

The reality is that all facilities compete in an environment where good governance and management have become a necessity.

Several facilities reported that steps taken by the CFI since 2012 convinced them that some adjustments were worthwhile as these could have a positive impact on the performance and long-term viability of their facility.

It is evident from the performance reports that the CFI's efforts to instill a culture of continuous improvement have been fruitful. All 12 facilities have evolved their governance and management structures commensurate with their lifecycle stage, complexity and nature. Changes were manifested in diverse ways, such as improving governance and management structures, evolving strategic plans and monitoring and mitigating risks. Several facilities explicitly stated their commitment to continue monitoring, adapting and improving their governance and management over time.



▲ SNOLAB is a research facility two kilometres underground in Vale's Creighton nickel mine in Sudbury. It is mainly dedicated to the study of extremely rare astroparticle interactions.

Case study: Supporting SNOLAB's expansion to a multi-experiment facility

The CFI's support to SNOLAB between 2007 and 2012, when SNOLAB began transitioning from a Nobel-prize winning SNO experiment to a multi-experiment facility, can be considered a precursor to the MSI Fund. CFI provided project funding to support the expansion and annual funds to cover part of SNOLAB's O&M needs.

As this special arrangement came with additional stewardship responsibilities, the CFI contracted a firm in 2008 to assess SNOLAB's governance and management structures, and oversaw the implementation of the recommended changes in subsequent years. Then, at the initial review for the MSI Fund in 2011, although the review committee acknowledged the significant progress SNOLAB had made in the area of governance and long-term strategic planning, it identified several areas for improvement in keeping with the evolution of the facility from construction phase to fully fledged operations.

Following conditions imposed in 2012, SNOLAB again underwent a full revision of its governance and management structures. For example, a new Board structure was established to ensure greater independence of its Directors, a clear separation between governance and management and better-defined reporting structures for senior management.

The management structure also evolved to place greater focus on the delivery of the science program, one of SNOLAB's key reputational risks owing to the fact that its success as a facility is ultimately tied to that of the experiments it hosts. Accordingly, SNOLAB's organizational chart was split into a Science division and an Infrastructure division with the Directorate Office divided into Core Services and Risk Management Services.

Another significant improvement was the adoption of a project lifecycle approach dictating all aspects of the management of projects conducted at SNOLAB, from the initial expression of interest to full decommissioning.

The revised management structure coupled to the lifecycle approach ensures that the facility's resources are optimally managed according to a well-defined set of priorities.

The 2014 midterm committee[1] and the 2017 committees were impressed by the above changes and agreed that SNOLAB's policy-driven governance, new management structure and lifecycle approach are defining the best standards for large international laboratories.

Even though science delivery remains an area of concern in the new funding cycle to which several conditions are attached, the 2017 committees acknowledged that the new structure has so far shown positive results in mitigating the risks associated with experimental challenges.

The governance model of SNOLAB is in the midst of another important shift as SNOLAB, up until now operating under a consortium of universities, is assessing incorporating as a not-for-profit entity in order to address remaining issues, namely liabilities associated with operating in a production mine.

1 Facilities funded for five years between 2012 and 2017 underwent a midterm review by a committee of experts in 2014 which determined the level of CFI funding for the last two years of the MSI award. Facilities funded in the 2014 Special Competition were not subject to a midterm review given the short timespan for the funding.

ACHIEVING IMPACTS AND BENEFITS

It was shown in previous chapters how stable operational funding has allowed facilities to optimize the allocation of resources to maximize their capacity and capabilities to best serve their user community. It was also shown how the promotion of best practices has encouraged facilities to make adjustments to their management and governance structures and practices to positively impact their overall performance. As Érudit summarized in its report, support through the MSI Fund has led to the "professionalization" of Canada's national facilities and has helped facilities think more strategically.

In other words, support through the MSI Fund is helping facilities do better what they were meant to do — enable world-class research. The achievements, impacts and benefits ensuing from the facilities' primary activities are highlighted here.

Common strategic goals resulted in common areas of impact

When asked to describe their top achievements and impacts for the funding period, all facilities reported accomplishments in line with their mission or strategic goals and objectives, as would be expected from good strategic planning.

By examining the strategic plans of the 12 facilities, common elements were identified, including enabling leading science and providing state-of-the-art research capacity and capabilities in terms of infrastructure. Outreach to a wide community of users and training of highly qualified personnel[7] were also common implicit or explicit goals. The remaining strategic goals varied depending on the nature of the research and the relationship of the facility to its community of users. Several facilities prioritized top-quality competitive services, international visibility and reputation, responsiveness to the needs of industry, health and security, efficiency of operations and sustainability, among others.

Accordingly, the most frequently reported areas of impacts and benefits relate to the common elements found in the majority of the facilities' mission statements and goals, many of which are themselves inherently

7 Highly qualified personnel (HQP) is defined as technicians, postdoctoral fellows, undergraduate and graduate students or research associates and excludes staff employed (human resources) at the facility.

interconnected. The most widespread impact identified was on the quality of the research conducted at the facility. Facilities reported an increased capacity to conduct research and advance knowledge in their supported fields of research, and an increased capacity to collaborate with Canadian and international researchers. These resulted in increased publication output. Investments in human resources, and in maintaining the infrastructure at the leading edge, resulted in better services and access to users as discussed in the section called "Expenditures grew over the funding period" on page 12.

These improvements had a positive impact on the domestic and international reputation and productivity of the facilities and the researchers making use of these resources. The effects of this enhanced reputation was reported to have translated into a better ability to attract new users as well as top researchers and highly qualified personnel as either users or staff. A similar effect was reported on the facility's (or researchers') ability to attract additional funding both from Canadian granting organizations as well as from international sources.

Facilities also reported that support through the MSI Fund strengthened the training and skills development for highly qualified personnel and enhanced opportunities for collaborations and partnership with the private sector. As discussed in the section called "Funding enhanced opportunities for partnerships with industry and technology transfer activities" on page 39, this resulted in technology transfer outcomes such as the creation of intellectual property. When asked to report on impacts on local or regional innovation, the benefits identified were mainly economic in that the facility provided employment of the local population and generated revenue for itself and its partners through contracts or service agreements, and enabled local industry to advance its research and development (R&D) capabilities.

A performance measurement strategy improved management and helped assess impacts

There is little doubt that the implementation of a performance monitoring system or measurement strategy benefits all types of organizations in becoming more effectively managed and sustainable. The adoption of key performance indicators (KPIs), provided these align with the organization's goals and are measurable and actionable, is a central part of this strategy.

In requiring that all facilities supported through the MSI Fund define a set of KPIs (or in several cases enhance a pre-existing set), the CFI aims to help facilities better define and measure progress toward achieving their vision, mission, key organizational goals and objectives, and ensure their long-term scientific and strategic relevance.

KPIs also contribute to the successful communication of results and achievements and are therefore of great use to the CFI in providing supporting evidence toward meeting program objectives and in demonstrating the impact of its investments to stakeholders.

From the very first version of the MSI oversight framework, the CFI recognized that its monitoring approaches needed to be tailored to the nature and complexity of each facility. The KPIs were no exception. As each of the 12 funded facilities worked closely with CFI staff to define, or refine, its set of KPIs, it was paramount that the final set reflected the unique context and critical success factors of the facility. As such, the number of KPIs being monitored and reported to the CFI on an annual basis varied among facilities and ranged from seven to 19.

In spite of this customization, commonalities were still found due to the fact that most facilities share similar organizational goals. Three KPIs were common to all — access to the facility (number of users), contributions to training highly qualified personnel, and knowledge transfer/advancement of research programs (number of scientific contributions) — although even in these KPIs the specific definitions and collection methods varied significantly among facilities.

Other frequent metrics included the number of technical contributions and industry partnerships, the facility's level of use, and the level of user satisfaction. For a discussion on lessons learned on performance management, see Appendix D.

Funding contributed to improved service delivery and user access, often allowing the facility to optimize the level of use

Since the raison d'être of these facilities is to serve a broad research community, all 12 of them tried to improve the quality of their services and the satisfaction of their users. All also aimed to increase or diversify their user base.

Increased user base

Each facility was asked to report the estimated number of users of facility resources per year. Only a few facilities provided the breakdown of users by sector (academic, public, private) or research domains. Also, given the diverse nature of the facilities, the definitions of a user varied across facilities. Typically, facilities which mainly provide data or remotely accessed resources (e.g., BIO, ONC) reported the number of data users (or a proxy thereof) while facilities providing access to instruments located at the facility (e.g., SNOLAB, CLS, CCGS *Amundsen*) only reported users physically present on site (even though other data- or end-users also exist but were not tracked or reported). In contrast, some facilities of the latter category did include the users of data or results obtained at the facility even though those users did not visit the facility in person. Moreover, some facilities are constrained in the number of users that are allowed to be present on site at any given time (e.g., 40 users in the case of the CCGS *Amundsen*). In the case of BIO, they separately tracked the number of external users who submitted physical samples for sequence analysis (over 200 per year on average) and the number of users of their Barcode of Life Database (17,000 users yearly among which 90 percent are from 135 countries besides Canada). In cases where more than one indicator was provided, the CFI chose the indicator which appeared the most consistent with that of the other facilities.

In light of variable definitions of a user, the challenges with reliability of the data collection (see Appendix A), and the nature of the facility itself, the reported number of users varied greatly from one facility to the next, as shown in Figure 5. The range extended from a handful of users in the case of Érudit through several hundred for SNOLAB, CCEM, TCP and CCTG to close to a thousand for CLS. ONC and BIO had by far the greatest number of data users (respectively 12,300 and 17,000 Canadian and international users yearly), while Compute Canada reported having slightly more than 3,100 confirmed users per year.

All but one facility (Érudit, related to the challenges mentioned in Appendix A) reported a growing user base over the three or five years of support of the order of three percent (CCEM) to 72 percent (ONC), or close to 40 percent on average for the last three years only. This growth is an indication that support through the MSI Fund not only allowed facilities to continue to serve an important community of researchers (as judged at the initial review stage) but that they managed to benefit an even larger user base. In the case of ONC, a change in the data collection method midway accounts for a step-wise increase, although steady growth is nonetheless observed yearly since the change in methodology. ONC also specified the proportion of principal investigators and researchers in their user base and mentioned that these grew from 180 in 2012 to over 500 in 2017. Compute Canada users also increased by 10 percent annually, which the facility attributed to the increasing importance of advanced research computing to internationally competitive research and innovation, as well as the sustained outreach of the four regional organizations to their respective research communities.

In summary, the total estimate of users benefitting from the 12 facilities, averaged over the last three years of funding, amounted to roughly 35,000 users per year. This number is likely an underestimate as discussed in Appendix A.

Approximately 35,000 users were supported each year

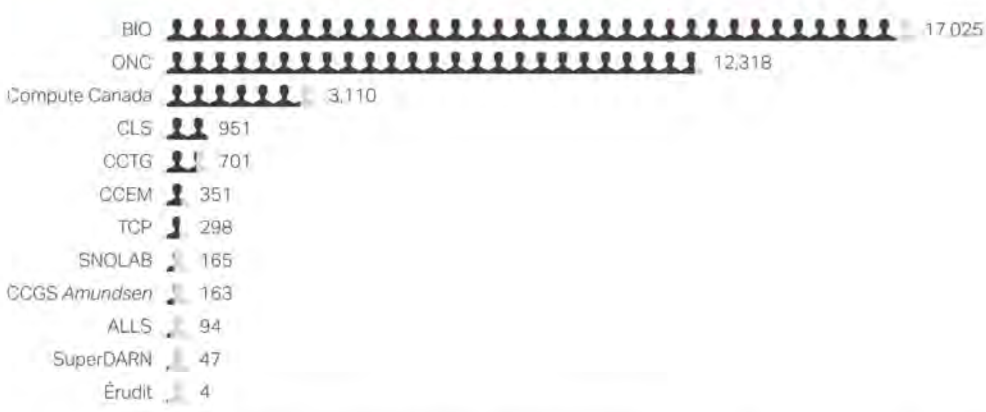


Figure 5: Annual number of users reported by each facility averaged over the last three fiscal years of the funding cycle (2014 to 2017). Note that facilities adopted a variety of definitions for what constitutes a facility user. The reported numbers in most cases are also underestimates. Therefore, the comparability among facilities is limited. See the section "Increased user base" on page 28 as well as Appendix A for more detail.

Improved access to facility resources

The method of granting access to users depended on the type of resources and services provided by the facility. Out of the 12 facilities, eight had a review system in place to determine user access which was typically, but not always, based on peer or committee review. Two facilities adopted a mixed approach where only some resources were openly available — data in the case of SuperDARN and computing resources deemed moderate (default allocation model) for Compute Canada. Four facilities adopted a completely open access policy (BIO, Érudit, CCEM and ONC). A few facilities, regardless of the type of access, set up a user fee structure.

Over the course of the MSI award, several facilities improved access to users, which helped maximize the use of the facility and outreach to new users or communities. CCEM, for example, implemented online booking, remote access and data collection systems, thereby increasing efficiency and allowing for better quantification of user access data. ONC reported that support through the MSI Fund "was the largest contributing factor to ONC's ability to provide access to the facility during the funding period, without which ONC would not have been able to deliver and archive data, and provide user support, web development, or at-sea operations." The Ocean 2.0 web portal attracted 56,000 unique visitors since it was launched at the beginning of the award. Besides ONC, the CCGS *Amundsen* was the facility that reported the most extensive development in this area as the mechanism to allocate ship time was completely revamped following the recommendations of the CFI review committee. A formal ship time application process was developed and an independent advisory committee was established. The website was also completely redesigned to improve visibility of the infrastructure for current and potential national and international academic, government and private-sector users.

Facility's level of use

As part of the effort to gauge the performance of facility operations, each facility was asked to quantify its level of use relative to potential capacity. This was perhaps the one metric for which the definition was the most variable among facilities given it had to be defined according to the facility's unique context of operations. Generally, it was a measure of the time a resource was used by the community in proportion to the time it was made available to it.

All facilities gave high priority to maximizing the use of their capabilities.

In the case of ALLS, for example, 100 percent utilization implied that all four lasers were fully operational and used by the community for research purposes for at least 36 weeks of the year (as the remaining 16 weeks were reserved for maintenance activities). In the case of Compute Canada, "utilization levels are calculated based on the proportion of time a computational node's resources are assigned to a job, from all the time that node's resources are available." It was clear from the responses received that all 12 facilities gave high priority to maximizing the use of their capabilities. Factoring in all circumstances, the 12 facilities reported having met or exceeded their targets for this metric. The review of what was reported in 2017 showed that this metric needed to be better defined by the facilities for the 2017–22 cycle.

User satisfaction

Although not all facilities were able to quantify the satisfaction of the users, those who have employed user surveys for the entire duration of the MSI cycle (CCGS *Amundsen*, ALLS, Compute Canada, CLS and CCEM) reported high levels of user satisfaction. TCP described that creating a customer services coordinator position significantly enhanced communication and customer satisfaction. All 17 facilities currently supported in the 2017–22 cycle have put in place user surveys.

Funding enhanced training and skill development for highly qualified personnel, staff and users

The majority of MSI-funded facilities make explicit commitments in their strategic plans to support the training of users, staff and highly qualified personnel, including the next generation of scientists.

Increased number of highly qualified personnel

The number of highly qualified personnel benefitting from the facility resources was one of the common KPIs that all 12 facilities were able to provide in their performance reports. In a few cases, the number included those employed by the facility (e.g., technicians), and in two instances (SNOLAB and ONC) workshops or lecture participants were also included. Some facilities, such as the CCGS *Amundsen*, reported only highly qualified personnel who were physically present on site while others also included those who were data users. This illustrates the variability of this measure among the facilities during the last MSI cycle. The accuracy of the reported totals is also limited by the facility's ability to estimate its users; hence, the numbers reported are likely also underestimates. As shown in Figure 6, the average number of highly qualified personnel per year (in the last three years) is close to 11,000 individuals. Compute Canada reported the highest number of highly qualified personnel among the funded facilities which accounts for 68 percent of the total.

The training of thousands of individuals enabled by support through the MSI Fund is mostly related to: training of graduate students from the facilities' affiliated academic institutions, who either use the facilities and their infrastructure (on site) or the data collected and disseminated by the facilities, as part of their research projects and training; or training of highly skilled staff (e.g., highly skilled research associates or technicians) responsible for the operations of the facilities (although these are typically not captured in the highly qualified personnel KPI).

Nearly all of the facilities gained users over the course of the award with an associated growth in the number of highly qualified personnel. In fact, over the last three years of the funding cycle the overall number of highly qualified personnel grew by 19 percent. This growth, however, is not always in direct proportion to the number of reported users. Eight out of 12 facilities had greater growth in highly qualified personnel than users, while for the other four, the opposite is true. For example, at ONC, the number of users and highly qualified personnel increased by 72 percent and 220 percent respectively. In contrast, at BIO, the proportional increase is 48 percent and 1.4 percent respectively.

Training of facility human resources

Facilities reported how MSI funding was critical in supporting the professional development and statutory training of its staff which was essential to maintaining and retaining the required highly skilled personnel. Each facility developed or enhanced its own suite of training activities for their staff as new techniques, regulations, scientific methodology and state-of-the-art equipment evolve rapidly. Staff may have attended specialized workshops at the national or international levels or have undergone training by manufacturers and suppliers on the latest methods, new software functions, "tricks" to get better data, and "dos and don'ts" of instrument operation. Such training contributed to both maintaining the advanced level of skills for facility staff and to significantly improving the use of specialized scientific instruments and the facility as a whole. For example, in 2015 Compute Canada became a Software Carpentry national partner. Software Carpentry conducts workshops internationally, training researchers in the basic software skills needed to effectively use advanced research computing resources. In 2017, Compute Canada signed a memorandum of understanding allowing it to certify its own trainers, thus expanding the potential reach of the training. This kind of partnership was made possible by support through the MSI Fund and enabled by the facility's corporate structure.

Given that these facilities are highly specialized, the skills acquired by highly qualified personnel and staff, and their relevance to careers in research and other fields were highlighted among the achievements of the facilities. They conclude that MSI funding helps train a new workforce for the fast-growing knowledge economy.

Approximately 11,000 highly qualified personnel were reported each year

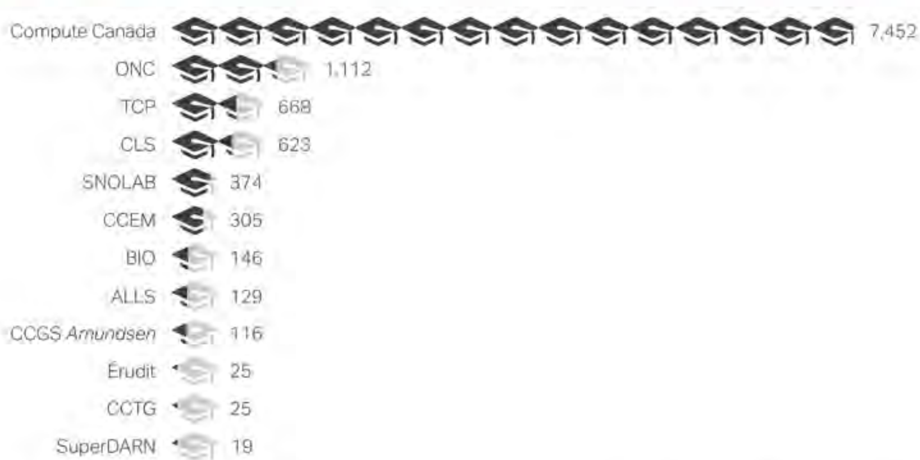


Figure 6: Annual number of highly qualified personnel reported by each facility averaged over the last three fiscal years of the funding cycle (2014 to 2017). Note that the definition of highly qualified personnel varied greatly among facilities as discussed in the section "Increased number of highly qualified personnel" on page 31. Therefore, the comparability among facilities is limited. The number of highly qualified personnel is also related to the reported number of users. See the section "Increased user base" on page 28 as well as Appendix A for more detail.

Diverse training opportunities

Facilities reported a wide spectrum of training approaches and opportunities. At some facilities (e.g., CCEM, TCP, BIO), the training comprises one-on-one, hands-on sessions, in leading-edge experiments using state-of-the-art equipment across a broad range of scientific disciplines. Support through the MSI Fund also resulted in an increased use of new techniques and fundamental methods delivered through practical sessions at workshops, training clinics, summer schools or regular academic training (e.g., master's or PhD levels). Such improvements were likely among the drivers behind the rise in number of highly qualified personnel attracted to these facilities. The CLS presented a good example of the breadth of training opportunities provided: "CLS training takes several forms, including formal training in specific applications using a synchrotron. Annual graduate and postgraduate summer schools have been conducted since 2006. Recent schools have focused on specific sub-fields of science, targeted at either attracting new clients, or helping existing clients become more productive ... These schools provide hands-on experience on our beamlines."

Several of the larger facilities extended training opportunities beyond Canada and to a diversity of users (e.g., companies who want to use new technology or test new approaches for production). Such opportunities varied from a few days (a typical visit to the facility or workshop) to many years, in the case of repeat users. For example, in addition to providing training opportunities for staff, CCTG also provided training for young investigators, which included a biennial three-day New Investigator Clinical Trials Course and a workshop held during their Annual Spring Meeting, both of which were critical components of their mandate to provide and facilitate investigator education and training with the essentials of conducting clinical trials in the Canadian research environment.

BIO was strongly involved in training and capacity-building activities, both nationally and internationally. Since 2014, BIO offered course modules from an introduction to DNA barcoding, to forensic applications of DNA barcoding. The introductory course alone had a total of 140 participants from 60 countries, including graduate students, university and government scientists, corporate researchers and educators. BIO also provided a complete Research Training Program in DNA barcoding which provided in-depth training to over 40 senior scientists and policy leaders from 16 developing nations.

Funding enabled research excellence and advancement of knowledge

Facilities reported an increased capacity to advance knowledge in the many research domains collectively supported by the facilities. In addition to numerous journal publications, instances of knowledge advancement also included: increasing the quality and availability of scientific data; improving data access for remote users; developing new research tools and techniques; and being the first facility to produce results using new methods or materials. Not all advancements led to publications; in some instances the direct adoption of the knowledge by the community provided a strong testament to its impact, as exemplified further under the section called "Advancement of knowledge" on page 35.

Number of scientific contributions

Facilities were asked to report the number of scientific contributions per year attributable to the use of their resources. As shown in Figure 7, the total number of scientific contributions for all 12 facilities, averaged over the last three years, amounted to roughly 3,300 per year. Two-thirds of the publications were linked to Compute Canada. A bibliometric analysis performed on the scientific publications reported by Compute Canada users in the last two years of support through the MSI Fund showed that "on a field-weighted basis, citation indices for Compute Canada-enabled publications are at least 90 percent greater than the world average and almost 30 percent above the Canadian average."

Approximately 3,300 scientific contributions were reported each year

Figure 7: Annual number of scientific contributions reported by each facility averaged over the last three fiscal years of the funding cycle (2014 to 2017). As discussed in Appendix A, the reported number of scientific contributions are often, if not always, underestimates.

In spite of challenges faced by facilities in accurately collecting and assessing their scientific output (see Appendix A), all 12 facilities reported a constant or growing number of publications, suggesting that all facilities were able to maintain or improve their scientific impact during the funding period.

Both ONC and CCTG stood out as the facilities with the most growth over the course of their respective MSI periods: 230 percent for ONC (from 60 publications to 196) and 290 percent for CCTG (from 28 to 109). CCTG reported that support through the MSI Fund allowed them to significantly increase the number of drug trials they conducted. At the same time their user base increased by close to 30 percent. For ONC, part of this increase can be attributed to better tracking of user outputs, but it clearly outperformed similar facilities at the international level in terms of yearly growth of publications, as stated in the case study for ONC presented on pages 41 and 42. SuperDARN Canada reported that although it operates only five radars (relative to about 35 worldwide), the small team at the University of Saskatchewan contributed to 26 percent of the global network's publications to date.

Quality of the research

A large portion of the high volume of scientific contributions were high-calibre research outputs. Significant research findings were published in leading peer-reviewed journals such as *Science*, *Nature* (and the *Nature* group of journals), *The New England Journal of Medicine*, *Angewandte Chemie*, *The Lancet Oncology*, *The Journal of the American Medical Association Oncology*, *Proceedings of the Royal Society B: Biological Sciences*, *Methods in Ecology and Evolution* and *Physical Review Letters*, to name a few.

An abundance of publications in high-impact-factor journals were reported by facilities. A few examples are listed here:

- CCEM's body of recent work in the fields of spectroscopy and plasmonics was published in leading journals, including *Nano Letters* and *Physical Review Letters*, and was described as pioneering and game-changing. In addition, thanks to the leading capabilities of the CCEM, researchers were able to identify new prospective candidate materials for higher capacity and longer life batteries, as published in *Nature Energy*.
- Compute Canada resources enabled Dr. Edward Sargent of the University of Toronto to break a world record in developing a tungsten-based catalyst used in the process to split water into its constituent parts (hydrogen and oxygen) that is three times better than the previous record holder. In the area of artificial intelligence, Compute Canada supported Dr. Michael Bowling of the University of Alberta in solving an imperfect information game (Texas Hold'em Poker) — a breakthrough published in *Science* in 2015. Advances on the optimization of neural networks realized by Dr. Yoshua Bengio of the Université de Montréal were selected by the French magazine *La Recherche* among their 10 chosen discoveries of 2015.

Advancement of knowledge

Aside from publishing in high-calibre journals, facilities also reported advancing knowledge for the betterment of the scientific community and in areas for which there are real-world impacts:

- In environmental sciences, CLS enabled advancements in mine remediation techniques, heavy oil extraction efficiencies, high efficiency catalysts for petroleum refinement, renewable resources, and energy storage, as well as remediation of contaminated groundwater and heavy metal contamination in soil and water. Furthermore, in the field of agricultural studies, CLS enabled the generation of new insights in improved crop and plant development, fertilizers, drought and temperature resistance, and soil management.
- SuperDARN Canada drove technology and operational improvements in the SuperDARN collaboration worldwide. Significant software advances were realized during the award period by SuperDARN Canada to improve the quality of the data, the most notable

being the improvement made to the software used by all SuperDARN sites for processing the radar outputs into meaningful physical parameters. While it is still in testing mode, it was agreed by SuperDARN International to be adopted as the standard and will be applied retroactively to all data acquired since 1990. Additionally, a new technique was developed by SuperDARN Canada to increase the amount of data recorded by the network by 50 percent and provide physics-based error bars for all parameters in all measurement areas, which was previously impossible. The Canadian team is also working on the foundation for the next digital upgrade to the network which should be implemented not only in Canada but on other sites globally.

- The CCGS *Amundsen* generated a wealth of invaluable datasets and oceanographic time-series in strategic locations of the Canadian Arctic. These data have fed into the core programs of ArcticNet which in turn enabled the development of four Integrated Regional Impact Studies (IRISes). These studies supported much-needed assessments of the Canadian North, which is rapidly shifting under the double pressure of global warming and industrialization, and have had significant influence on policies.

Facilities supported a wide number of disciplines

The research enabled by the full cohort of facilities encompassed an extensive breadth of disciplines across all domains of inquiry from the social sciences, to engineering, natural and health sciences. For example, the CCGS *Amundsen* supported 20 major multidisciplinary research programs comprising more than 100 individual sub-projects. At the CCTG, a multidisciplinary team including academic, industry and regulatory experts developed a consensus-based guideline which addresses the novel characteristics of a new class of anticancer therapeutics, thereby ensuring consistency in trial design and data collection. Another example is ALLS providing its hard X-ray betatron beamline as a key tool for X-ray imaging of plants in the "Designing Crops for Global Food Security" initiative led by the University of Saskatchewan (funded through the Canada First Research Excellence Fund). This initiative not only brings together agricultural and nutritional scientists, computer scientists, physicists and engineers, but also two facilities supported through the MSI Fund: ALLS and the CLS.

While Compute Canada is known to serve the advanced research computing needs of many disciplines, it reported that "Compute Canada-enabled publications in humanities, social sciences, and multidisciplinary research are, based on bibliometric evidence, particularly impactful. It is notable that the field weighted citation index of Compute Canada-enabled publications in humanities is the highest of any discipline, with Compute Canada users scoring more than two times the Canadian average and four times the world average."

Funding enhanced the international stature of the facilities, attracting talent to Canada and stimulating collaborations around the world

As global reputation is largely driven by high quality research, facilities supported through the MSI Fund, in being recognized as foci of research excellence in Canada, significantly add to the stature of Canadian science on the world stage. Nearly half of facilities reported an enhancement of their international reputation, or that of the researchers and groups using their facility, during the funding period. In turn, this facilitated international collaborations and the attraction of leading researchers to Canada as well as international users.

Facilities supported through the MSI Fund, are recognized as foci of research excellence in Canada, and significantly add to the stature of Canadian science on the world stage.

Visibility on the world stage

Ample evidence was provided of the worldwide recognition gained over the course of the award period for several facilities.

SNOLAB reported the most recognition of any facility during the funding period. The 2015 Nobel Prize (and the 2016 Breakthrough Prize in Fundamental Physics) awarded to Dr. Arthur McDonald of Queen's University contributed to raising SNOLAB's profile internationally and outside the physics community. The analysis of the data that led to those prizes would not have been possible without the resources provided by Compute Canada. In connection to these awards, a major exhibit showcasing SNOLAB's achievements took place in London, and toured the rest of the United Kingdom and also Canada.

SNOLAB's Executive Director has also been appointed as representative for the deep underground facility community to a working group of the International Union of Pure and Applied Physics to develop coordination across nuclear physics facilities all over the world.

Moreover, the attraction of a flagship US$30 million second-generation dark matter project from the United States, named SuperCDMS, was considered by the 2014 MSI midterm committee as an "indubitable tour de force for SNOLAB" indicative of its international stature as the location of choice for underground science. SuperCDMS is the only project funded outside the United States by the Department of Energy. The beginning of the construction phase at SNOLAB was announced in May 2018.

Both SNOLAB and TCP were key contributors to the concept of establishing a coordination and best-practice framework among facilities for the G7 Group of Senior Officials on Global Research Initiatives. Of seven "mature" globally distributed infrastructures identified by this group, the two that were selected as seminal case studies — the Underground Laboratories Global Research Infrastructures and the International Mouse Phenotyping Consortium — included these two facilities.

Another example of international recognition of a facility is the 2017 Group Achievement Award received by SuperDARN International from the Royal Astronomical Society, which stated that "SuperDARN has been a scientific backbone for the U.K. and international magnetosphere, ionosphere and solar-terrestrial physics community."

Érudit's collaboration with the Canadian Research Knowledge Network (a partnership of Canadian universities dedicated to expanding digital content for academic institutions in Canada) was awarded the American Library Association's Outstanding Collaboration Citation for 2017 for developing "a framework for a new relationship between publishers and libraries … helping to provide financial support to Canadian journals during the transition to a fully open access model."

International collaborations

The high calibre and impact of research enabled by facilities was also manifested by numerous international research collaborations, cited by many facilities as an important achievement enabled by support through the MSI Fund. Among the key examples are:

- Compute Canada's role as a critical enabler of major international collaborations such as the ATLAS experiment at CERN's Large Hadron Collider, which brings together over 150 Canadian scientists with more than 3,000 international scientists and the provision of resources for prototyping future large-scale international projects like the Square Kilometre Array and PanCancer. Overall, an analysis of the Canadian Common CV[8] has shown that 2,364 institutions in 108 countries collaborate with Canadian Compute Canada users;
- CCGS *Amundsen*'s support to a range of international multidisciplinary programs like NETCARE, the international Arctic Geotraces project, the joint France-Canada Green Edge program, the Chukchi Sea Observatory, and the ROV Arctic Ocean Seafloor Exploration project;
- SuperDARN's role as an enabler of collaborations with ground- and space-based satellite missions led by the Canadian Space Agency, the European Space Agency and NASA (e.g., CASSIOPE/ePOP, Swarm, THEMIS, Van Allen probes);
- ALLS's role as the main Canadian laser infrastructure to maintain partnerships with researchers of the Extreme Light Infrastructure in Europe, the largest ongoing global effort in ultrafast laser science and its applications. ALLS has also created formal linkages with national and international institutions in the Laboratoire International Associé – LUMAQ (LUmière Matière Aquitaine Québec) to facilitate the international training of graduate students;
- BIO's pivotal contributions to the International Barcode of Life (iBOL) consortium (involving 26 countries) which allowed the project to meet its phase-I milestone of delivering DNA barcode records for 500,000 species in 2015. BIO reported that "by providing funding for key personnel, service and maintenance of research infrastructure, the MSI award allowed BIO to deliver on its ambitious goals while also sustaining uninterrupted support to the global research community."

8 Launched in 2002, the Canadian Common CV (CCV) is a web-based application that provides researchers with a single, common approach to gathering CV information required by a network of federal, provincial and non-profit research funding organizations. The CCV uses a common standardized data model to capture information that is used for peer-review and reporting activities.

These examples and others demonstrate influence that extended beyond the national research arena and promoted Canada's research capabilities internationally.

Attraction of international talent

Several facilities also emphasized how increased visibility and recognition at the international level contributed to the recruitment of outstanding researchers from abroad during the award period. For example, TCP explained how it was able to attract Dr. Graham Collingridge, an eminent neurophysiologist and the 2016 recipient of the Brain Prize, one of the world's most coveted science prizes. Dr. Collingridge highlighted that "TCP was a very significant factor in my decision to move to Canada."

Similarly, SNOLAB was instrumental in attracting Dr. Gilles Gerbier, a world-renowned expert in astroparticle physics, from France to Queen's University as Canada Excellence Research Chair in 2014.

Recognition of the leading quality of the facilities and of their infrastructure and services also played a key role for attracting international researchers as users of the facilities. Several examples were provided by the facilities in their final reports. For example, 20 percent of CLS's onsite users were from outside Canada, while ALLS reported 50 percent from outside Canada. BIO supported more than 300 research groups in 51 nations.

Funding enhanced opportunities for partnerships with industry and technology transfer activities

Support through the MSI Fund allowed facilities to maintain or increase their participation in industrial R&D, enabling private enterprises to accrue economic benefits through new or improved products and services and to increase their reputation as industry leaders. The funding also enabled facilities to maintain or increase their technology transfer activities including the number of patents, and declarations of invention from researchers.

A handful of facilities have provided as a KPI the number of technical contributions (e.g., patents, spinoffs, report of inventions, etc.) and/or number of industry partnerships during the MSI funding period, although here again definitions were inconsistent and in some cases the numbers reported were very low or null. A few facilities — Compute Canada, ONC, TCP and ALLS — stood out as having a solid record of knowledge and technology transfer activities with the private sector. Seven facilities reported seeing increases in revenue and in the value of contracts with industry as well as the establishment of start-up companies and the registration of patents and licences.

Among the facilities having reported partnerships with industry, Compute Canada was by far the largest contributor with a total of 182 unique collaboration agreements reported during the award period. Researchers using its resources also reported filing or being granted more than 800 patents, 77 instances of technology transfer, 54 instances of involvement in the creation of a start-up company, 92 technology product or process developments, and 130 instances of consultation for industry, associations and other organizations. A prime example was the development of a new drug for treating prostate cancer by a research team at the Vancouver Coastal Health Research Institute and the University of British Columbia using Compute Canada's advanced resources for computer-aided drug design. Their breakthrough is being licensed to the pharmaceutical company Roche, the future revenues of which are estimated at over US$141 million.

ALLS underlined the critical role of the infrastructure in supporting the emergence of new technologies benefitting the local economy. It reported a yearly average of 30 patents and declarations of invention for the 15 local researchers from the host institution alone (i.e. not counting ALLS users from other institutions), the creation of two new spin-off companies, few-cycle Inc. and Ki3 Photonics Technologies (both in Montréal), and collaborative R&D projects with several Canadian companies in advanced manufacturing and information and communications technologies.

Other examples of technology transfer success were brought by CCEM, CLS and TCP. Canadian high-tech companies, namely ON-Semiconductor (Burlington, Ont.), used the CCEM to develop more reliable tunable capacitors found in most cell phones sold in the world. For its part, CLS reported having assisted 55 companies, including 42 multinationals, to solve technology problems from identifying forms of arsenic found in the environment for the mining sector to helping create improved composite materials for the aerospace sector. A good example of a facility expanding its services is TCP, which secured the first licence awarded to a Canadian entity to use new cutting-edge gene editing technology (CRISPR) to produce gene-edited mouse models for academic and industry users.

Evidence supporting the broader impact of facilities to the local economy is provided by SNOLAB. KPMG conducted an assessment of its economic impact on Ontario, and Canada more broadly, and published the results in March 2016. The report indicated five dollars of economic activity are generated for every dollar of CFI investment in SNOLAB.

▲ The University of Victoria's Ocean Networks Canada (ONC) monitors the west and east coasts of Canada and the Arctic to continuously deliver data in real time. Using cabled observatories, remote control systems, interactive sensors and big data management, ONC enables evidence-based decision-making on ocean management, disaster mitigation and environmental protection.

Case study: Producing a diversity of positive impacts through Ocean Networks Canada

Ocean Networks Canada positions the country as a global leader in ocean data, research and technology. Thanks to its many achievements, its impact across many sectors and its worldwide network of collaborators, ONC has become the steward of good ocean management and responsible ocean use.

Its improved data management system, Ocean 2.0, was recently recognized as a "World Data System" by the International Council for Science. Moreover, a scientific analytics consulting firm benchmarked ONC's scientific output against six international ocean observing facilities and, while the total output was comparable to the world average, its impact and collaboration rates were found to be increasing at a higher rate than all other ocean observatories.

ONC is tackling global issues with partners in every sector in Canada and abroad by designing and implementing solutions for marine safety, economic development of shipping and port activities, public safety and several types of environmental monitoring.

The commercialization revenues and direct economic impact to Canada of ONC's Innovation Centre during the MSI funding period was estimated at $102 million. For example, ONC developed an underwater listening station in support of the whale protection program which is being used by the marine transport industry and is attracting interest from other port authorities globally.

It is also implementing Canada's first earthquake early warning system which it hopes will be commercialized for use in other areas of Canada and the world. Its tsunami research program, involving more than 80 stakeholders, develops innovative solutions for real-time detection and supports preparedness and risk mitigation for public safety; models developed are expected to become the new standards in North America.

To assess the critical threat of ocean acidification, ONC is working with industry to improve acidification sensors and is hosting the first generation of field-deployable sensors on the west coast and in the Arctic Ocean, two regions particularly vulnerable to acidification.

In addition to ONC's strong track record of training highly qualified personnel, its impact is also visible in local communities. It established a program with First Nations in British Columbia and Indigenous communities in the Arctic to provide education and training to conduct environmental and safety monitoring.

CONCLUSION AND NEXT STEPS

The 12 facilities funded in the 2012 and 2014 MSI Fund competitions encompass a wealth of capabilities and expertise, forming a diverse set of collective resources that benefits user communities in all domains of inquiry. The multidisciplinarity of these facilities illustrates that there is a significant need for large-scale research facilities in every area of research. This need dovetails with the CFI's mandate to support the full range of research disciplines.

Canada's national research facilities are strengthened through the MSI Fund

The breadth of success stories and accomplishments described in the final performance reports of the 12 facilities provides an abundance of evidence that MSI Fund objectives are being met. Among the key messages the facilities emphasized were:

- The eligibility of O&M costs and partner contributions under the MSI Fund were sufficiently broad and flexible to meet their distinctive operational needs.
- Stable operational funding allowed them to maximize their capacity and capabilities to best serve their user community and become more sustainable.
- The CFI's recognition of the facilities' unique operational challenges and its resulting tailored-to-facility oversight approach was instrumental in the facilities' success.
- The award conditions imposed through the merit-review process drove positive change, most notably in the facilities' governance models, management practices, outcome measurement and user-access processes. This had a positive impact on their performance, and helped them think more strategically in the long term.
- Support through the MSI Fund: contributed to improved service delivery and user access; enhanced training and skill development for highly qualified personnel, staff and users; enabled research excellence and advancement of knowledge; and improved opportunities for partnerships with industry and technology transfer activities.
- In turn, support through the MSI Fund contributed to enhancing the global stature of the facilities, attracting talent to Canada, and stimulating international collaborations.

The CFI's experience with the 12 facilities, combined with the information provided in their performance reports, confirms that support through the MSI Fund enabled them to deliver outstanding world-class science. The fund's impacts far exceed financial contributions, as shown by the great strides the facilities have made toward optimizing their use and improving their governance, management and operations practices. Considering the short time span (three or five years) of support, the advances made by all facilities toward meeting their strategic objectives are impressive.

All facilities achieved gains, even those that received very modest MSI awards. The award size reflected the type and complexity of the facility rather than correlating directly with the facility's level of productivity and success.

Ongoing support for the sustainability of Canada's national research facilities has long been recognized as a major challenge by the Canadian research community, funding organizations and government. With the development and delivery of the MSI Fund, the CFI has addressed some of these challenges and created a model of successful support and oversight for national research facilities. In that sense, the MSI Fund is delivering on its promises. However, the pursuit of a well-integrated funding solution for Canadian research facilities continues.

The CFI can help facilities do even better

Even though facilities are performing well, there are opportunities for them and the CFI to build on the knowledge and experience gained in this analysis to continue to improve. In the short term, this analysis helped define the themes of the 2018 MSI workshop and is informing the planning of the midterm review for the facilities funded in the 2017–22 funding cycle. The CFI is also using these insights to refine its approach to overseeing facilities, as well as its reporting framework.

The CFI is considering options to address some of the challenges identified in this report (see Appendices A and D). For example:

- providing more guidance and clearer reporting requirements and expectations for facilities;
- sharing best practices for facilitating the collection of data from users and for communicating the broader impacts of facilities' activities and achievements;
- adapting the performance reports to better capture more information that is relevant to the objectives of the fund.

As MSI-funded facilities are significantly different from standard infrastructure projects, the findings of this report will help the CFI's staff gain a better understanding of the facilities, including the stages of their evolution in terms of operations, governance, management, etc. This will also help the CFI adapt its activities to better manage the MSI Fund. Moreover, additional training for CFI staff in areas such as governance, management or impact assessment could improve the quality of oversight provided. These steps would bolster the CFI's capacity to be a good steward of public investments by taking part in the evolution of facilities and by promoting good practices.

Key observations converge to confirm that the "tailored-to-facility" approach ensures that funding decisions and committee recommendations are made in the best interests of all stakeholders and should therefore be applied to the facilities funded in the 2017 competition. The review process at the midterm of that funding cycle, in 2019, will be based on a common set of criteria, but will be customized to each facility, its stage of evolution and areas of concern identified by past review committees. The midterm review guidelines and documentation required from facilities will be fine-tuned accordingly. In addition, some past members of the review committees will be reappointed to ensure that any recommendation or condition imposed for the remaining years will be relevant and useful to help facilities continue to improve. These same guiding principles will be applied to the individual oversight plans of these facilities, as well as in the review of facilities in future funding cycles.

New insights will inform the evolution of the MSI Fund

The final performance reports of the 12 facilities examined did not dwell on challenges and issues; in fact the feedback was largely that most O&M needs are met. Nevertheless, the CFI is reassessing the parameters of the MSI Fund in consultation with the community at large. Through this consultation, the CFI will address, as best as possible, remaining gaps in meeting the needs of the facilities.

In the 2018 federal budget, the Government of Canada announced a commitment to stable operational funding for the CFI, reaffirming the CFI's role in sustaining facilities under the MSI Fund. This puts the CFI in a good position to evolve the MSI Fund program to better meet the needs of facilities included in the next funding cycle starting in fiscal year 2022–23.

There is a need for a coherent approach to funding that covers the whole lifecycle of facilities.

Several facilities indicated in their final performance reports that equipment upgrades beyond minor repairs and replacements were necessary to maintain the infrastructure at the leading edge. These types of upgrades are not eligible under the MSI Fund, so many facilities applied for new equipment through the CFI's John R. Evans Leaders Fund and its Innovation Fund with good success. But in some cases facilities explained that the infrastructure needed would not meet the criteria of any of the CFI's funding programs.

This reiterates the need for a coherent approach to funding that covers the whole lifecycle of facilities supported through the MSI Fund and for better synchronization within the Canadian funding bodies of the different research infrastructure funding instruments and possibly for the direct costs of research. For example, requests for both operating funds and new equipment could be reviewed concurrently, as was done for Compute Canada's MSI Fund and Cyberinfrastructure Initiative

Challenge 2[9] proposals in 2015 (at the midterm of the 2012–17 cycle) and again in 2016 (for the 2017–22 funding cycle). This first attempt at an integrated lifecycle review was considered a successful approach that should be applied to other facilities supported through the MSI Fund. Both the CFI and review committees agreed that the lifecycle approach would: help optimize investments in the face of limited funding; reduce risk and ensure scientific relevance, international competitiveness and alignment with the facility's strategic goals; and, foster greater sustainability.

As this course of action can only feasibly be implemented in the next funding cycle for the MSI Fund, using existing mechanisms, such as reserving part of the next Innovation Fund budget, or creating a dedicated stream within it, to address the infrastructure needs of MSI-funded facilities could be an option. The review process could also be designed to ensure some overlap and continuity through the reappointment of past committee members for the MSI Fund.

The CFI is also keenly aware of the challenges its 40:60 funding model creates for some larger-scale facilities, such as the CLS and ONC, which are limited in their ability to attract sufficient partner investment to be able to exploit the full range of their capabilities. Often, these facilities operate within funding constraints that tend to translate into short-term trade-offs to the detriment of attaining longer-term goals which are yet vital to the competitiveness of the facility. The CFI will continue to discuss these ongoing operational challenges and concerns with the government and explore solutions such as increasing the percentage of CFI's contribution as was recommended in the report from the panel on Canada's Fundamental Science Review, published in 2017.

The CFI is keenly aware of the challenges its 40:60 funding model creates for some larger-scale facilities.

Both the CFI and MSI-funded facilities are developing strategies to improve the sustainability of national science facilities and lines of communication are established among facilities, universities and provincial and federal funding partners. Given that, the CFI will examine how the knowledge gained from this report could lead to better planning of future investments and defining a longer-term vision and future research directions for facilities. The CFI could also play a role in promoting international collaborations between researchers or networks of international facilities.

9 Challenge 2 of the Cyberinfrastructure Initiative involved two competitions through which the CFI invested in upgrades and modernization of the computational and data storage capacities of the pan-Canadian advanced research computing platform managed by Compute Canada.

▲ Compute Canada (CC) leads the acceleration of research and innovation by deploying state-of-the-art advanced research computing systems, storage and software solutions across Canada.

The challenges of advanced research computing

Among the facilities supported under the MSI Fund, Compute Canada poses a number of unique challenges, many of which are described in the pages of this report. As the ultimate example of a national service platform, catering to the needs of an incredibly diverse user base, with widely different needs and spanning across all disciplines, advanced research computing has become an enabling, ubiquitous shared resource for the country's research community. Uniquely, advanced research computing, itself funded under the MSI Fund via Compute Canada, also provides critical support to many of the other facilities funded under the MSI Fund. As such, it is becoming more and more difficult to view and manage advanced research computing through a traditional competitive funding lens; increasingly, calls to manage advanced research computing outside a competitive framework, given its "foundational" nature, have been cogently argued. In 2015, the CFI published its perspective in a report called "Developing a digital research infrastructure strategy for Canada," proposing enhanced coordination of the digital research ecosystem, and longer-term predictable and renewable funding for advanced research computing, very much in the same way CANARIE[1] is currently funded. The 2018 federal budget announced a significant ongoing investment for digital research infrastructure, starting with the development of a national strategy.

---

1 CANARIE is a non-profit corporation, with the majority of its funding provided by the Government of Canada. It manages an ultra-high-speed network and digital research infrastructure.

APPENDIX A – Methodology and challenges

Methodology used in this report

The observations and analyses presented here are based on information and data provided by the facilities in their final performance and financial reports which covered a three- or five-year period depending on the facility. The final performance report was designed to obtain a summary of the facility's operations, progress and key achievements during the funding period. It contains annual and cumulative data and information related to the objectives of the MSI Fund.

More specifically, facilities were required to describe the overall impact of the funding on their operations, on maintaining research capabilities and human resources, and on providing access to users. They were also required to report on the evolution of their governance, management and strategy, as well as on scientific achievements and benefits to Canada. Key performance indicators were established to frame progress in each of these areas. Information was also drawn from the facilities' strategic and management plans.

CFI staff compiled and analysed the final reports of the 12 facilities examined for this report to identify possible commonalities among facilities, obtain information on their successes and challenges and gain a better overall understanding of their context for operations. The CFI recognizes some limitations in this approach, which are outlined here.

Challenges in using self-reported information

Although the information provided in the final reports was rich in content, several challenges arose in using self-reported information as the basis for an analysis. These included variability in the interpretation of the reporting guidelines which led to potential omissions, lack of relevance, avoidance of issues, etc. In addition, there was variability in how facilities collected data and completed the reports. Where gaps were identified in this analysis, the information was supplemented and assumptions validated by CFI staff responsible for the given facility. Findings were also validated with the facilities themselves.

In addition, the small number of facilities and short timespan for data collection limited the CFI's ability to generalize findings beyond the MSI Fund program.

Challenges in the identification of users lead to underestimates

The identification of data users remains a challenge for several facilities. For example, SuperDARN's open access policy precludes user registration. The facility also has an agreement with the other countries operating the radars in the international network that the data can be mirrored onto several sites, each managed independently. It is therefore impossible for SuperDARN to monitor how data coming from Canadian radars is used in other countries. SuperDARN relies instead on two indirect measures: the number of distinct institutions per year involved in publications worldwide (about 70 per year) and the distribution of users based on global journal publications (about 50 publications per year).

For Compute Canada, the number of users is estimated from the yearly renewal of user accounts and may not capture all users, including users of research platforms and portals. Similar limitations were also reported by BIO.

In the case of Érudit, the reported number of users — averaging four per year — reflected the number of requests for extraction from the repository and did not take into account the number of researchers accessing the open data via the online portal or other users of the extracted data.

These are examples of how the reported numbers of users are often if not always underestimates.

Challenges in measuring publications lead to underestimates

While all facilities provided an estimate of the number of publications linked to the use of their resources, they didn't all use the same definition. Several included conference presentations or non-peer-reviewed publications, while others did not, rendering comparisons of totals less meaningful.

Facilities applied different approaches to how they reported the number of users and highly qualified personnel versus how they reported the number of publications. This leads to an apparent mismatch between the numbers reported for those KPIs. For example, the CCGS *Amundsen* reported an average of 257 publications per year, but only 163 users and 116 highly qualified personnel on average, which would imply that each of those individuals produced one or more publications, which is not the case. This discrepancy is because only users and highly qualified personnel physically present on site were reported, while the number of publications reflects a much larger user and highly qualified personnel base.

Some facilities, including Compute Canada, changed their data collection method midway through the reporting period. Also, because it is difficult to identify and track users, their resulting publications are likely not included in the reported numbers.

Moreover, there are often delays between the time of use of the facility and the publication of research results or conference presentations, as well as in the reporting of those by users.

As ONC explained in its final performance report, many scientific contributions are found using automated citation harvest tools, but since not all researchers properly attribute their use of research facilities those records are also likely incomplete.

ONC also pointed out that conference presentations cannot be tracked using automated techniques because the majority of conferences and symposia do not produce citation indexes that can be easily ingested by bibliometric aggregators such as Web of Science. For these, ONC relies on polling of the scientific community, but response rates to such surveys are often low.

These are examples of how the reported numbers of scientific contributions are often if not always underestimates.

Value of this analysis

Although the CFI is aware of these limitations, it recognizes that this first exercise has value in providing evidence to demonstrate the objectives of the fund, avenues to improve reporting requirements for the 2017–22 cohort of facilities, and the management of the MSI Fund.

APPENDIX B – Details of the financial analysis

Individual funding profiles of the 12 facilities

As the overall MSI budget was largely reflective of the contributions to the four major facilities funded in 2012 ($490 million, 82 percent of the total investment), a breakdown of the contributions to each facility is necessary to expose their funding profiles (see Figure A1). CFI's investment in proportion to the total revenue ranged from 16 percent for TCP to 40 percent for ONC and Compute Canada. The average CFI contribution per facility was 31 percent.

It is evident from this comparison that there was no typical funding profile for these facilities. A facility's profile instead depended on the nature of the research it enabled and the types of services it offered.

For a few small- to medium-sized facilities such as TCP, CCGS *Amundsen*, CCEM, ALLS and Érudit, revenue derived from user fees covered a larger part of their operating budget. Larger facilities such as SNOLAB, CLS, Compute Canada and ONC tended to adopt a free-access policy for academic researchers and hence were mainly funded by the federal and provincial governments, institutions and the CFI.

Individual O&M expenditures of the 12 facilities

Figure A2 shows the O&M expenditures averaged over all facilities alongside the facilities' individual expenditure profiles. As was the case in the previous section, there was also no typical profile of O&M expenditures across the 12 facilities, as each one has unique O&M needs.

Consistent with total O&M expenditures for the entire cohort, the majority of funds for seven of the 12 facilities was spent on salaries. On average, almost half of expenditures (49 percent) was for human resources. For example, CLS spent most of its funds to support the staff that ran the beamlines, whereas Compute Canada spent most of its funds on staff who maintained the computing systems and provided user support. Similarly, the three health-related facilities (TCP, CCTG and BIO) reported that highly-skilled scientific and technical support staff constituted their largest operational costs.

Two facilities, ONC and CCEM, reported the majority of their expenditures were on "maintenance and repairs." For ONC, maintaining equipment deployed in the hostile sea environment was very challenging. Ship time and replacement parts for the observatory nodes accounted for most of this category of expenditures. CCEM's maintenance relied almost solely on supplier service contracts, which they believe was the best approach to keep the instrumentation operational and up to date with the most current technology.

For both SNOLAB and the CCGS *Amundsen*, expenditures were predominantly for services, although

In the case of the latter, these were the direct costs for ship operations including both crew and maintenance, so there was some overlap with the personnel and maintenance and repairs categories. For SNOLAB, a large portion of its expenditures corresponded to the services provided by Vale as in-kind contributions to the operations of the facility. Similarly, ONC's services were mainly covered by a contribution from the Department of Fisheries and Oceans.

Each facility had a distinctive funding profile

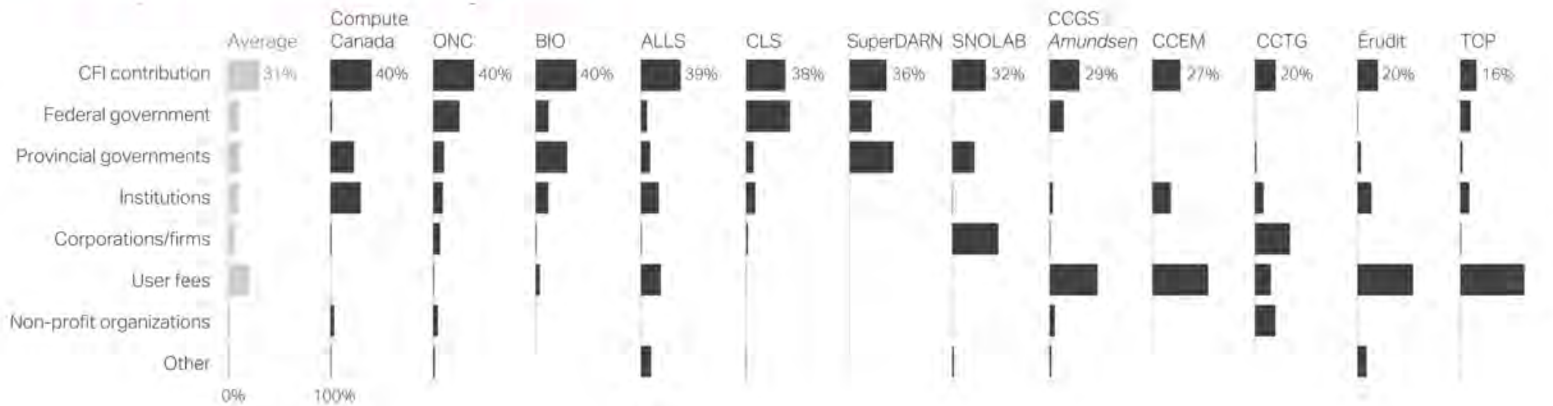


Figure A1: CFI and partner contributions relative to each facility's O&M budget in descending order of CFI contribution percentage

Each facility had distinctive O&M needs

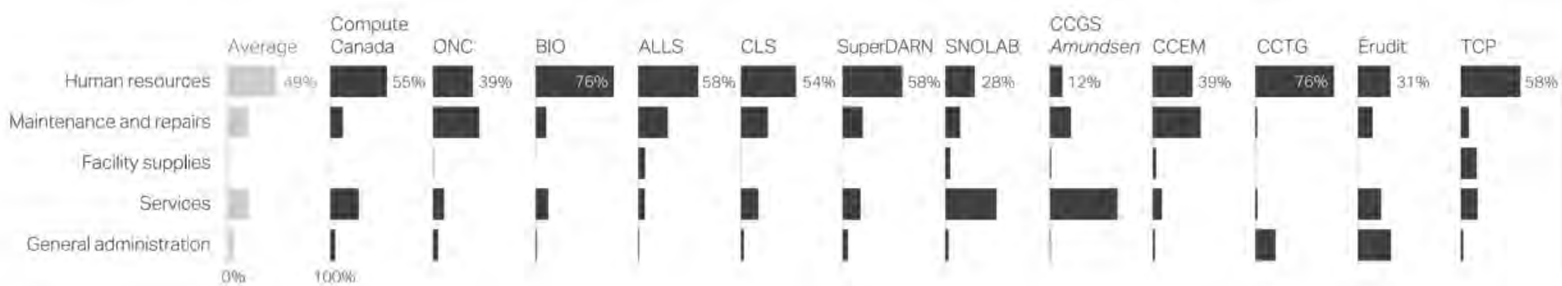


Figure A2: Breakdown of each facility's O&M budget by category of expenditures relative to its total expenditures

APPENDIX C – Conditions applied to the facilities during the first funding cycle

The CFI imposed conditions on the facilities that addressed different areas for improvement.

Areas for improvement and facilities affected	Examples of conditions	Examples of actions taken to meet conditions
Governance model (16 instances at five facilities: CC, CCEM, CLS, ONC, SNOLAB)	• Create a Board of Directors (BoD) that is independent • Clearly delineate between governance and management responsibilities • Implement a competency and skills matrix for BoD members composed of directors with the appropriate mix of competencies	• Created new committees (e.g., International Advisory Committee) • Developed standards of director independence and terms of reference for BoD members

Areas for improvement and facilities affected	Examples of conditions	Examples of actions taken to meet conditions
Management structure (eight instances at four facilities: CCGS *Amundsen*, Compute Canada, CLS, SNOLAB)	• Develop a more robust management plan that includes a strategy and priorities for the facility • Strengthen national management by hiring a CEO, a Chief Scientific Officer and a Chief Technical Officer • Create a management plan to reflect management best practices to include the performance measurement framework, the human resource management framework as well as a more robust risk register	• Integrated decentralized management structure into a single national facility centralizing operations • Revised management structure to address increase in technical and managerial team enabled by support through the MSI Fund
Performance management (five instances at four facilities: Compute Canada, CLS, Érudit, ONC)	• Develop a performance measurement framework identifying scientific, organizational and operational performance metrics to provide management and the Board with sufficient information to make informed decisions • Set clear objectives to track the progress and the success of the technology transfer enterprise	• Translated strategic plan into a management plan reflecting best practices to include a performance measurement framework • Implemented strategies to improve the discovery and tracking of scientific contributions using automated publication and citation alerts and Digital Object Identifiers for datasets

Areas for improvement and facilities affected	Examples of conditions	Examples of actions taken to meet conditions
User access (five instances at four facilities: ALLS, CCGS *Amundsen*, ONC, SNOLAB)	• Apply merit-based access policy to experimentalists • Be more responsive to the needs of the community and increase the opportunity to attract non-standard clients	• Increased and diversified the expertise of the Time Allocation Committee • Improved access to data by enabling anonymous access to data portal
Operational efficiency (five instances at three facilities: Compute Canada, CLS, ONC)	• Conduct a cost/benefit analysis leading to a clear consolidation plan as well as a guide to the allocation of additional infrastructure • Review the mandates of the operational committees to reduce their number in light of synergies between platforms	• Conducted a cost/benefit analysis and implemented a consolidation plan
Science plan (three instances at two facilities: ONC, SNOLAB)	• Demonstrate stronger scientific leadership in collaboration with the relevant Canadian research communities • Develop a plan to grow the science program beyond particle physics	• Established a Science Implementation Strategy • Constructed Public Strategic and Implementation Plans (2017–22) guided by substantial community engagement

Areas for improvement and facilities affected	Examples of conditions	Examples of actions taken to meet conditions
Human resources (two instances at two facilities: ONC, Compute Canada)	• Develop a human resources management framework that includes policies and procedures for hiring, training and deployment of resources • Provide more detailed information about the additional personnel requested, including job descriptions and justification of added value	• Created a human resources management framework • Provided details (e.g., job descriptions) and justified the added-value of additional personnel
Partner funding (two instances at two facilities: CLS, ONC)	• Develop a revised business development strategy to enable a more targeted approach for engaging industrial R&D partners • Diversify funding sources by engaging other institutions	• Revised the Business Development Plan which highlights strategies to engage fee-for-service use of the facility
Risk management (two instances at two facilities: CLS, ONC)	• Fully implement an enterprise risk management system	• Implemented the system
Outreach (six instances at one facility: ONC)	• Develop a strategy to attract the best researchers at the national and international level	• Engaged several Canadian organizations to maximize the Canadian research community's ability to fully exploit the network's unique capabilities

Areas for improvement and facilities affected	Examples of conditions	Examples of actions taken to meet conditions
Other (eligibility) (two instances at one facility: Compute Canada)	• Incorporate the facility to bring greater clarity to accountability and fiduciary responsibility	• Incorporated as not-for-profit
Cybersecurity (one instance at one facility: Compute Canada)	• Implement a cybersecurity program	• Implemented a cybersecurity plan and policies, defining roles and responsibilities for the implementation and operation by cybersecurity personnel for the life of the project

APPENDIX D – Lessons learned on performance management

The selection and prioritization of reliable measures is one of the most difficult stages in performance-based management and evaluation. Defining measurable key performance indicators (KPIs) that were both meaningful for the facilities and useful to the CFI in demonstrating the impacts of the MSI Fund was a challenge during the funding cycles analyzed for this report.

As a result, the CFI refined its expectations for KPIs for the facilities funded in the 2017–22 funding cycle. Since KPI customization limits the CFI's ability to make comparisons among facilities, facilities and the CFI have been working together to mitigate some of these difficulties for the 2017–22 funding cycle. For example, the CFI standardized, in name and definition, six overarching and common KPIs between all facilities.

Still, the varying contexts of facilities, as well as difficulties collecting the required data will lead to limited comparability among facilities. In light of these challenges the CFI and facilities will continue to work together to improve how they communicate results and outcomes to their stakeholders.

The identification of targets for each of the KPIs was also challenging. Although targets were requested from the facilities funded in the 2012–17 funding cycle, most either did not provide targets or simply entered the actual measure of the preceding year.

Setting KPIs and identifying targets are difficult in part because facilities have limited control over typical scientific measures (e.g., number of publications, number of highly qualified personel) that are mostly associated to their user base.

Another important consideration is the fact that scientific research often does not progress linearly, and failure is part of the process. This increases the uncertainty of performance measures and targets, a situation compounded in a climate where high-risk, high-reward research is promoted.

The CFI is cognizant that its expectations must mirror the realities of the research process. At the same time, setting meaningful targets to achieve aspirations and drive continuous improvements is important, and even more so for KPIs over which facilities can exercise a high level of control (e.g., level of satisfaction, level of use).

Another lesson learned from the 12 facilities examined is that many research-based organizations do not see the benefits of this type of performance measurement strategy. Although they established KPIs and implemented performance measurement strategies, many did so solely to comply with the CFI's requirements and for the first few years they remained skeptical of the value to their organization. For instance, one facility did not provide targets as they were said not to carry any meaning for the organization.

Even so, several facilities now understand how this performance strategy can be used to their advantage and not for mere compliance to the CFI's requirements. When they started using KPIs and targets to support their daily operations, they began to recognize their potential.