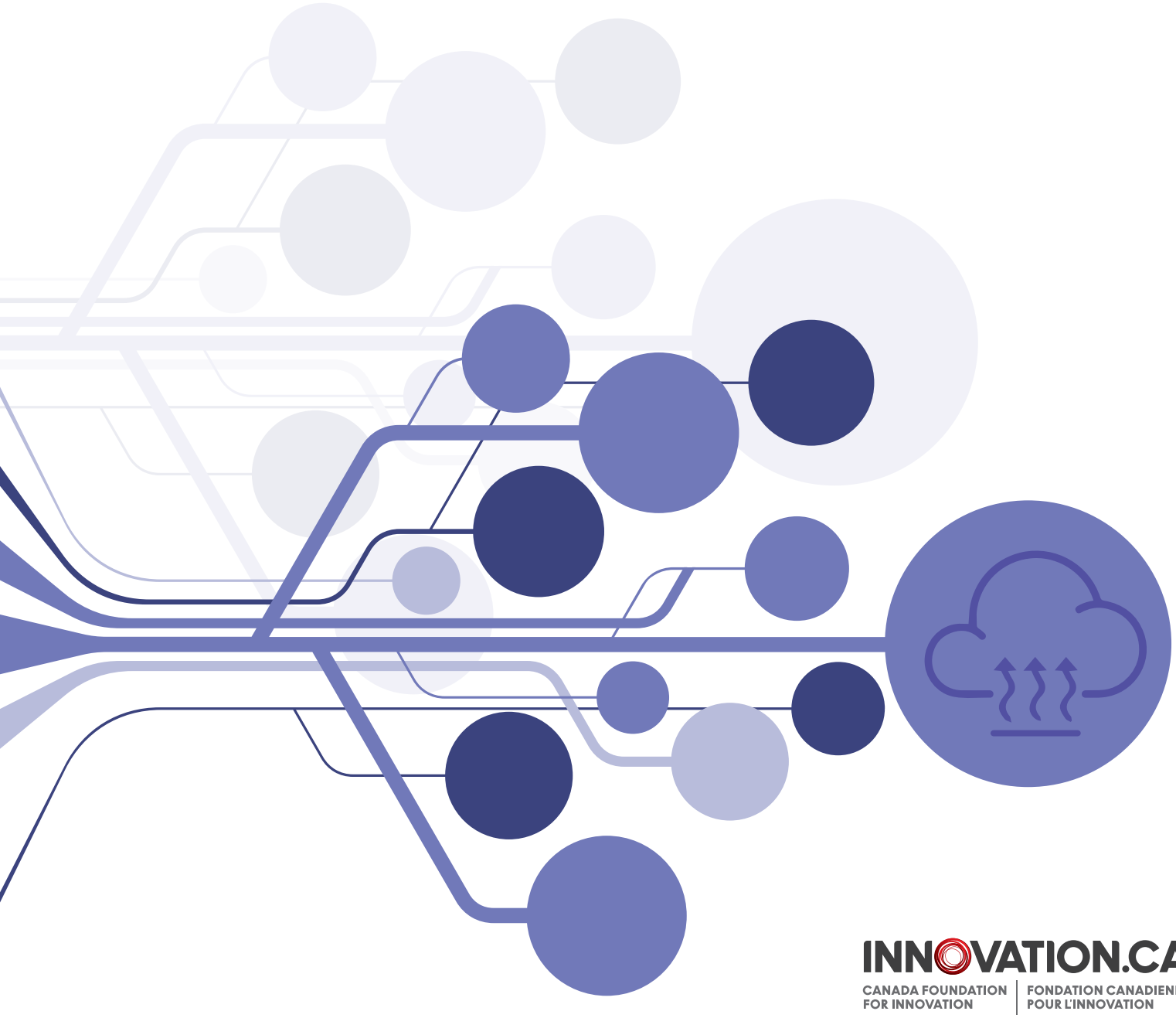
MAPPING INVESTMENTS TO IMPACTS: **AGRICULTURAL RESEARCH**

Greenhouse gases

April 2018



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The CFI would also like to thank Frédéric Bertrand and members of our Advisory Committee, composed of representatives from 20 organizations including universities, federal and provincial government departments and agricultural associations, for their time, expertise and advice in the development of this project.

METHODOLOGY

Using a data collection framework, administrative documentation and performance data on selected projects were reviewed, including project proposals, budgets, financial, progress and final reports as well as bibliometric analysis of publications authored by project leaders. Findings from interviews and the document review are integrated to assist in the interpretation of findings and to guide the logical flow from CFI funding to research evidence leading to possible outcomes with social, economic and environmental benefits. A subset of projects within each area of study were selected for detailed analysis through the above methods. This selection was made using multiple criteria to maximize the collection of evidence on impact pathways while confining the scope of the study.

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KEY FINDINGS: Pathways from agricultural greenhouse gas research to impacts

Resource sharing between government stakeholders and scientists, end-users and research institutions enables important collaborations.

- The community of researchers working on greenhouse gas emissions in agriculture is small and includes academics, government scientists and students who rely on each other for collaborations, infrastructure and data sharing.
- Field work for greenhouse gas studies is frequently done on privately owned farms, creating many opportunities for researchers to network and collaborate with the industry and end-users.

Knowledge transfer and collaborations through trainees enable a strong research and policy sector.

- Networking among academics is encouraged and facilitated by funding and policy programs at the national level, such as the Agricultural Greenhouse Gases Program (AGGP).
- HQP using the CFI-funded infrastructure have the opportunity to collaborate with various sectors, creating diverse knowledge dissemination pathways.
- Former trainees find employment in the public and academic sector while continuing to collaborate with CFI-funded facilities.

Government, researcher and end-user linkages are reinforced through sharing of research evidence.

- Research evidence on the farm scale helps inform end-users about adoptable practices tailored to Canadian farmers to help reduce the environmental impact of agriculture.
- Research conducted on farms allows Canadian farmers to receive firsthand information with proven results to make informed decisions about practices on their farms.
- Research evidence has informed government stakeholders and influenced land-use policy, standards and regulations and strategies for sustainable agriculture.

GREENHOUSE GASES IN AGRICULTURE

CFI investments in research infrastructure to study greenhouse gases (GHG) in agriculture enable the development of: improvements in GHG measurements from agriculture; best management practices for farmers; new mitigation technologies; and federal and provincial policy recommendations for mitigating GHG emissions.

BACKGROUND

Greenhouse gas emissions are a major contributor to climate change. Global GHG emissions grew by approximately 40 percent between 1990 and 2011, with the bulk of the growth coming from emerging markets and developing countries. Canada's share of world cumulative emissions since 1990 has been below two percent.[1]

From 1990 to 2005, total Canadian GHG emissions grew from 591 megatonnes to 736 megatonnes. The majority of this increase occurred in the transportation, oil and gas and electricity sectors.[1] In 2012, Canada emitted about 699 megatonnes of carbon dioxide equivalent of greenhouse gases to the atmosphere.[2]

In 2010, agriculture represented the second largest source of GHG emissions globally, at 13 percent.[3] In Canada, 10 percent of GHG emissions are from crop and livestock production, excluding emissions from the use of fossil fuels or from fertilizer production.[4]

Agriculture can be both a source (absorber) and a sink (emitter) of several greenhouse gases. Methane is emitted by cattle through enteric fermentation and from manure, but can also be absorbed by mineral soils. Nitrous oxide is emitted following the application of nitrogen fertilizers to soils. Carbon dioxide exchange is very dynamic with crops removing this from the atmosphere but then releasing this again during respiration; the net balance is often difficult to measure.

This report studies the impact of CFI investments across the spectrum of GHG research in agriculture from research funding obtained by project leaders, to collaborations enabled through infrastructure, and the impact of training of Highly Qualified Personnel (HQP). This report also touches on the important knowledge transfer pathways and the benefits of research evidence in terms of social, economic and environmental value to Canada.

CFI INVESTMENTS

The 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. Between 1998 and 2015, the CFI invested a total of $15.7 million in 29 projects related to GHG in agriculture. These projects are located at 10 Canadian universities, shown in **Figure 1**.

Among the 29 projects, the University of Manitoba received the greatest amount of funding and has the most projects, with seven of them totalling $4.9 million since 2000. CFI-funded infrastructure for these projects ranges from analytic equipment like data loggers and spectrometers, to the creation and construction of new labs such as the Laboratory for Agricultural and Forest Micrometeorology and the Laboratory for the Study of Bioprocesses in Freezing and Thawing soil.

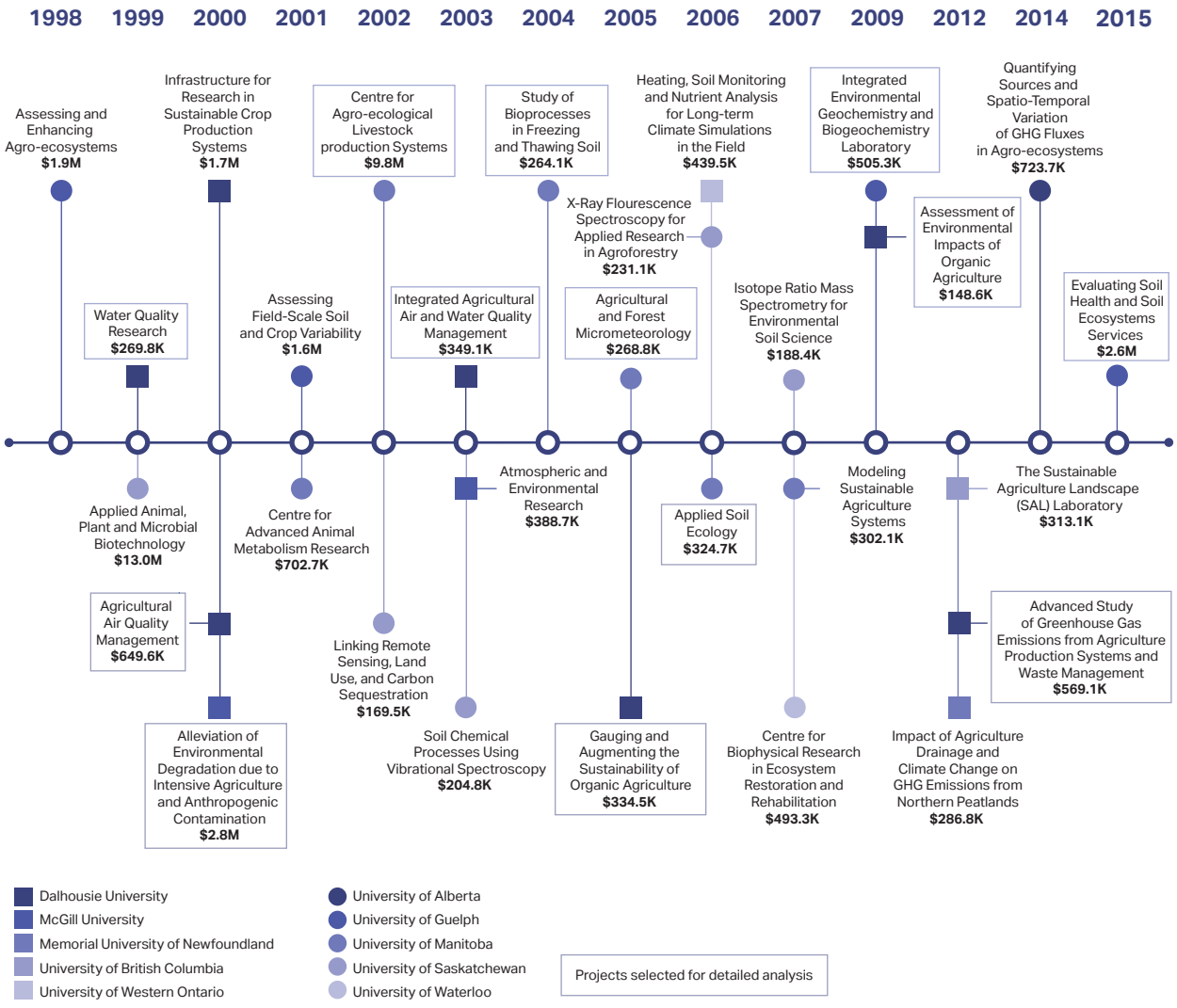
1 Environment Canada (2014) Emissions Trend Report (ETR) p. i-7. Retrieved from: http://publications.gc.ca/collections/collection_2014/ec/En81-18-2014-eng.pdf

2 Excluding emissions/removals from Land Use, Land-use Change and Forestry (LULUCF) (2014 ETR p. 7) Retrieved from: http://publications.gc.ca/collections/collection_2014/ec/En81-18-2014-eng.pdf

3 United States Environmental Protection Agency (August 2016) Climate Change Indicators in the United States: Global Greenhouse Gas Emissions p. 2 Retrieved from: https://www.epa.gov/climate-indicators

4 Agriculture and Agri-Food Canada (August 2016) Greenhouse gases. Retrieved from: http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/agriculture-and-climate/greenhouse-gases/?id=1329321969842

Figure 1: Timeline of CFI projects in agricultural GHG



Note: CFI administrative data as of April 15, 2016. Dollar amounts reflect the total project cost of which only 40 percent is the CFI contribution. Amounts for some projects are based on interim financial reports and are therefore provisional.

Other investments were made at the University of Guelph, which received funding for five projects totalling $2.5 million. The projects varied from soil assessment and farm management practices to analysis and enhancement of agroecosystems. The research infrastructure included both on-site farm equipment like crop planters, equipment trailers, and field soil probes; as well as laboratory equipment like cabinets, ion analyzers and CAT scan systems.

From the 29 agricultural GHG projects funded by the CFI since 2000, a subset of 13 projects at four universities were selected for this report in order to conduct a more detailed analysis of the pathways leading from research to impacts in the community. The remainder of this report focuses on this subset of projects which are identified in **Figure 1** above. Projects were selected using multiple criteria with a view to maximize the collection of evidence on impact pathways while confining the in-depth analysis at the project-level and managing the scope of this case study. Considerations were made to the materiality of the CFI funding, balance between infrastructure types, research outcomes and targeted impacts.

Infrastructure supported by the CFI includes:

Research equipment:

- Microscope
- Gas analyzers
- Chromatography equipment
- Advanced computers
- Pipettes
- Centrifuges
- Lab software

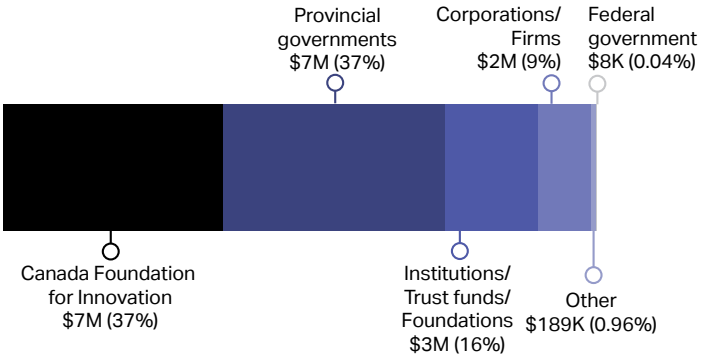
Construction:

- Growth chambers
- Integrated environmental geochemistry and biochemistry laboratory
- Sustainable Agricultural Landscape (SAL) laboratory
- Centre for Biophysical Research in Ecosystem Restoration and Rehabilitation

MATCHING FUNDS

CFI contributions can represent up to 40 percent of a project's research infrastructure costs. Matching funds are often provided by provincial governments in combination with the host institution and industry partners. As shown in **Figure 2**, the projects have diverse combinations of funding sources.

Figure 2: Matching funds for CFI investments in 13 selected agricultural GHG projects



Note: CFI administrative data as of April 15, 2016. Amounts for some projects are based on interim financial reports and are therefore provisional.

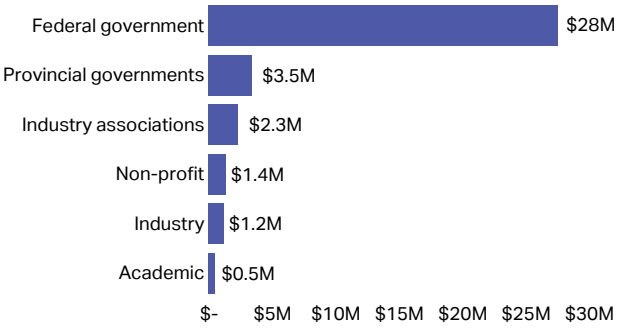
RESEARCH FUNDS

The availability of CFI-funded research infrastructure has enabled Canadian researchers working in GHG in agriculture to obtain research funding to advance their research and support trainees. Sources of funding are varied and come from federal and provincial governments, non-profits, industry and academia, as shown in **Figure 3**.

Project leaders for the 13 selected projects have been successful in obtaining funds from many sources with strong provincial and federal government support. Research funds come from many government agencies including: the Natural Sciences and Engineering Research Council of Canada (NSERC), Agriculture and Agri-Food Canada (AAFC), the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), Networks of Centres of Excellence (NCE) and the Fonds de recherche du Québec- Nature et Technologies (FRQNT). The

Canadian government's support through various federal agencies of these research projects with funding programs dedicated to agricultural GHG research, can be seen as a prioritization of their interest in mitigating the harmful effects of agricultural greenhouse gas emissions. CFI investments in research infrastructure to study agricultural GHG emissions have also enabled project leaders to obtain additional funding over the medium and long terms. For example, three of the eight project leaders hold or have held Canada Research Chairs — Robert Gordon, PhD; Derek Lynch, PhD; and Mario Tenuta, PhD — which they were awarded either concurrent with or subsequent to their CFI awards.

Figure 3: Research funds obtained by project leaders since initial CFI award for 13 selected agricultural GHG projects



Note: Awards and amounts included were reported and validated by project leaders and only include funds obtained since year of initial CFI award. Awards and amounts may not be unique counts due to the co-applicant status of the project leaders.

NETWORKS, COLLABORATIONS AND LINKAGES

CFI investments in the 13 selected projects have supported established research groups, enabled the formation of new networks of scientific collaborators and users, and created linkages between industry, academia and government. As a result, the project leaders have participated in research consortia, funding collaborations, partnerships and joint training initiatives at the regional, provincial, national and international levels.

"Students gain crucial skills through training on highly specialized equipment. It is not just about collecting data, it's about getting hands-on training that allows them to troubleshoot and understand. These are the skills which distinguish them in their careers."

Claudia Wagner-Riddle,
University of Guelph

Given that this type of research requires both laboratory and on-farm testing, the end-users — farmers and industry — are actively involved in the research process. Experiments, trials and data collection often take place on working Canadian farms and create important linkages between researchers, farmers and industry stakeholders. These linkages have benefits for all parties. They allow farmers and industry players to take advantage of the possible benefits of new technologies and practices and allow researchers to collect necessary data to customize GHG mitigation solutions to Canadian conditions.

A very important symbiotic relationship also exists between the academic community and staff scientists working for federal, provincial and municipal governments and agencies. For instance, there is a high degree of bottom-up coordination for research activities and sharing of infrastructure amongst faculty researchers and their students with scientists at AAFC for research activities and to share infrastructure. In the case of Chandra Madramootoo, PhD, at McGill University, the research program and infrastructure were designed to be shared by well-established,

internationally recognised research teams at McGill University, Université de Montreal, Laval University, the Institut de recherche et de développement en agroenvironnement (IRDA) and AAFC.

Collaborations extend beyond Canada: both Tenuta and Brian Amiro, PhD, University of Manitoba, have developed linkages in the United States through their participation in the North American Carbon Program (CarboNA), an international collaboration between Canada, Mexico and the United States for carbon cycle science research throughout North America and adjacent coastal waters. Related research on GHG emissions from forests has enabled Amiro to further collaborate extensively with his American partners on a five-year US National Science Foundation project.

Lynch's multidisciplinary research program on the sustainability of organic agriculture at Dalhousie University, has formed many linkages with networks of researchers from various disciplines including soil science, pest management and horticulture. His team's CFI-funded field equipment and its enhanced sample processing and laboratory analytical capacity has enabled him to collaborate with horticulturalists and vegetable specialists at AAFC in Bouctouche, N.B. and to establish an Eastern Canada AAFC research network focused on organic vegetable production. The research has attracted significant industry support from Nova Agri Inc. and Dow AgroSciences.

Select list of project collaborators:

INDUSTRY & INDUSTRY ASSOCIATIONS

- Dairy Farmers of Canada
- Ontario Soil Crop Improvement Association
- Ontario Federation of Agriculture
- New Energy Farms
- Mendel BioEnergy Seeds
- Canadian Fertilizer Institute
- Nova Agri Inc.
- Wild Blueberry Producers of Nova Scotia
- Laser Drainage

ACADEMIA and ORGANIZATIONS

(In addition to academics of funded institutions collaborating on CFI-funded infrastructure)

- National Water Research Center (Egypt)
- Institute for Water Resources and Hydraulics (China)
- United Nation's Food and Agriculture Organization
- Global Environmental Monitoring Systems (GEMS)

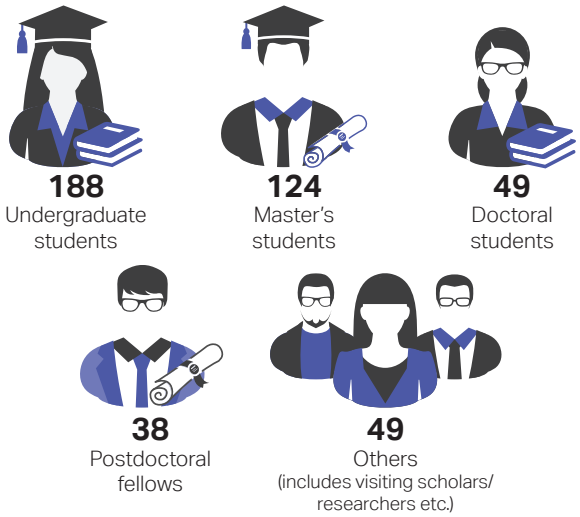
GOVERNMENT

- Agriculture and Agri-Food Canada
- Ontario Ministry of Agriculture, Food and Rural Affairs

ATTRACTION AND TRAINING

CFI-funded infrastructure provides an enriched training environment that is critically important for the training of students and technicians from across Canada and from around the world. Through undergraduate, graduate and postdoctoral training, internships and exchange programs, many trainees as well as established researchers have used the CFI infrastructure to develop and advance their research skills and to successfully obtain employment related to their field of expertise. Furthermore, the infrastructure provides new possibilities for collaboration, which has in turn provided an effective means for increased opportunities for Highly Qualified Personnel (HQP), and has helped to attract faculty researchers.

CFI infrastructure has helped train Highly Qualified Personnel (HQP)[5] including:



The CFI infrastructure is central to Lynch's research program and has been key to attracting researchers and greatly enriching the training environment provided within the research program. Close to 50 percent of Lynch's graduate students have been awarded NSERC scholarships, and one recent MSc graduate, Karen Nelson, received the Governor General's Gold Medal at Dalhousie University for outstanding thesis and graduate work.

The CFI infrastructure at Dalhousie helped the Nova Scotia Water Quality Research Group (NSWQRG) provide more attractive training opportunities for both graduate students and postdoctoral fellows. Through this program, Gordon has supervised undergraduate, master's, and doctoral students as well as postdoctoral fellows (PDF) in addition to hosting visiting scholars from Korea, China and Vietnam. Gordon himself is an example of how HQP move within the universities in Canada with programs specializing in agriculture and environmental studies. He obtained his PhD from the University of Guelph in 1996 and then spent a decade at the Nova Scotia Agricultural College (now part of Dalhousie University), where he held a Canada Research Chair in Agricultural Resource Management and served as dean of research, department head, and associate professor in the Department of Engineering. He moved back to the University of Guelph in 2008 to serve as Dean of the Ontario Agricultural College until 2015.

KNOWLEDGE TRANSFER

Through their research activities and use of the CFI-funded infrastructure, the project leaders of the 13 selected projects have advanced the knowledge in their expert domains, and communicated these results beyond the academic community to government and end-users in a variety of outputs. Reported research results include new or improved processes, procedures, methods, datasets, management systems, best management practices, products, tools and technologies.

Project leaders conducting research on CFI-funded infrastructure are among the top-ranked researchers in agriculture in terms of scientific output. The eight project leaders together total nearly 2,000 citations across 325 papers combined between 2008 and 2014. In terms of scientific impact, half of the researchers are above the world average as ranked by the averaged normalized citation impact.[6]

Claudia Wagner-Riddle, PhD, a professor at the University of Guelph, creates impacts that extend beyond Canada and enables knowledge transfer and collaborations at an international level. She has presented her research with collaborators, including Gordon, at international conferences like the Greenhouse Gas and Animal Agriculture Conference held in Melbourne, Australia in 2016. The conference was attended by 335 delegates from over 40 countries and presented industry trends, new technologies and innovative research in the agricultural GHG research area.

5 Highly qualified personnel (HQP) include technicians, research associates, undergraduate students, graduate students and postdoctoral fellows. Numbers as reported by project leaders for 13 selected agricultural GHG projects.

6 Bibliometric analysis conducted by the CFI from Web of Science InCite over the time period of 2008 to 2014. Publications and citations may not be unique counts due to the co-authorship of publications between project leaders.

"We are cultivating relationships and creating collaborative environments for people to come together to explore new research approaches. We host events focused on sustainable agriculture that attract researchers, graduate students and our external research partners to share what we know and generate new knowledge together."

Christine Rawluk,
National Centre for Livestock
and the Environment, University of Manitoba

Collaborations and knowledge transfer between academics are also enabled by unique infrastructure such as the CFI project led by Karin Wittenberg, PhD, which created the National Centre for Livestock and the Environment (NCLE) at the University of Manitoba. This centre has extensive facilities, equipment and land to support fundamental research that addresses environmental, economic and social issues related to livestock. The NCLE facilities are unique in North America through their provision of long-term and multifaceted research programs for the redesign of both extensive and intensive animal production systems and development of environmentally and economically sustainable management practices.

Project leaders also disseminate results to end-users and government to help mitigate GHG emissions from farms. Wagner-Riddle used the CFI-funded infrastructure to study carbon and nitrogen cycles and their relationship to GHG emissions in dairy livestock-cropping systems and in bioenergy feedstocks such as switchgrass. Her team has developed best management practices that farmers can use to reduce the carbon footprint of the products they produce. Tenuta has developed new practices to reduce GHG emissions and increase crop use of nitrogen from synthetic and manure-based fertilizers. To communicate these findings to non-academic audiences he has given numerous workshops and invited presentations to high school students, industry, commodity groups and policy makers on how 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®) for nitrogen fertilizer management can help achieve national emissions reduction targets for nitrous oxide. Active on social media, Tenuta also reaches non-academic audiences through YouTube and Twitter.

BENEFITS TO CANADA

CFI investments in GHG in agriculture research infrastructure have resulted in social benefits through increased air, water and soil quality; economic benefits through the development of efficient and cost-effective farm management practices for end-users; and, environmental benefits through new practices and technologies to mitigate greenhouse gas emissions.

Lynch and David Burton, PhD, along with their colleagues at the Organic Agriculture Centre of Canada located at Dalhousie University, in conjunction with farmer and industry input are ensuring that improved production practices and technologies suitable to organic standards are being developed to benefit this growing sector.

The team researches and develops organic production systems, not only as a means of social and economic benefit, but also as an environmental benefit though GHG mitigation. These impacts are achieved through increasing the soil quality, reducing the impact of farming on water and air quality, and increasing the yield of organic crops.

Soil can be used as a GHG 'sink', it can store GHG and prevent them from entering the atmosphere. Carbon rich soil helps release nutrients for healthy plant growth, and promotes healthy, fertile soil. Using the farming soil as a sink for potential sources of GHG can help reduce emissions, all while creating healthy and fertile soil for farmers.

At the University of Guelph, Wagner-Riddle's team is providing scientific evidence for best management practices that can be used by farmers to reduce their carbon footprint and mitigate GHG emissions. For example, they have shown that methane emissions from digestate during biogas production are reduced compared to emissions from untreated dairy manure. Biogas is an alternative source of energy that can be used to produce electricity. As a result of this research, Wagner-Riddle was invited to contribute to an agricultural technical committee supporting the National Greenhouse Gas Inventory led by Environment Canada and Climate Change and was also invited to the technical task team supporting the development of an Anaerobic Digestion Protocol for the climate change programs of Quebec and Ontario. Clovermead Farms in Alma, Ont. have adopted these practices and installed an anaerobic digester recommended through the emission reduction practices. The anaerobic digester transforms cow manure into two products — dry matter (digestate) that can be used as a fertilizer, and biogas. The farm obtains significant economic and environmental benefits, both by saving money on fertilizer and because the biogas generates enough electricity to heat the house, barn and sell energy back to the grid.

Gordon's research evaluates GHG emissions on a whole-farm approach. He considers mitigation strategies throughout the entire farm, including manure and wastewater management systems. His research has led to a more profound understanding of GHG emissions in relation to atmospheric properties, air and water quality and farming practices. This novel approach bridges the gap between air and water quality research and provides the agricultural sector with more accurate information and management recommendations to increase air and water quality while mitigating GHG emissions. His research helps create positive environmental impacts throughout farm waste management systems and surrounding environments.

CONCLUSION

Through its investments in state-of-the-art research infrastructure to support leading-edge research in GHG in agriculture, the CFI has enabled ten Canadian institutions to increase their capacity to conduct internationally recognized research and to train a highly qualified workforce for academia, industry and the civil service. The research conducted with CFI-funded infrastructure has played a major role in the development of new farm management practices, the conception of new technologies and research approaches and the creation of federal and provincial GHG emission mitigation policies. The significant research evidence and the actual and potential social, environmental and economic benefits highlighted in this report explain why so many institutions and organizations, along with governments at all levels, support innovation and research collaboration to reduce GHG emissions in agriculture.