

Genome Canada Five-Year Evaluation Evaluation Report

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Genome Canada

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Acronyms

ARC	average of relative citations
CFI	Canada Foundation for Innovation
CIHR	Canadian Institutes of Health Research
GAPP	Genomic Applications Partnership Program
GC	Genome Canada
GE ³ LS	Genomics ethical, environmental, economic, legal or social aspects
HQP	highly qualified personnel
iBOL	International Barcode of Life Project
NRC	National Research Council
NRCan	Natural Resources Canada
NSERC	Natural Sciences and Engineering Research Council
PI	principal investigator
R&D	research and development
SI	specialization index
SSHRC	Social Sciences and Humanities Research Council
STIC	Science and Technology Innovation Centre
USPTO	United States Patent and Trademark Office

1 Executive Summary

This report presents the findings, conclusions and recommendations resulting from the second five-year evaluation of Genome Canada, which assessed the organization's relevance and retrospective performance in the context of the Canadian research and innovation system from 2009-10 to 2013-14. It also comprises a prospective dimension as it seeks to inform management and other stakeholders on how best to implement the organization's strategic direction (Strategic Plan 2012-2017).

With regard to **relevance (continued need)**, the evaluation finds that the underlying rationale for Genome Canada remains strong. There is an ongoing need to achieve Genome Canada's mission to maintain Canada's position in genomics through the funding of large-scale strategic genomics projects, leading to applications that, "generate impact on and benefits for Canadians" as per the Strategic Plan. In fact, given the challenge posed by traditional leading countries (i.e., UK, US, Germany, France and Japan) and rising stars (e.g., China, India, the Republic of Korea), such support for genomic research is more than ever necessary to maintain Canada's leadership position at the world level. Yet, based on observed trends, Canada is unlikely to maintain its lead over emerging countries in coming years, in genomics overall, or in identified strategic sectors. Thus, with sustained investments in genomic research, Canada can retain its position relative to other traditional leading countries, but should consider rising stars as increasingly worthy collaborators rather than as competitors to outrank.

An international review shows that meeting these needs through a separate dedicated organization is not the only possible model. However, the evidence confirms that the current model is appropriate in the Canadian context because Genome Canada has been effective in helping develop specific regional and sector expertise in genomics. As such, the evaluation concludes that Genome Canada is well-positioned to continue delivering and building on its mandate in its current form.

The evaluation findings are positive overall with regard to the achievement of Genome Canada's expected outcomes over the last five years (2009-10 to 2013-14). Genome Canada has clearly contributed to enhancing support and capacity for genomics research in Canada in accordance with its national strategy, more specifically by focusing on priority strategic sectors and on increasing coordination, as well as through the development of highly qualified personnel (HQP) in genomics. Evaluation evidence further confirms that Genome Canada projects have contributed to increasing breadth and depth of knowledge in genomics—overall, in strategic sectors, and in GE³LS¹.

- Compared to their non-funded counterparts, Genome Canada-funded researchers produced more peer-reviewed papers, which were generally more focused in genomics and some of the strategic research themes. These papers also had a higher scientific impact, supporting the finding that Genome Canada has contributed to Canada's increased global impact in genomics since 1996—with the highest increase observed in the last five years.

¹ Genomics ethics ethical, environmental, economic, legal and social issues

- Genome Canada has contributed to increased coordination among Canadian researchers and with other stakeholders (e.g., funders, partners), and has played an ongoing role in supporting international collaboration.
- Genome Canada has had a positive influence on Canada's leadership, international profile and visibility in genomics research as a result of the high-impact collaborative work conducted in the context of large-scale projects and international consortia.
- Genome Canada has directly contributed to increasing the supply of HQP in Canada, allowing training and career opportunities that would not have been afforded otherwise.
- Several examples were found of transformative research funded by Genome Canada, although some projects have not achieved their full potential. Similarly, a variety of socio-economic benefits were noted, but there is room for improvement regarding the translation of research into practical applications.

This evaluation's findings have a number of implications for Genome Canada as it continues to implement its Strategic Plan. First, with regard to the strategic objective to "respond to societal needs by generating discoveries and accelerating their translation into applications", the evaluation stresses the fact that achieving transformational scientific results and socio-economic benefits take time and that not all projects will experience both. Delivering on this objective will require earlier and stronger engagement with partners and end-users, which were identified as factors that enable translation in the case studies. Barriers to translation include a number of external/contextual factors in the innovation system (e.g., complex regulatory processes, funding gap at the product validation stage, and limited engagement of the private sector). In this context, maintaining momentum through long-term sustainability of funding for transformational research, translation and application will be paramount.

This will require not only continued long-term federal support, but also the attraction of greater funding from other sources. Genome Canada delivered on its commitment to achieve a 1:1 co-funding ratio during the evaluation period, but co-funding was primarily obtained from provincial (51%) and foreign partners (30%), while industry accounts for 7% of total external funding. As such, there is an opportunity to leverage greater funding from private sources, including through strengthened partnerships in emerging sectors (e.g., energy) and through new industry-focused programs such as the recently launched Genomic Applications Partnership Program (GAPP). It is important to note that this closely aligns with the Strategic Plan objectives and will be supported by Genome Canada's new commitment to leverage 1:2 co-funding ratio. In addition:

- Genome Canada, working with the Genome Centres, should seek out and/or create joint initiatives with a broader range of public and private organizations aiming to achieve similar objectives (e.g., R&D funding programs, partnership programs, business innovation, etc.).

To support further investment and uptake of research results, Genome Canada recognizes that it also needs to conduct more upfront and in-depth engagement and communication with potential and actual partners. However, both project-level coordination and broader communication activities are areas that could be strengthened within Genome Canada and streamlined through closer work with the Genome Centres:

- Genome Canada's performance was modest with regard to raising awareness among policy-makers, industry and the general public on the risks and benefits of genomic research.
- Communication between project teams, stakeholders and the Genome Centres was found to be a key facilitating factor for the success of funded genomics projects. However, communication activities represent the main area where duplication is occurring among the Genome Centres and between Centres and Genome Canada, resulting from a lack of coordinated efforts (e.g., messaging, sharing of tools and expertise).

In order to reduce duplication and increase the effectiveness of communication efforts:

- Genome Canada should coordinate with the Genome Centres to develop a communications and engagement plan that identifies strategies for specific audiences/sectors and facilitates the sharing of communications tools and resources.

Canada has become a world leader in GE³LS research, which is at least partly attributable to Genome Canada's efforts. However, despite the broad recognition of the value of GE³LS research, there are mixed views on embedding GE³LS research into every project. The evaluation was mandated to examine the extent to which Genome Canada's model of embedding GE³LS facilitated the translation of genomics research but found there was not enough evidence to make a direct link between integrated GE³LS and facilitated translation. As such:

- Genome Canada should address current information gaps on the effectiveness and weaknesses of integrated GE³LS to confirm its value in facilitating translation of genomics research and to develop criteria and guidelines to help adjust practices for the integration of GE³LS.
 - Recognizing that Genome Canada has already taken steps to address GE³LS integration, the organization can now seek to expand on these practices. First, a more in-depth analysis is necessary to address the current gap in evidence on the benefits and effectiveness of integrated GE³LS (e.g., where its absence is most detrimental; where it works/doesn't work to facilitate translation—and *why*; other indirect or non-translational benefits of GE³LS). This analysis could build on existing studies and evaluation data (e.g., surveys, case studies), and collect additional data from both Canadian and international examples.
 - Secondly, the results of this analysis would help develop a set of criteria to identify programs (or individual projects on a case-by-case basis) where integration of GE³LS would be most and least beneficial, as well as guidelines/best practices.

This evaluation found that Genome Canada's approach to focus on strategic sectors is sound. The sector strategies developed in partnership with the Genome Centres are fine-tuned to reflect the high degree of variability across sectors (e.g., needs, capacity, context). The evaluation also concludes that achieving Genome Canada's strategic objectives will require not only large-scale projects, but also smaller scale and/or more flexible industry-focused projects that help build both research and end-user capacity to support greater transfer and application. Genome Canada's initiatives such as the Genomic Applications Partnership Program, the Bioinformatics and Computational Biology Competition and others are a first, effective step in this direction. Moving

forward, this suggests an opportunity to continue to develop more flexible programming (including the size and terms of awards) to address the particular needs of individual sectors, perhaps even to address specific priorities within sectors:

- Genome Canada should further improve working relationships with Genome Centres and collaboratively develop focused and customized funding programs that address the needs of specific sectors, including both large-and small-scale projects, as appropriate.

The collected evidence indicates that Genome Canada provided adequate and sufficient access to enabling technologies, but there are areas of improvement that are expected to become more critical moving forward as technology and the capacity of other countries evolve. To remain competitive by adding value to their current services:

- Genome Canada should encourage the five Science and Technology Innovation Centres (STICs) to build on their unique strengths (e.g., providing analytical expertise, developing training programs and providing leading-edge technologies at an affordable cost) and to develop clearer policies and guidelines regarding data sharing and intellectual property, with a view to promote more open access to data.

Finally, communication, investment and strategic decision-making will all be supported by ongoing improvements in performance measurement practices and tools that better capture, measure and articulate the value of Genome Canada and of genomics research. In particular, there is a need to better define concepts and measures of transformative, translational, and socio-economic impacts—which may include targeted studies and/or socio-economic impact analysis—in order to better tell the full story of Genome Canada’s impact. This will also help provide robust evidence to guide additional adjustments to Genome Canada’s programs and governance structure in the future. As such:

- Genome Canada should continue to improve its performance measurement and reporting structures, as well as seek to better integrate its different databases.

It should also be highlighted that Genome Canada’s ongoing implementation of the Strategic Plan and all of these recommendations will require additional efforts from Genome Canada and Genome Centre staff, which implies a potential increase in operating expenses, and at the very least, maintenance of the current level.

As a final point, Science-Metrix recognizes that Genome Canada is a mature organization, active in reflecting on and adapting its practices, both to improve efficiency and effectiveness as it proceeds with the implementation of its Strategic Plan. For example, there are ongoing efforts to explore new funding models, to build new partnerships, to bring new expertise to its staff and Board, as well as adjustments to the organization’s governance and program management practices (e.g., coordination, reporting, performance measurement). The recommendations herein should therefore be considered as means to complement and/or help focus on these continuous improvements.

2 Introduction and Context

This report presents the findings, conclusions and recommendations resulting from the second, five-year evaluation of Genome Canada. The evaluation assessed Genome Canada's relevance and past performance over the period from 2009-10 to 2013-14. It is also intended to help inform management and other stakeholders on how to best implement the organization's strategic direction. Another important contextual element is that as per funding agreements with Industry Canada, Genome Canada is required to submit an independent third-party evaluation of its activities and projects every five years; this evaluation fulfils that requirement.

The organization of the report, including the themes, issues, and questions examined as part of this evaluation, is presented in Annex 1, along with a methods overview. Supplementary materials and detailed methods are also available in separate Appendices.

Genome Canada, established in 2000, is a not-for-profit organization that invests in large-scale genomics initiatives in sectors of strategic and economic importance to Canada, aiming to strengthen genomics research and technical capacity in Canada, and foster multi-sectorial partnerships nationally and globally. With a view to generating economic and social benefits for Canadians, its target sectors include health, agriculture, environment, forestry, fisheries and energy and mining. Genome Canada has also worked to ensure that genomics research efforts consider underlying ethical, environmental, economic, legal or social aspects (GE³LS).

Genome Canada receives funding from Industry Canada (\$1.04 billion² to date) and has raised over \$1.2 billion through co-funding commitments,³ for a total investment of over \$2 billion to date. Co-funding partners include provincial governments and agencies, international non-governmental organizations and research institutes, industry, universities, and research hospitals.

Genome Canada delivers its mandate through six regional centres: Genome British Columbia, Genome Alberta, Genome Prairie, Ontario Genomics Institute, Genome Quebec and Genome Atlantic. This operational model seeks to combine national leadership with the ability to respond to regional and local needs and priorities. The Genome Centres play a role in the development of regional expertise, in developing partnerships to strengthen regional leadership and competitiveness, in creating unique and innovative public outreach programs, and in securing co-funding for projects from both domestic and international investors. The Centres also manage projects funded by Genome Canada, in addition to operating their own regional programs.

In addition, Genome Canada provides Canadian scientists with advanced technologies and expertise through five Science and Technology Innovation Centres (STICs). Genome Canada supports STIC operations through a competition process, and the STICs provide service to the projects on a cost-recovery basis.

² As per funding agreements, dated 2005 to 2013, indicating federal funding allocated between 2000 and 2017. This does not include latest \$165M from Industry Canada.

³ Source: Genome Canada. (2013). Financial Data (as of November 26, 2013).

Genome Canada's expenditures during the first four years of the evaluation period (2009-10 to 2012-13) are presented in Table 1, including Genome Centre Expenditures.

Table 1 Genome Canada and Genome Centres Expenditures, 2009-10 to 2012-13 (in thousands)

	2009-10	2010-11	2011-12	2012-13
Genome Canada Expenditures				
Projects and STIC Funding	\$69,212	\$47,394	\$50,926	\$43,837
Genome Centres Base Funding	\$5,505	\$5,505	\$5,505	\$4,847
Centres Program Management Fees	\$966	\$594	\$1,208	\$1,085
Other Research Funding	\$388	\$0	\$0	\$0
Genome Canada Operating Expenditures	\$5,829	\$6,254	\$6,161	\$6,168
Total Expenditures	\$81,900	\$59,747	\$63,800	\$55,938
Genome Centre Expenditures				
Expenses (Less Depreciation/Platforms)				
Research Projects	\$97,698	\$80,142	\$75,701	\$80,043
Operations (Non-Research Projects)	\$15,587	\$16,025	\$16,477	\$16,091
Total Expenditures	\$113,286	\$96,167	\$92,178	\$96,134

Source: Genome Canada. (2013). *Summaries of Centres Operating Expenditures Over Four Years, based on audited Financial Statements*

Finally, it is important to highlight that Genome Canada has placed a greater focus in its 2012-2017 Strategic Plan on the endpoint of the research process, placing more emphasis on the translation and application of "knowledge gained from research to grow the Canadian bio-economy and address real-world challenges".⁴

⁴ Genome Canada. (n.d.). *Genome Canada Strategic Plan 2012-2017*.

3 Key Evaluation Findings

3.1 Relevance (continued need) and sector identification

This section presents the results of the evaluation on Genome Canada's relevance in the context of the Canadian research and innovation system. The evaluation found that there is a continued need for Genome Canada, which is backed by a strong rationale and focused on high-priority strategic research themes.

Rationale for Genome Canada

In 2009, the OECD reported that the world is moving towards a global bioeconomy, involving three elements: biotechnological knowledge, renewable biomass, and integration across applications.⁵ Genomics research can address many challenges of the bioeconomy such as climate change and energy issues, increasing food prices and water shortages as well as increasing healthcare costs. In the Canadian context, there is well-documented evidence showing that genomics research has contributed to important advances in a wide variety of sectors such as human health, agriculture, environment, aquaculture and forestry.^{6,7} For instance, a study found that commercial benefits in several life science research clusters are being captured in hubs across the country in biomedical technology and devices, in the agricultural sciences and to some extent in pharmaceuticals. The study's author clearly states that the "imperative for engaging in the life science economy appears to be well grounded in theory and evidence. Advanced, industrial economies like Canada have little choice."⁸

The importance of Genome Canada's role in supporting genomics research is evident, in particular its contribution to the production and impact of national genomics research over the past decade (see additional details in Section 3.2). Evidence from bibliometric analysis shows that Genome Canada contributed to strong growth in genomics research since 2004, allowing Canada to recover from a decline in growth that started in the late 1990s, as compared to the world level ('pre-Genome Canada Trend', Figure 1, next page). However, given that Canada's output in genomics did not keep pace with the world output from 2008 to 2011 (Figure 1), it might not be possible to ensure that Canada has the financial means to continue to outrank the strong growth of emerging countries in this field (e.g., China, India, the Republic of Korea). In this context, there is still a rationale for sustained investments in genomic research to maintain Canada's favourable position among traditional leaders (i.e., UK, US, Germany, France and Japan), in genomics overall, and for strategic investments to maintain Canada's lead in sectors that are particularly relevant to the national industry (see below). Meanwhile, Canada should consider rising stars as increasingly worthy collaborators rather than as competitors to outrank.

⁵ Organisation for Economic Co-operation and Development. (2009). *The Bioeconomy to 2030: Designing a Policy Agenda*

⁶ Genome Canada Annual Reports (2009 to 2013).

⁷ Government of Canada Economic Action Plans (2011 to 2013).

⁸ Phillips, Peter. (2010). Genomics and public policy: Wealth for Canadians. *Integrated Assessment Journal*, 10 (1), pp 7-21.

A strong rationale for Genome Canada can be drawn by examining what would have happened in its absence. As will be shown in more detail in the next section, bibliometric analyses show that it is likely that, in the absence of Genome Canada, part of the research would not have been carried out: the output (i.e., number of peer-reviewed papers) of principal investigators (PIs; i.e., lead researcher on projects) who received Genome Canada funding was significantly higher than output of those who applied for but did not receive funding. This finding was supported by 96% of surveyed PIs, who reported that without Genome Canada, there is very low likelihood that the funded genomics projects would have proceeded within current timeframes/scope; similar responses were observed in other surveyed groups and this was also clear across all eight case studies.

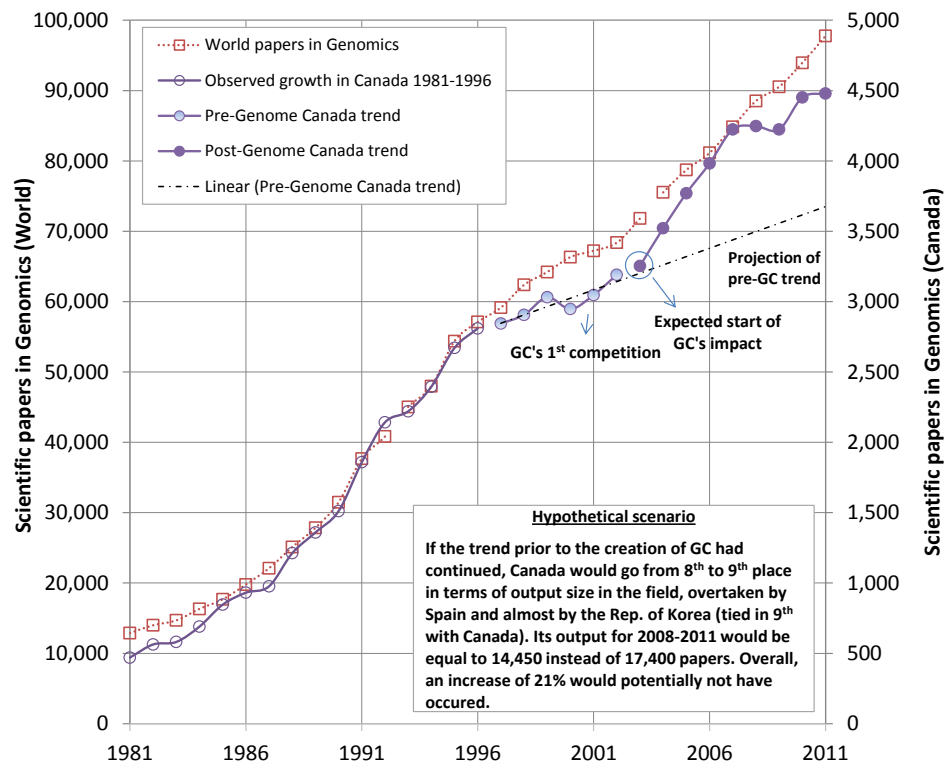


Figure 1 Growth in genomics in Canada and the world, including trends in the absence of Genome Canada, 1996 to 2011

Source: Computed by Science-Metrix using WoS (Thomson Reuters) data.

The majority of the Genome Canada-funded projects are large-scale, i.e., comprising multidisciplinary and/or multi-stakeholder elements, with a variety of funders. Such projects are important to develop applications of genomics research in strategic sectors (i.e., health, agriculture, fisheries, forestry, environment etc.) for the social and economic benefit of all Canadians. Interviewees noted that Genome Canada’s support is critical for these large-scale strategic genomics projects and more than three quarters of survey respondents agreed. These projects often require access to complex infrastructure, involve a large number of collaborators and personnel, and generate large datasets. No other organization operating across Canada provides a similar level or type of funding for such genomics projects. In comparison, federal granting councils, that is, the Canadian Institutes of Health Research (CIHR) and the Natural Sciences and Engineering Research

Council (NSERC) and the Social Sciences and Humanities Research Council (SSHRC) support small and medium-scale research projects across a range of scientific disciplines⁹; it is also important to note that CIHR and NSERC have issued joint calls in partnership with Genome Canada for funding programs that address each of their respective mandates.¹⁰

Moreover, both interviewees and documentary evidence point towards growing public and federal expectations to demonstrate ‘return on investment’ from publicly funded research. As noted by Genome Canada in its 2012-2017 Strategic Plan, the first ten years of its existence were about building a robust, national genomics research community. The overarching goals are now to support the integration of genome science to applications and enhanced translation, “in order to generate the greatest impact on and benefits for Canadians as quickly as possible.”¹¹ Similarly, several international organizations in countries such as the US, Norway and China are following a translational trend, although international interviewees caution that translation takes time and socio-economic benefits are not likely to be observed in the short term.

In this context, evaluation interviewees suggested that there is a need to balance large projects with initiatives targeted towards pilot ventures, technology validation and translation to end-users, in order for Genome Canada to fulfil its strategic goals of moving towards translation and application of genomics research. For example, Genome Canada’s consultations with forestry industry stakeholders found that, “while the technical aspects of genomics are reasonably well-known within industry, the business case for application is not always fully appreciated.”¹² Similarly, it was noted that genomics research in the energy and mining sector is still in its “infancy”, thus there is limited capacity to date although “tremendous opportunity” to make headway in this emerging sector.¹³ Moving forward, Genome Canada’s Strategic Plan outlines a more explicit approach to supporting genomics research and translation within identified priority sectors.

Identification of strategies to focus on high priority strategic research themes

To develop its 2012-2017 Strategic Plan, Genome Canada consulted over 160 stakeholders from 70 organizations, including representatives from the six Genome Centres. Following

⁹ In Canada, the main source of federal science and technology support for the higher education sector – both to conduct research and to sustain and enhance the research capacity (i.e., talent, infrastructure, networking) – are the three funding agencies (NSERC, SSHRC, CIHR), and the Canadian Foundation for Innovation (CFI). Each of these organizations provides more funding to the higher education sector (NSERC \$982 million, CIHR \$966 million, SSHRC \$640 million, CFI \$425 million in 2011-12) than all the other major federal departments and agencies combined (\$248 million in 2011/12). In comparison, between 2009 and 2013, Genome Canada provided \$50-76 million per year in contributions to Genome Centres, for large-scale genomics projects and STICs. It should be pointed out here that the Canadian government has provided \$980 million to Genome Canada since 2000, to which it added \$60 million with the 2012 Contribution Agreement. This is a significant and long-term investment in a targeted research area and quite unusual in the Canadian context.

¹⁰ For example, the 2013 Advancing Big Data Science in Genomics Research Discovery Frontier funding program (involving Genome Canada, NSERC, CIHR and the Canadian Foundation for Innovation), or the 2012 Bioinformatics and Computational Biology funding program involving Genome Canada and CIHR.

¹¹ Genome Canada (2012). *Genome Canada Strategic Plan 2012-2017*.

¹² Genome Canada (2013). *Forest Sector Challenges, Genomic Solutions*. Sector strategy.

¹³ Genome Canada (2013). *Advancing Canada’s Energy and Mining Sector through State-of-the-Art Genomics Applications*. Sector strategy

recommendations from the Genome Centre Funding Renewal in 2012, Centres were given the responsibility to develop sector strategies engaging potential users of genomics research in forestry, aquaculture/fisheries, energy/mining and agriculture.¹⁴

As explained by interviewees in different regions, this process efficiently identified priorities, as it was supervised by the Centres familiar with regional needs, and brought together a wide range of stakeholders from industry, academia and the public sector. Indeed, participatory models involving broad consultation was found to be in line with international best practices; all organizations examined in the international review, undertaken for this review, developed their research and funding strategies following such an approach, where many stakeholder voices were heard and incorporated. Survey evidence was also positive on this point. Two-thirds of PI and GE³LS researchers considered the approach used by Genome Canada in identifying and focusing on high-priority strategic research themes effective; three-quarters of ‘other stakeholders’¹⁵ surveyed indicated the selected sectors were high-priority.

Further confirmation of these findings comes from the bibliometric analysis, which examined growth trends in a broad range of research areas in genomics: the growth of certain scientific subfields in Canada was plotted against that at the world level to determine areas where there may be a strategic match. It was found that Canada’s growth was usually well-aligned with trends at the world level. Subfields that already complement Genome Canada’s strategic areas and in which stronger growth could be beneficial to Canada’s performance included biomedical engineering, agricultural economics and policy, fisheries, dairy science, sport sciences and forestry.

This analysis also identified a few subfields outside the current suite of Genome Canada strategic areas where stronger growth would be beneficial to Canada’s performance, in particular statistics and probability, and networking and telecommunications (the latter being linked to computational genomics and bioinformatics). This suggests an ongoing need for more bioinformatics research and development (R&D) in light of other evidence from case studies and interviews, which indicated that managing and processing ‘big data’ emerging from genomics research remains an important challenge, particularly outside the health sector. As discussed elsewhere in this report, Genome Canada has collaborated with national granting agencies in recent years to begin to address such issues.

In addition, the bibliometric analysis showed that, in the absence of Genome Canada, Canada’s output would likely have dropped in at least two strategic areas:

- Agricultural Genomics: Canada would have dropped from 11th to 13th place in terms of output size in the field, overtaken by Australia and the Republic of Korea.
- Environmental Genomics: Canada would have dropped from 7th to 11th place in terms of output size in the field, overtaken by Spain, Australia, Brazil and Italy, and almost by India.

¹⁴ Genome Canada. (2012). *Genome Centre Base Funding Renewal*. Report of the External Panel. March 11, 2012.

¹⁵ Included collaborators, partners, current and potential end-users and other unclassified stakeholders.

In other words, as international competition is already strong and growing, minor slips such as the above would have meant a loss of advantage for Canada and would have made it more difficult for Canada to catch up with time.

Just prior to, and in line with the new Strategic Plan, Genome Canada also began to fund projects with a high potential for translation into practical applications. This was clearly reflected in the eight case studies (selected from two Competitions launched shortly prior to the strategic planning process), which were generally well-aligned with the Plan's main objectives, especially to accelerate translation, to attract investment from a wider range of stakeholders, and to enhance GE³LS opportunities. Similarly, while all of the cases began before the Genome Canada sector strategies were officially launched, it is clear that each case was in fact well-aligned with key priorities outlined for each sector.

Need for a separate organization to support genomics research in Canada

Documentary evidence show that national support for genomics research programs helps build national capacity, can help establish/maintain competitiveness in strategic areas, and position a country internationally. Whether or not this support comes from a separate organization often depends on the individual country context (e.g., its size, goals, and strengths in genomics infrastructure or expertise), as confirmed by international interviewees. For example, one centralized genomics program within the Research Council of Norway addresses the needs of this country's small and well-knit scientific research community. In contrast, the US National Human Genome Research Institute is a semi-autonomous body of the National Institutes of Health, and funding calls or grant administration often happens collaboratively between the two. In the UK, the government provides funding to several different research councils to support genomics research. These models may reflect the wide variety of stakeholders and research players, the larger population, and the well-established genomics communities in the US or UK.

In contrast, given the modest size and broad regional distribution of the research community in Canada, the establishment of a separate organization to fund large-scale genomics projects was seen by interviewees to have helped develop specific regional and sector expertise. As supported by the findings in the remainder of this report, Genome Canada is generally seen to have the capacity and expertise to work within the Canadian innovation system in order to make demonstrable progress in achieving its expected outcomes. Overall, the evidence shows that Genome Canada is well-positioned to address the need to support and enhance genomics research in the Canadian context.

Furthermore, no evidence was found that Genome Canada should fundamentally revisit its current design and delivery model. Generally, interviewees and survey respondents were supportive of Genome Canada's mandate to dedicate funding specifically to genomics research in the form of large-scale projects. These features (i.e., dedicated funding and focus on large-scale projects) were in fact considered by surveyed researchers as the organization's best features, contributing to international competitiveness and visibility.

Long-term sustainability

With a view to ensure long-term sustainability, Genome Canada committed in its 2012 Federal Ask to “leverage federal funds to a greater degree”¹⁶ with a 1:2 ratio instead of a 1:1 ratio. To achieve this goal, Genome Canada requested and secured multi-year funding from the federal government, which is expected to position the organization as a “credible partner for those who wish to invest with [them].”¹⁷ Genome Centres are also reportedly much more engaged with companies, associations and not-for-profits than they were a decade ago, while Genome Canada has established stronger partnerships with granting agencies. A few interviewees expressed concerns that Genome Canada may not be adequately equipped to successfully reach out to private partners and is likely to remain highly dependent on public funders (i.e., Industry Canada), as will be discussed in the next section. In the same vein, some interviewees noted that long-term genomics support is required to maintain ‘momentum’ in certain sectors and increase capacity, coordination and awareness-building for GE³LS.

3.2 Extent to which Genome Canada has contributed to enhanced support and capacity for genomics research

The evaluation evidence generally indicates that Genome Canada has directly contributed to enhanced support and capacity for genomics research through its funding programs, and through the development and implementation of a coordinated national strategy. This section also discusses Genome Canada’s overall positive contribution to enhancing Canada’s international profile and visibility in genomics, and to attracting additional investments to support genomic research. However, there is evidence that the communication of relative risks, rewards and long-term impacts of genomics presents room for improvement.

Support and capacity for genomics research: overall and in strategic sectors

As noted in the previous section, informed opinions collected in the interviews, the bibliometric analysis, and surveys all indicated that Genome Canada’s process to identify high-priority strategic research areas was effective. Key evidence to measure the extent to which Genome Canada has enhanced support and capacity for genomics research, overall and in its strategic sectors, also comes from the bibliometric analyses. Described in detail below, the analyses examined the effect of Genome Canada on:

- the genomics research output, impact and focus of funded PIs, and
- Canada’s specialization and impact trends in genomics in general and within strategic areas.

Genomics output, scientific impact and focus of funded researchers: Genome Canada has contributed to increasing the output of funded researchers. Indeed, bibliometrics shows that the number of peer-reviewed papers produced by PIs increased significantly with Genome Canada funding. In comparison, PIs who applied but were not awarded funding and who had not been

¹⁶ Genome Canada. (2012). *The Way Forward*. Submission to Industry Canada, 2013 Federal Budget.

¹⁷ Ibid.

previously funded by Genome Canada also significantly increased their scientific production, but it was to a significantly smaller extent than funded PIs.

Furthermore, the scientific impact (i.e., citations to papers, proportion of papers in the 10% most cited) of the supported researchers increased significantly with Genome Canada funding, whereas the impact of unsuccessful applicants did not increase significantly over the same timeframe.

Genome Canada has also contributed to increasing the focus¹⁸ of funded PIs' research activities on genomics overall and in three of the Genome Canada's targeted sectors, namely Environment, Fisheries and Health (Table 2). Note that in the health sector and for genomics overall, this finding only applies to PIs who were not previously funded by Genome Canada (PI-NPF). More specifically, the share of PI output (calculated as the proportion of their peer-reviewed papers in genomics or in a given sector) increased significantly in these three sectors after PIs were supported (i.e., 'supported' period; S) by Genome Canada under Competition III¹⁹ compared to before (i.e., 'not supported' period; NS). It also appears to have increased in the remaining sectors, although the statistical tests were not significant, possibly due to the small population sizes.

Table 2 Number and share of PI peer-reviewed genomic papers in the targeted sectors before and after application to Competition III

Sector	Group	N		Share		p-value
		NS	S	NS	S	
Agriculture	NPF/PF	46	62	35%	44%	0.18
Environment	NPF/PF	36	68	47%	76%	0.00*
Fisheries	NPF/PF	61	103	18%	52%	0.00*
Forestry	NPF/PF	76	95	50%	56%	0.23
GE ³ LS	NPF/PF	75	122	24%	28%	0.27
Health	NPF	520	709	25%	31%	0.02*
	PF	631	788	37%	38%	0.32

Notes:

- **Period:** NS = Not supported (before Competition III); S = Supported (after Competition III).
- **Groups:** NPF = Not previously funded by Genome Canada; PF = Previously funded by Genome Canada. NPF and PF were grouped for the analysis of sectors other than Health because of the small population size.
- * = statistically significant.

Source: Computed by Science-Matrix using Genome Canada and Web of Science (Thomson Reuters) data.

Specialization and scientific impact of Canada in genomics: Despite the above, there was no increase of Canada's specialization index (SI) in genomics. The SI is an indicator that determines whether Canada's research intensity in genomics (i.e., the percentage of total scientific output in this field) is greater or less than the corresponding percentage at world level. An SI greater than 1 means that Canada is more specialized in genomics than the world average, while an SI below 1 means the reverse. In fact, Canada's SI remains almost unchanged since 1996 (Figure 2, horizontal axis). This contrasts the results for China and the Republic of Korea—two upcoming global players

¹⁸ The term 'focus' describes what share of a researcher's entire oeuvre of publications is in a given area e.g. genomics.

¹⁹ In July 2004, Genome Canada launched this Competition to support world-leading genomics and proteomics research. Results were announced in August 2005 and \$346 million was invested in 33 projects for duration of three to four years. For further detail see: <http://www.genomecanada.ca/en/portfolio/research/competition3.aspx>

in many scientific areas—that have both become more specialized in genomics (i.e., increased their SI). Nonetheless, in light of world trends noted in the previous section, it is likely that without Genome Canada support, Canada would have lost ground in this respect, rather than maintained its position.

In contrast, Canada’s scientific impact in genomics has increased over the past 16 years (Figure 2, vertical axis, based on the average of relative citations [ARC]). Moreover, Canada’s peer-reviewed papers in genomics had one of the highest scientific impact scores among the countries with the greatest number of publications in this field (UK, US, Germany, France), ranking third between 1996 and 2007 and fourth in 2008-11. As the gains were most pronounced in the periods following the creation of Genome Canada, especially from 2008 to 2011, it is likely that the increase in Canada’s overall scientific impact in genomics is at least partly attributable to the organization.

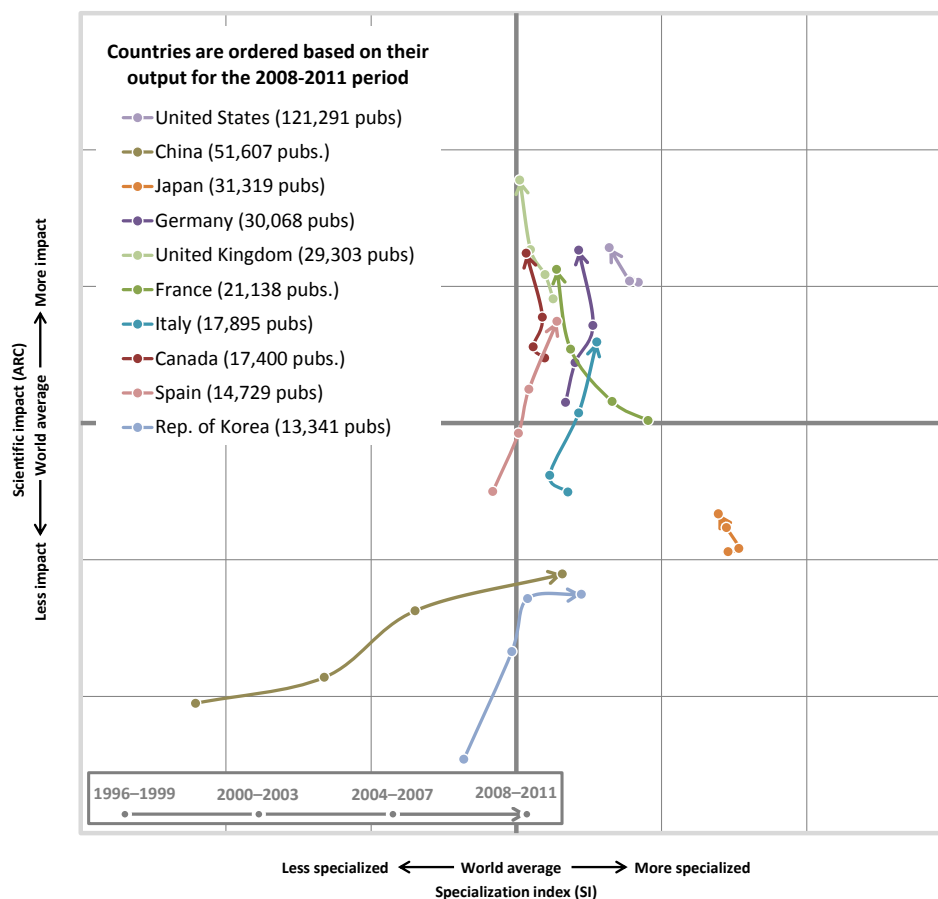


Figure 2 Specialization and scientific impact trends in genomics, 1996 to 2011

Note: The ten most publishing countries in genomics were selected based on the size of their production in the most recent four-year period (i.e., 2008-2011).

Source: Computed by Science-Metrix using Web of Science (Thomson Reuters) data.

It is also worth noting that a sector-specific analysis shows that over time, Canada’s SI actually decreased in the two areas it is most specialized: Fisheries and Forestry. This is because the concentration of the world’s output in these areas has been increasing while Canada’s has remained stable. At the same time, in GE³LS, Canada’s SI has increased markedly since the creation of

Genome Canada; please see also Section 3.4 for a more detailed bibliometric analysis of Genome Canada's contribution to GE³LS research. This also supports an ongoing need for Genome Canada, which should continue to focus in these areas to maintain the country's position among global players.

Increasing coordination among the national and international parties

All lines of evidence confirm there has been increased collaboration between Genome Canada and a variety of other national and international parties during the evaluation period. Examples of collaboration with national granting agencies, primarily via joint competitions and initiatives, include partnerships with CIHR, CFI, and NSERC, to advance bioinformatics, large-scale applied research and 'big data' science. Collaboration with end users such as academia, industry and not-for-profits, has been a target of the recently implemented Genomic Applications Partnership Program (GAPP). International collaboration has been enhanced through Genome Canada participation in initiatives (e.g., International Barcode of Life Consortium, the Structural Genomics Consortium, the International Knockout Mouse Consortium and the Public Population Project in Genomics). Increased coordination was also observed by interviewees in particular, between Genome Canada and the Centres in developing the coordinated sector strategies.

Box 1 Coordination improved over time (survey results)

Comparing the PI survey population from the 2009 evaluation to present, there is a trend towards more positive responses overall.

For example, 46% of PIs reported the international coordination effort was effective in the 2009 survey while 67% of PIs agreed or strongly agreed that Genome Canada contributed to coordination of the international effort in 2013.

In the current survey, 75% of PIs believed the genomics research effort would not have been well-coordinated in the absence of Genome Canada. This proportion was around 50% in the 2009 survey.

Survey evidence was similarly supportive; combining all surveyed groups, more than half of the respondents (52% to 65% depending on the group) reported that the Canadian genomics research effort was overall well-coordinated during the 2008-2013 period. Additionally, a large majority (67% of co-PIs, 75% of PIs, 83% GE³LS researchers) said that Genome Canada helped increase coordination among Canadian researchers, while less than 10% of survey respondents believed the genomics research effort would have been well-coordinated in the absence of Genome Canada.

More than half of survey respondents across all groups said that Genome Canada contributed to increasing the coordination of Canadian research with the international genomics research effort. Genome Canada also contributed to increasing coordination between Canadian researchers and end-users/receptors of research results, according to 48% of the 'other stakeholders' group.²⁰ Box 1 provides further survey evidence that coordination has improved over time.

Bibliometric analysis of the national and international collaboration rates (calculated based on co-authorship of peer-reviewed papers) before and after Competition III provides more nuanced information with regard to Genome Canada's role in increasing collaboration in genomics research.

²⁰ Included collaborators, partners, current and potential end-users and other unclassified stakeholders.

PIs who received funding in Competition III increased their national collaboration rates, and in the case of PIs who had not been funded in previous competitions (PI-NPF), in their international collaboration rates as well (Table 3). PIs also had higher national collaboration rates than the overall Canadian average in genomics both before and after Competition III. Moreover, the end of Genome Canada funding was associated with a drop in the national collaboration rate of previously funded PIs. Overall, these findings confirm that a partial effect of Genome Canada funding in terms of recognizing and fostering collaboration is likely, especially for national collaboration.

The evolution of collaborative behaviour of the 500 most-published Canadian researchers in genomics²¹ was also examined using social network analyses. As shown in more detail below, these analyses show that researchers funded by Genome Canada become more ‘central’ to the collaboration network of Canadian researchers.

Table 3 National and international collaboration rates before and after Competition III

Group	N		Natl. coll. rate				Intl. coll. Rate			
	NS	S	NS	S	Δ (in % points)		NS	S	Δ (in % points)	
					p-value	p-value				
PI-NPF	651	912	50%	56%	7	0.00*	41%	55%	14	0.00*
PI-PF	851	1,111	51%	63%	12	0.00*	45%	48%	3	0.13
UNPI-NPF	1,060	1,381	38%	49%	12	0.00*	35%	46%	11	0.00*
UNPI-PF	508	533	57%	49%	-8	1.00	37%	51%	14	0.00*
Canada[‡]	13,737	17,400	31%	34%	3	0.00*	46%	52%	6	0.00*

Notes:

- NS = Not supported (before Competition III); S = Supported (after Competition III). For Canada, NS = 2002-2005 and S = 2008-2011.
- PI = Successful principal investigator applicants; UNPI = Unsuccessful applicants with a PI role in the proposal (control group); NPF = Not previously funded by Genome Canada; PF = Previously funded by Genome Canada.
- * = statistically significant.
- ‡ Canada refers to all Canadian papers in the genomic dataset.

Source: Computed by Science-Metrix using Genome Canada and Web of Science (Thomson Reuters) data.

In the social network analyses, these 500 researchers were grouped under three categories: PIs funded by Genome Canada, co-PIs on Genome Canada-funded projects, and researchers who were never funded by Genome Canada.²² Note that this assessment of ‘centrality’ is based on the average number of co-authors in the collaboration network of genomics researchers in Canada, but other measures generally confirm these findings.²³

²¹ These 500 researchers were selected based on their total production in genomics from 1998 to 2011.

²² Number of PIs, co-PIs, and Never Funded by Genome Canada = 52, 62, 342 respectively. Note that PIs and co-PIs only funded in later competitions (i.e., after 2006) were not included in this analysis.

²³ For example, the average betweenness centrality (a measure of how often a scientist is on the shortest paths between any two pair of scientists in the collaboration network) is much larger for PIs than scientists that were never funded by Genome Canada. Other measures help describe the fact that PIs and co-PIs are scattered throughout almost every region of the collaboration network, with only a handful of groups (clusters) not being represented by Genome Canada-funded scientists.

- Prior to the creation of Genome Canada (1999-2002), PIs that were eventually funded were already more central players in the collaboration network, with an average of 4.7 distinct co-authors within the network. Alternatively, co-PIs had an average of 3.7 co-authors, comparable to unfunded researchers (2.4).
- From 2004 to 2007, when an effect of Genome Canada's first competitions could be expected, the number of co-authors increased by a much larger margin for PIs (86%, to 8.7) than for co-PIs (50%, to 5.5). In turn, the co-PI score also increased by a much larger fraction than that of unfunded researchers (22%, to 3.0).
- From 2008-2011, PIs maintained their gains despite a small drop of 10% (to 7.8), while both co-PIs and unfunded researchers had a small drop (4% and 6%, respectively). This relative stability is not surprising as many of the PIs and co-PIs continued to receive Genome Canada funding in subsequent competitions.

Enhancing Canada's international profile and visibility in genomics research

The previous sections strongly support the conclusion that Genome Canada has had a positive influence on Canada's international profile and visibility in genomics research through the high-impact collaborative work funded in the context of large-scale projects and international consortia.

Indeed, international interviewees and documents confirm that Canada performs quality research in health, conducting internationally recognized work on autism, cancer stem cells and rare diseases. Canada's leadership in genomics has also increased significantly over the last few years according to survey results. Over 80% of PIs reported that Genome Canada helped the country become a world leader in genomics research, generally (this number was 65% for co-PIs) and in their specific area; note that this assessment was somewhat more muted in the case of co-PIs (about 65% of co-PIs agreed for genomics research generally, 60% for co-PIs).

In fact, while Canada's leadership in genomics (and other -omics) remains modest compared with larger countries such as the US and UK, international interviewees confirmed that Canada produces renowned scientists in cancer research, and is considered a leader in some areas of forestry and fisheries genomics. Canada is also internationally recognized as pivotal in coordinating disparate groups working in similar areas of genomics. Specifically, Genome Canada is reputed to be a neutral broker, bringing together different people and ensuring that similar global projects are coordinated appropriately (e.g., International Bovine Sequencing Project, International Cancer Genome Consortium and the International Barcode of Life).

A number of studies have also placed Canada within the top ten countries for genomics research and public funding allocated to genomics.^{24,25} As shown earlier, this was confirmed by bibliometric analyses conducted for this evaluation, which showed that without Genome Canada, Canada would likely have lost ranking among the most publishing countries overall in genomics (Figure 1). Moreover, Canada's impact in genomics increased over the last 16 years and it ranks within the top

²⁴ Science-Metrix (2008). *Benchmarking of Canadian Genomics-1996-2007*. Report to Genome Canada.

²⁵ Reineke Pohlhaus, J., Cook-Deegan, M. "Genomics Research: World Survey of Public Funding" *BMC Genomics* 9 (2008):472.

five countries based on output (Figure 2). This supports that suggestion that Canada has remained a world leader in genomics in an increasingly competitive landscape, in part because of Genome Canada.

Communicating the relative risks, rewards and long-term impact of genomics

During the period covered by this evaluation, Genome Canada participated in various activities to communicate the value of genomics to its stakeholders (e.g., international and national conferences on the human genome, biotechnology and science policy issues; a series of events on GE³LS; a Health Summit organized with Genome Québec; youth education initiatives, exhibitions, etc.).²⁶ Nonetheless, there was a wide consensus among internal and external stakeholders that further efforts must be made to educate policy-makers, industry and the general public on the benefits of genomic research. This was clearly confirmed by the survey evidence:

- Less than 20% of GE³LS researchers and ‘other stakeholders’²⁷ surveyed considered that Genome Canada had effectively communicated the relative risks of genomics to its external stakeholders. An even smaller proportion—less than 7%—thought that Genome Canada had effectively communicated the relative risks of genomics to the general public.
- A slightly higher proportion considered that the rewards of genomics (benefits, long-term impacts) were effectively communicated by Genome Canada to external stakeholders (38% GE³LS and 30% ‘other stakeholders’) and the public (22% GE³LS, <10% ‘other stakeholders’).
- The proportion of respondents who could not answer the questions (i.e., selected “don’t know/not applicable”) was relatively high; about a third regarding communication of risks and more than a third regarding communication of rewards. As these respondents were not adequately informed enough to provide answers to the questions, this speaks again to the need for more effective communication.

It is also worth noting responses to a survey with MPs, senior policy analysts and decision makers commissioned by Genome Canada at the end of 2012.²⁸ Participants tended to say consistently that Genome Canada needed to reach out and engage more broadly. There was a desire to hear more about research outcomes and successes, including products that had been developed and commercialized. Almost half of the participants in this survey (44%) reported that they were not adequately informed on the importance of the field of genomics.

Suggestions from the surveys and interviews to improve communication included simplified language, increased transparency, and increased use of both traditional and social media outlets. It was also noted that Genome Canada must proactively promote its successes in genomics especially towards key influencers and receptors/end-users (e.g., via industry conferences and online presence). Finally, Genome Canada could leverage the in-house expertise of communication leaders

²⁶ Genome Canada Annual Reports (2010 to 2013).

²⁷ Included collaborators, partners, current and potential end-users and other unclassified stakeholders.

²⁸ Earncliffe Strategy Group. (2013). *Audit of Elite Opinion Ottawa*. For: Genome Canada (January 2013).

in Genome Canada, the Centres and Board of Directors to develop a much-needed national communication strategy in collaboration with the Genome Centres.

Extent to which Genome Canada's investment has been matched by additional resources

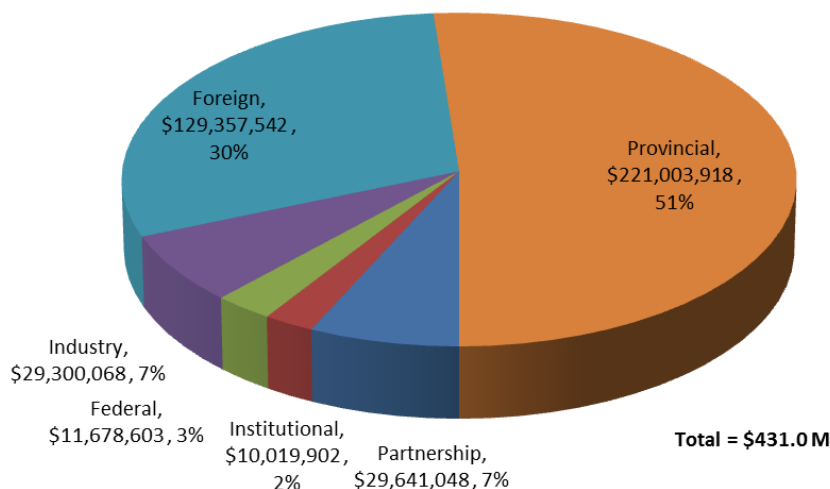
An analysis of project co-funding data indicates that \$431 million was secured from external sources over the 2009-2013 period, exceeding Genome Canada's contribution of \$306 million to these projects.²⁹ As such, the 50% matching requirement (as per the funding agreements with Industry Canada) has been exceeded at 58%.

Since 2000, the health sector has provided the most co-funding (63% of total), followed by the agriculture (10%) and environment (5%) sectors. In addition, 7% of total co-funding is used by Genome Centres to support their operations.

Project co-funding comes primarily from provincial (51%) and foreign partners (30%), while industry accounts for 7% of total external funding (Figure 3). There has been considerable variability in last five years in the amounts and proportion of co-funding provided by different sources. Compared to 2000-2008, more funding was obtained from provincial sources during the 2009-2013 period (29% vs. 51%). Meanwhile, the percentage obtained from industry decreased from 16% to 7%, the percentage from federal sources dropped from 12% to 3% and the percentage from institutional sources dropped from 8% to 2%. Note that these changes also reflect the addition of a new "Partnership" category, which represents 7% of the co-funding provided.

It is important to note that, with the addition of this new category and the large influx of provincial co-funding, the decreased share of industrial, federal and institutional co-funding should not be interpreted as evidence of disengagement of these types of funders. Rather, these trends show that the contribution from these sources has not kept up with provincial funding, and points to an opportunity to attract further investment from these sources in the future. For example, co-funding from industry is expected to increase in the coming years with the recently launched GAPP program, which focuses on industry partnerships.

²⁹ Co-funding information was provided in aggregate form for 2000-2013. Co-funding amounts covering 2000-2008 (as presented in the 2009 evaluation) were subtracted to obtain co-funding information for 2009-2013.



*As of November 26, 2013

Figure 3 Co-funding by source, 2009 to 2013

Note: Sub-categories of industry and foreign sources were combined to allow for a comparison with data from the 2009 evaluation.
Source: Genome Canada. (2013). *Financial Data* (as of November 26, 2013)

Some anecdotal evidence of additional leveraging (e.g., additional research grants on top of allocated co-funding amounts) also exists for some of the projects examined in the case studies, although amounts were difficult to quantify as direct project leveraging is not systematically reported. It is also interesting to note that Canada’s approach to co-funding is most similar to that of Norway, and that Canada and Norway focus on all of the same priority sectors (Box 2).

Despite exceeding the required 1:1 ratio, it appears that, moving forward, there is an urgent need for Genome Canada to increase investment in genomics from both the private and government sectors. For example, Genome Canada recently committed to “leverage federal funds to a greater degree” aiming for a 1:2 ratio.³⁰ Progress in this regard has already been observed; a 1:2 ratio was achieved in the case of the 2012 Large-Scale Project Program, and even higher co-funding ratios were seen in the case of international consortium initiatives and the Cancer Stem Cell Consortium. In fact, all new Genome Canada programs launched since 2012 have together achieved a total co-funding ratio of

Box 2 International perspectives

Research focus: Organizations in China and Norway emphasize applied research, while those in France, the UK and the US maintain a mix of applied and fundamental research. In terms of priority sectors, Genome Canada and Norway target all of the same areas. Health is the only sector targeted by all of the organizations examined.

Delivery model: Large-scale projects with national collaboration are conducted by all the organizations examined. International linkages were more important in the Norway and the UK, than for the others. Organizations in Canada and Norway are the only ones requiring project co-funding.

³⁰ Genome Canada. (2012). *The Way Forward*. Submission to Industry Canada, 2013 Federal Budget

1:2.1.³¹ However, to continue to achieve this level of co-funding, interviewees indicated that partnerships must be strengthened in emerging sectors such as energy, as well as in areas where genomics research capacity is not as well-developed, such as forestry. Successful examples in more established sectors, such as agriculture or health, could be used as models (e.g., Genome Alberta partnerships with the Alberta Livestock and Meat Agency and Alberta Innovates).

Additionally, given that most leveraged funding comes from public sources, some interviewees and case study participants were concerned that partnerships with industry may represent an underutilized resource. To this end, Genome Canada could continue to engage in public-private partnerships such as the Structural Genomics Consortium where it makes sense.³²

Finally, various lines of evidence highlight the fact that increasing external investment also presents challenges and point to possible means to address these challenges:

- A few interviewees doubted that Genome Canada has sufficient in-house expertise to make the bridge with industry or private partners. As such, some suggested that Genome Canada bring in additional expertise in business development and venture capital.
- Despite growing provincial support, there were indications that not all provinces are equally engaged with their respective Centres. To this end, the 2012 Centre Renewal Review recommended that Genome Canada and the Centres urge “all provinces that are not currently contributing adequately to the operational costs of the Centres to begin to do so.”³³ This would allow the Centres to better coordinate regional activities and represent provincial priorities.

3.3 Extent to which Genome Canada has contributed to Canada’s HQP in genomics

The evaluation evidence clearly supports the finding that Genome Canada has directly contributed to building genomics capacity in Canada. Indeed, over three-quarters of surveyed researchers across all groups (80%) reported that Genome Canada’s support contributed to the attraction and retention of HQP in genomics. Moreover, within the eight projects examined in the case studies, over 260 students from all levels (undergraduate to doctoral) and postdoctoral fellows participated in funded projects, ranging from 15 to upwards of 60 students per project³⁴.

Students benefited from their research experience both during and after working with Genome Canada-funded researchers. These findings are supported by case study and survey evidence,

³¹ Genome Canada. (2014). *Genome Canada; Advancing Genomics to Strengthen Canada’s Bioeconomy*.

³² This consortium brings together public and private organizations to develop new genomics tools and structures. An independent evaluation of the consortium conducted by the RAND Corporation found that private funding helps maintain industrial quality and reproducible science, while public support plays a fundamental role to maintain open access. Thus it is important to keep a balance of both public and private funding in order to contribute to innovation and spill over benefits.

³³ Genome Canada. (2012). *Genome Centre Base Funding Renewal*. Report of the External Panel. March 11, 2012.

³⁴ Genome Canada’s new National Performance Metric Database will collect data on a number of key performance indicators including Highly Qualified Personnel

including opinions from 153 HQP involved in Competition III projects. Surveyed researchers and HQP agree that, while involved in large-scale genomics projects, HQP received high quality training in research, and gained valuable skills and experience (Table 4). They also benefited from opportunities relating to multi-stakeholder project management and governance, industry relations, and GE³LS. In particular, HQP frequently reported having benefited from increased networking opportunities, notably through participation in genomics conferences, colloquia and seminars, as well as collaborations with national and international colleagues. Other benefits of participating in Genome Canada projects included access to advanced technologies, equipment or infrastructure, as well as a direct contribution to the student's degree.

Table 4 HQP research-related benefits most frequently cited by surveyed researchers and HQP

	PIs	co-PIs	HQP
HQP gained research experience (knowledge and skills)	86%	78%	
research and analytical skills			88%
additional 'soft' skills			79%
technical and computer skills			78%
skills related to GE ³ LS			32%
Increased networking opportunities	75%	70%	65%
Direct contribution to their degree	80%	65%	55%

Note: Survey respondents: PI N = 52; co-PI N = 135; HQP N = 150
Source: Surveys of PIs, co-PIs and HQP

Subsequent to their work on Genome Canada-funded projects, many HQP were offered academic opportunities or research positions (e.g., as professors, researchers, or postdoctoral fellows; Table 5). The vast majority of the 'other stakeholders' surveyed³⁵ offered employment opportunities to HQP. Over three-quarters of these stakeholders reported that HQP were offered research positions within their organization while 20% of stakeholders hired HQP as an independent contractor/consultant.

Table 5 Career path of HQP involved in Genome Canada-funded projects

HQP...	PIs	co-PIs	HQP
Were offered a research position			
within the PI's research team	65%	40%	
within another research team	63%	44%	
Were offered a subsequent academic opportunity	63%	52%	
Pursued a career unrelated to research	25%	14%	
Are currently working full-time or part-time			87%
academic sector			71%
government sector			14%
not-for-profit			8%
private sector			6%
current job position is based in Canada			74%
Currently in academic training			10%
Changed job position since involvement in GC-supported projects			65%

Note: Survey respondents: PI N = 52; co-PI N = 135; HQP N = 150
Source: Survey of PIs, co-PIs and HQP

³⁵ Includes collaborators, partners, current and potential end-users and other unclassified stakeholders.

A large majority of surveyed HQP reported an increase in salary and working conditions (86%) since their involvement in Genome Canada-supported projects, and over two-thirds attributed these changes to Genome Canada (Figure 4). Interestingly, over two-thirds of surveyed HQP reported that their current position required experience and expertise in genomics to a large or great extent; building on this finding, 88% of stakeholders indicated that the HQP’s experience (knowledge and skills) influenced their organizations’ decision to employ HQP who had participated in Genome Canada-funded project.

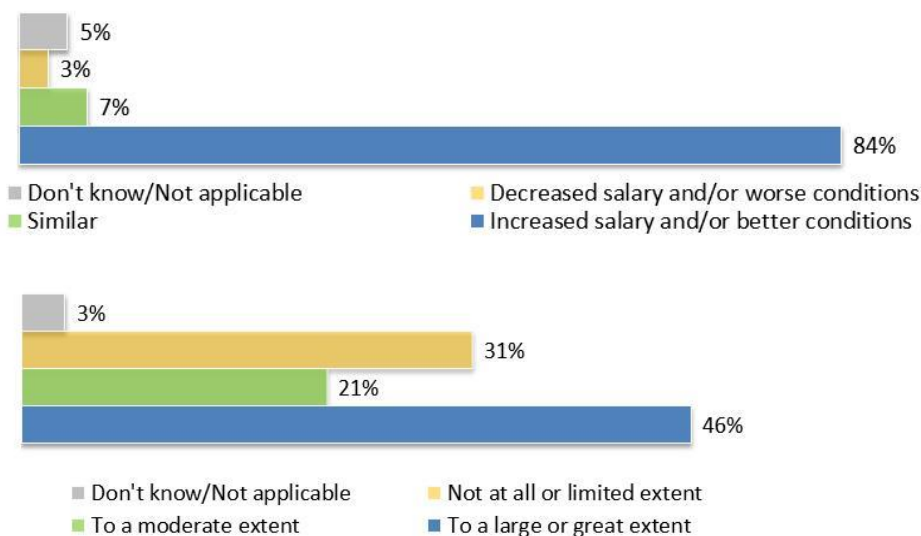


Figure 4 Changes in HQP salary and/or working conditions (top) and extent to which these changes were due to HQP involvement in Genome Canada-supported projects (bottom)

Note: Survey respondents: N = 150
Source: Survey of HQP

Case study evidence indicates that several HQP also moved on to positions in the private (e.g., pharmaceutical) and government sectors (e.g., provincial policy work, NRCan’s Canadian Forest Service). For instance, HQP involved in the Atlantic Cod Genomics and Broodstock Development project are now in charge of fish breeding programs and microarray work for several Canadian universities. HQP involved in the Environmental Barcoding project were offered positions in China, France and Brazil working on the umbrella iBOL project.³⁶ Thus, Genome Canada can be said to have contributed to the career advancement of many HQP involved in supported projects, which constitutes an indirect socio-economic impact, as will be discussed further in Section 4.5.

³⁶ The International Barcode of Life (iBOL) project, is the largest biodiversity genomics initiative ever undertaken, aimed at assembling 5 million DNA barcodes representing 500,000 species by 2015.

3.4 Extent to which Genome Canada has contributed to increasing the breadth and depth of knowledge in genomics (including GE³LS)

The breadth and depth of genomics research, including GE³LS research, has indeed been expanded through work supported by Genome Canada. As discussed in Section 3.2, the organization clearly contributed to increasing scientific outputs, scientific impact, and collaboration, all of which contributes to this outcome. However, while findings point to actual and potential discoveries resulting from funded projects, it is too early to conclude that funded research has fully transformed the wider genomics scientific community. In addition, there remains room for improvement regarding the translation of research into practical applications, and better integration of GE³LS into projects.

Transformative research

In the context of the present evaluation, ‘transformative research’ was generally understood as research that:

- enabled new questions to be asked or old questions to be addressed using genomics (enabled long standing puzzle to be solved);
- led to shifts in research paradigms;
- changed ways to conduct research;
- resulted in unanticipated/unexpected discovery that could lead to new theories or discard old theories; and/or
- introduced new disciplines or multidisciplinary research not considered before.

Findings from the survey, case studies, and the management delivery review point to the production of research that led to significant discoveries in health genomics and other strategic areas. A large majority of survey respondents across groups reported that various ‘transformative effects’ resulted from the research supported by Genome Canada; some specific examples are described in Box 3. The survey and case studies provided multiple examples of genomics projects supported by Genome Canada that enabled new questions to be asked or old questions to be addressed in ways not possible before (77% of PIs, 53% of co-PIs, 50 of GE³LS researchers), such as by developing new methods or tools. Notable examples include work on gene discovery (e.g., rare diseases, cancer, autism), genome sequencing (e.g., salmon, conifer) and identification of important plant and animal traits (e.g., disease resistance, environmental adaptation). To a slightly lesser extent, survey respondents also indicated that funded research led to the creation of new datasets (50% of GE³LS respondents, 80% of co-PIs, 85% of PIs), and shifts in research paradigms (54% co-PIs, 57% GE³LS, 73% PIs). Meanwhile, 80% of GE³LS researchers also reported that Genome Canada-funded projects introduced new disciplines or multidisciplinary research that was previously not considered.

However, case study evidence indicates that one must be careful in concluding from the above findings that Genome Canada has been very effective in generating transformative research. Projects examined did produce new genetic mechanisms for plant/animal disease resistance, innovative genetic tools, methods and techniques with a variety of applications and sequencing of large parts of the genomes of organisms with commercial value (e.g., salmon, cod, canola).

However, most projects have not yet achieved their full potential for transformation. In some cases, projects are too early in their lifecycle to account for such achievements; in others, it may simply be due to the immaturity of genomics research or that no strong evidence was found that research conducted will generate significant transformations in the wider scientific community. Note that the uptake by other communities (e.g., industry, policy sector) is discussed in a later section on research translation.

International interviewees also identified factors that contribute to the achievement of transformative research, such as: attracting the best researchers in the field through the provision of individual grants (e.g., ‘head-hunting’); early open access to data; international collaborations; and balanced funding to large and smaller-scale projects.

Leadership in GE³LS

The evaluation found that Canada has become a world leader in the field of GE³LS research. Survey, case study and interview evidence confirms that Genome Canada contributed to reinforcing Canada’s position as a leader in the field. For instance, nearly 80% of GE³LS researchers reported that Genome Canada has effectively increased the quantity of GE³LS research in Canada, while 60% agreed it has increased its quality. Additionally, PIs (52%) and co-PIs (35%) reported a higher standing of Canada in GE³LS research in 2008-2013 compared to 2002-2007 (21% for PIs, 15% for co-PIs), and the proportion of PIs who attributed this standing to Genome Canada is higher in 2013 than in 2009 (55% vs. 33%).

Moreover, bibliometric data shows that Canada ranks third in the production of GE³LS peer-reviewed papers worldwide and is one of the few leading countries in genome research that specializes in this area.

Furthermore, while this area grew importantly both in Canada and worldwide from 1981 to 2011, Canada’s growth was slightly faster than the world’s growth since Genome Canada’s creation (data not shown); this points to a possible direct contribution of Genome Canada to this growth. Additionally, the production of GE³LS papers by PIs supported by Genome Canada increased significantly after they received Genome Canada funding. Note that bibliometric data may not fully capture the range of GE³LS outputs (e.g., books, grey literature, peer-reviewed literature not

Box 3 Examples of transformative research funded by GC

As part of initiatives that operate a major shift from disease-oriented to personalized medicine, research on arrhythmogenic right ventricular cardiomyopathy (ARVC) led to the discovery of the gene responsible for this rare heart disease that has caused the premature death of many healthy middle-aged men in Newfoundland. As a result of this discovery, a diagnostic tool was developed to identify and treat patients at risk of being affected by the disease. In this way, more than 100 lives have already been saved in the past few years.

The Aborea-II project aimed at identifying specific genes associated with growth and wood quality and developing tools and protocols to select well adapted high-performance spruce trees with better-quality woods. As part of this project, a new approach to genomic tree selection was developed, which is deemed much more promising than the previous approach based on association studies in terms of application for the forest industry. This work will contribute to promote the competitiveness of the Canadian forest industry by shortening the time it takes to select and breed trees with desired traits.

As a component of the iBOL project, the Environmental barcoding through massively parallelized sequencing project developed a technology to sequence and analyze genetic information of biota in bulk environmental samples as opposed to single specimen analysis. This represents a significant shift in the type and amount of information gathered and can be used for monitoring variations in species that indicate the overall health of an ecosystem, such as aquatic insects. It is a much more effective method than simplistic measurements of physical and chemical variations in natural habitats, which lack sensitivity and specificity required to accurately predict ecosystem change.

covered in main bibliographic databases), such that further studies could help provide a more comprehensive analysis of the evolution of Canadian leadership in this area. Also noteworthy, bibliometric analyses of the social sciences could underestimate the production of non-English speaking countries and it is therefore not impossible that other countries would rank better if we had more extensive bibliographic databases than those currently available.

Despite the above findings, there appears to be a difference of opinions among stakeholders on the most effective model to support GE³LS research in Canada in the future. On the one hand, many national and international stakeholders are highly supportive of Genome Canada's unique approach of embedding GE³LS research into all large-scale projects. Examples of benefits of using such an approach that were highlighted by interviewees and survey respondents include the following:

- It allows for consideration of GE³LS aspects early in the lifecycle of a project. If there is no GE³LS component with funding tied to it, GE³LS aspects will not be considered in the design phase of the project and thus may not be dealt with as effectively.
- PIs who are not required to address GE³LS issues associated with their genomics research may be tempted to ignore them, which may create delays at later translational stages (e.g., commercialization of a controversial genomic technology).
- Without a GE³LS requirement, there is also a risk that GE³LS research conducted in the context of stand-alone projects *only* would be disconnected from the specific GE³LS issues faced by the genomics research.
- When incorporated properly, the multidisciplinary research resulting from the incorporation of GE³LS can be beneficial to both science and the social sciences (e.g., a single project can result in transfer to a broader range of researchers).

On the other hand, survey respondents and interviewees noted that the integration of GE³LS into genomics research has proved challenging and findings are mixed on the extent to which this integration has been a success. Not quite half of researchers across all groups indicated that GE³LS considerations have been effectively integrated into Genome Canada-funded projects. There was also a consensus among case study respondents that scientific work and GE³LS work often continues to function in silos. The term 'forced fit' was often used to describe the current situation between GE³LS and genomics research in some Genome Canada-funded projects. Interviewees frequently referred to the inherent difference of culture and perspective between social and natural sciences, which can constitute a barrier to integration, notably when trying to incorporate GE³LS into project goals.

In this context, it is not surprising to observe that the majority of GE³LS researchers (58%) indicated that the integration of GE³LS into all Genome Canada-funded projects was the most effective model to support GE³LS research in the future, while only a third of PIs and co-PIs (30%) held that view. Even GE³LS researchers often stated that there is room for improvement and further efforts should be made by Genome Canada to build awareness and capacity in GE³LS (e.g., increase the pool of world-class GE³LS researchers in Canada; improve networking between GE³LS researchers). It is worth noting that Genome Canada has already recognized that the integrating model may not be appropriate in all case, for example targeted, smaller-scale projects or those projects further down the innovation pipeline, and thus chose not to require that projects

funded under the Genomic Applications Partnership Program (GAPP) include a GE³LS component.

Such a flexible approach is consistent overall with what is done elsewhere. Except for the Research Council of Norway, which uses a similar integrative model to that of Genome Canada, the National Human Genome Research Institute (NHGRI) and the Wellcome Trust do not require that all funded projects incorporate GE³LS considerations. The NHGRI reserves 5% of its funding to support Ethical, Legal and Social Implications (ELSI) research, which is not automatically integrated into biomedical-funded projects. The Wellcome Trust assesses the need for research into ethical issues on a case-by-case basis. Some international interviewees cautioned that requiring GE³LS integration in all funded projects may lead to an inappropriate use of resources, as not all projects carry GE³LS issues.

Research translation

The evaluation was mandated to examine the extent to which Genome Canada's model of embedding GE³LS facilitated the translation of genomics research. However, given the challenges faced in integrating GE³LS research into projects, researchers did not tend to consider GE³LS integration as a key facilitator of the translation of genomics research into applications. In fact, only about 20% of PIs and co-PIs considered GE³LS a facilitator for the majority of categories examined (i.e., health care protocols, direct and indirect technology transfer, best practices in manufacturing, environmental benefits). The exception to this was for improved public policies and societal benefits (Table 6), for which 50% of PIs and at least one third of co-PIs considered GE³LS a facilitator in these cases.

Table 6 The integration of GE³LS facilitated exploration, development and/or integration of the following applications to a good or great extent

	PI	co-PI	GE ³ LS
New or improved public policies or programs (including improved regulations, standards, codes of practice, decision tools, etc.)	50%	43%	76%
Societal benefits (e.g., better teaching methods, community planning, social structure, economic reform, justice system, etc.)	50%	34%	75%

Source: Surveys of PIs, co-PIs, GE³LS researchers.

Interestingly, a much greater proportion of GE³LS researchers, around 75%, considered that GE³LS is a facilitator for research translation in several of the categories examined. Further supporting that GE³LS does play a role in this regard, documentary evidence found that integrated GE³LS projects have more interactions with industry than standalone GE³LS projects, hence suggesting a greater focus on applications.³⁷

³⁷ Genome Canada. (2012). *10 years of GE³LS*

More generally, there was a wide consensus that there is much room for improvement regarding the translation of genomics work into practical applications. For instance, case studies showed that uptake by end-users was generally moderate at this time and that more work remains to be done to translate genomics research into everyday applications. Major barriers to be overcome include external/contextual factors in the innovation system, such as complex regulatory processes, a funding gap (e.g., in public funding and venture capital) at the product validation stage, and limited engagement of the private sector, as well as limited public and end-user understanding of the benefits of genomics. Additionally, survey respondents expressed a need for increased funding support and time to carry out research translation activities (e.g., trials, knowledge translation, partnerships with industry). Nonetheless, multiple examples of translational research were found across all lines of evidence, as illustrated in Box 4.

With respect to Genome Canada's enabling role in research translation, there is some evidence suggesting that researchers were directly involved in

multiple activities in the context of their Genome Canada-funded projects that could help lead to the development of practical applications from genomics research (which are discussed in the next section). For example, researchers across groups were most involved in presentations at user organizations (80% of GE³LS researchers, 66% of PIs, 48% of co-PIs) and the formation of new research consortia or networks (66% of PIs, 52% of GE³LS researchers, 42% of co-PIs). Additionally, 48% of PIs contributed to new product/process development, co-PIs directly participated in major health (27%) or industrial (15%) R&D projects, and about a third of GE³LS researchers (32%) contributed to new standards, regulations or codes of practice.

As described across the case studies, factors that enable translation included early end-user engagement, a strong communication and outreach strategy and assistance from the individual Genome Centres (Box 5). Similarly, key enablers to translation cited by international interviewees

Box 4 Examples of research applications

Use of genomics technologies to develop diagnostic tools and adapt treatments based on patients' genetic profile, e.g., identification of patients who need a pacemaker to prevent death from sudden cardiac arrest; identification of patients at risk of having adverse drug reactions; development of a molecular analysis technology used to diagnose various types of disease (DVS Sciences).

Transfer of knowledge and/or samples following development of genetic markers and tools for tree, animal and plant selection/breeding, e.g., spruce breeding to improve growth, wood properties and insect resistance; selection and transfer of genetically superior cod broodstock to Canadian and American industry; small-scale field testing of a biomarker detection device which can monitor vine water status to detect drought stress in leaf samples.

Development of pandemic surveillance technologies based on genetic understanding of infections, e.g., implementation of a Centre for Disease Control in BC to quickly track H1N1 infections; development of *E. coli* and *Listeria* early detection technologies to be used routinely by Canadian inspectors within the next few years.

Development and transfer of resources to inform policy-making and regulations, e.g., production of resources used by DFO and Environment Canada to evaluate fish response to pollution, identify health fish stocks, and compare transgenic and domesticated fish to inform federal regulatory processes.

Ability to replicate and sequence a unique DNA barcode for individual organisms has led to many applications. For example, the barcode can be compared to a growing reference library to determine whether food product labels reflect the actual ingredients (iBOL project).

Genomics tools used to **improve the genetics of flax for oil production and fibre production** in the composite industry as well as the clothing industry.

included strong engagement of partners (e.g., industry), enhancing networking and collaboration opportunities, as well as balancing funding between large and smaller-scale projects.

This last point was also raised by some interviewees, as discussed earlier in the Relevance section. Furthermore, an independent evaluation of the international Structural Genomics Consortium also found that a flexible research model (i.e., one that may allow for large or small projects) facilitates access to a larger range of diverse networks, collaborations, and new scientific areas.³⁸

Finally, many interviewees cited the new GAPP program as a potential facilitator to translation. They are hoping that this initiative will receive increasing support from Genome Canada in the future, as it is designed to help reduce the gap between academia and end-users/industry, which is seen as one of the main barriers to translation.

Box 5 Translation enablers – case study evidence

Early end-user engagement: Conscious efforts to include the ideas and opinions of end-users and potential product consumers at every step of the way, from project inception to final result, facilitated translation of knowledge into practical uses such as:

- barcoding technology being used by Environment Canada and Parks Canada for park biomonitoring.
- FP Innovations currently field-testing enzymes to improve the pulp and paper bleaching process.
- Developed spectrometry technology used by international partners for commercial oilseed production.

Communication and outreach strategy: The Consortium for Genomic Research on All Salmonids (cGRASP) project was part of a larger international collaboration with salmonid groups from Norway, the US and the UK. Working together, extensive outreach efforts were made such as participation in regional, national and international conferences, workshops aimed at introducing government and industry stakeholders to the benefits of genomics in aquaculture, and dozens of media appearances. This targeted effort allowed for the use of project results by government agencies to evaluate fish populations and inform regulatory processes.

Genome Centre guidance: Several projects reviewed in the case studies cited guidance from individual Genome Centers during the proposal stage as a key enabler to downstream translation. Specifically, Centre advice and direction helped shape the research plan to best fit the available expertise and infrastructure. Centres also acted as a bridge to help establish partnerships with the private sector in the regions where the work was to be carried out.

3.5 Socio-economic benefits of the research that has been funded by Genome Canada

It is difficult to quantify direct socio-economic benefits due to Genome Canada funding. There are well-known difficulties in measuring such impacts, such as long-term effects that have not yet manifested, or the fact that such benefits are not always clearly defined or understood (e.g., include knowledge translation). Documentary data also tends to focus on projected economic gains versus actual. For example, one Canadian study estimates that by 2030, biotech development and use (including genomics research) will generate about \$144 billion in economic value, equivalent to 3.99% of the GDP in Canada.³⁹ Although such benefits are not yet systematically recorded by the

³⁸ Rand Europe. (2013). *Evaluation of the Structural Genomics Consortium*. Summary document.

³⁹ Centre for the Study of Living Standards (2011). *Measuring the Contribution of Modern Biotechnology to the Canadian Economy*. CSLS Research Report prepared for Genome Canada, December 2011.

organization, it is commendable that Genome Canada has made tangible efforts to measure impacts through a benefit-cost analysis conducted in 2009.⁴⁰

Note that this evaluation sought to examine both direct (e.g., commercialization of new products or technology) or indirect (e.g., foregone costs, improved health outcomes, reduced environmental damage) socio-economic benefits. In the broadest sense, new or improved public policies, training of HQP and other societal benefits, such as better community planning, are also considered to provide indirect socio-economic benefits.

Overall, despite the limitations noted above, the evaluation evidence appears to point to a gradual increase in the development of applications that have, or have the potential to, lead to socio-economic benefits. The surveys point to several different types of practical applications that have already been applied as a result of Genome Canada-supported research (Table 7). This is in addition to practical applications that are currently being explored or actively developed. Indeed, more than two-thirds of survey respondents said that Genome Canada contributed at least partially to the exploration, development or applied direct or indirect technology and knowledge transfer for new and improved commercial products, processes or services; new or improved health care; and new or improved public policies or programs (data not shown). As a general trend, new or improved health care applications are more often reported to be at the exploration and development stages, while indirect technology and knowledge transfer, new or improved public programs and policies and applications leading to societal benefits are more often being actively developed or applied. Furthermore, while the small survey populations do not allow for a detailed comparison with survey evidence from the 2009 evaluation, there were fewer respondents who reported that no benefits were planned or achieved between 2008 and 2013 (across the types of benefits listed) as compared to the 2009 results.

Table 7 Practical applications from Genome Canada-supported research, conducted from 2008 to 2013

	PI	co-PI	GE ³ LS	Other stakeholders
Indirect technology and knowledge transfer for new or improved commercial products, processes, or services (e.g., expert advice, tacit knowledge, etc.)	28%	17%	22%	12%
Direct technology transfer for new or improved commercial products, processes, or services (e.g., patenting, copyrights, licensing agreements, spin-off companies, etc.)	27%	9%	5%	7%
New or improved public policies or programs (including improved regulations, standards, codes of practice, decision tools, etc.)	10%	3%	22%	10%
Societal benefits (e.g., better teaching methods, community planning, social structure, economic reform, justice system, etc.)	11%	5%	38%	8%
Best practices in manufacturing, organizational structure, healthcare, etc.	4%	6%	12%	5%
Environmental benefits (e.g., reduced harmful impacts, improved ecosystems)	4%	5%	3%	13%
New or improved health care protocols, diagnostics, prognostics, therapeutics, etc.	4%	4%	2%	8%

Note: Survey respondents: PI N = 53; co-PI N = 147; GE³LS = 48; Other stakeholders = 89

⁴⁰ KPMG. (2009) *Pilot Test of Benefit-Cost Analysis of Genome Canada projects*. Draft Report prepared for Genome Canada

Source: Surveys of PIs, co-PIs, GE³LS researchers and 'Other stakeholders' (i.e., collaborators, partners, current and potential end-users and other unclassified stakeholders)

Other examples of direct benefits of Genome Canada projects, or the potential for such benefits, mentioned across several lines of evidence (including documents and case studies) are as follows:

- The creation or advancement of approximately 30 spin-off companies (Box 6).
- The use of genetic markers to identify trees that grow faster and are more resistant to disease or drought has the potential for annual economic gains of up to \$300 million.
- Various aquaculture projects have contributed to a 20% decrease in grow out time to market for halibut, the patenting of markers for selected industry traits in cod and improved environmental conservation and monitoring for salmonids.
- Canola seed varieties with improved nutritional value have been developed and are at the approval stage. Work is also ongoing to improve crop yields and oil content, which could represent billion-dollar gains for the agricultural industry.
- Research on several diseases has already led to thousands of life savings (e.g., research on the genetic causes of cancer led to the development of a genetic test, along with a risk-prediction model to identify women at risk of being affected by breast cancer: by the end of the project, doctors will be able to identify 10 times more women at risk using these new techniques).
- Advances in pediatric care (e.g., establishment of the Canadian Pediatric Cancer Genome Consortium and a network of 2500 pediatricians who report on adverse drug reactions) are expected to contribute to a significant reduction of healthcare costs and health benefits to thousands of patients.

Box 6 Examples of companies spun off from GC-funded projects

DVS Sciences Inc. developed CyTOF in the context of an OGI-funded project. CyTOF is a high-throughput mass cytometer for individual cell analysis based on a novel elemental mass-spectrometry detection technology. Revenues as of August 2010 were totalling \$2.5 million.

Boreal Genomics was spun off the Technology Development Platform project. The company was founded in 2009 and develops and commercializes DNA concentration technology. The company was already able to secure institutional (\$7M) and angel investments.

Sirius Genomics was advanced as a result of funding from Genome BC received in 2011. The company develops DNA based companion diagnostics and pharmacogenomic tests for acute medical conditions. Genome BC and Sirius co-invested in the final steps towards development of a biomarker aimed at dramatically improving the treatment of sepsis.

DuVax Vaccines and Reagents benefited from funding from Genome BC. The company was founded in 2011 and is developing and marketing a platform technology which will be used to produce a line of highly protective and cost effective vaccines and biological reagents.

This evaluation also examined Genome Canada's effect on patenting, using bibliometrics. Among countries patenting genomics innovations, Canada ranked fourth based on the number of patents from 2004 to 2011 (i.e., after the creation of Genome Canada, allowing for a lag time between funded research and patenting). However, its share of world total patents declined slightly overall in the 2000s, and no conclusive evidence was found on the impact of Genome Canada funding on researchers' propensity to patent. However, this might be due to certain limitations, for example,

given the time required to prepare and issue a patent, the post-grant interval may be too short to allow patenting activity to be adequately detected and measured. In the future, Genome Canada may be better equipped to capture such information using its own performance measurement and reporting processes.

The evaluation did find evidence of a number of other indirect socio-economic benefits. For example, contribution to the production and training of HQP (see Section 3.3) is also a clear indirect socio-economic benefit noted across lines of evidence. Finally, most Genome Canada projects include some national or international collaboration. As noted in the case studies, these contacts often expand to spin-off projects and the formation of new research consortia or working groups for new product/process development.

3.6 Extent to which Canadian genomics research is enabled through the provision of leading-edge technologies

The collected evidence indicates that Genome Canada provided adequate and sufficient access to enabling technologies, as well as analytical expertise, mainly through the STICs. Moreover, it appears that the STICs are used by a high proportion of funded researchers. Indeed, about 80% of surveyed PIs and five⁴¹ out of eight cases examined used at least one STIC in the last five years. The McGill University and Genome Québec Innovation Centre was the most frequently accessed (54% of PIs), followed by the Genomics Innovation Centre at the BC Cancer Agency Genome Sciences (31%) and the Centre for Applied Genomics (TCAG; 25%). Some of the cases reviewed also used various other technology platforms (both previously funded and not funded by Genome Canada) or built their own platforms with Genome Canada project funding.

Generally, funded researchers found the facilities used (STICs or non-Genome Canada funded facilities) were of high quality and the supporting staff were cited as knowledgeable and helpful. Genomics research infrastructure was considered adequate by 60% of surveyed PIs and co-PIs. Furthermore, many PIs rated as “high” both the technical capability (80%) and the operational capability (65%) of the STICs. It is also worth noting that the technical capabilities of the STICs were rated slightly higher in 2013 (4.2/5) than in 2009 (average of 3.6/5). In particular, the quality of the STICs was rated good or excellent for the following features:

- Information regarding the platforms (79%);
- Policies and procedures regarding eligibility of users (76%);
- Availability and effectiveness of support personnel (74%); and
- Policies and procedures regarding pricing (69%).

Additionally, the Genome Canada STIC International Review Committee was overall very satisfied with the progress made by the STICs and their rapid scope expansion.⁴²

⁴¹ One of these cases used technology platforms that are no longer funded by Genome Canada since 2006 and 2011.

⁴² Genome Canada Science and Technology Innovation Centre International Review Committee. (2013). *Chair's Report*.

However, some areas of improvement relating to the STICs were noted across all lines of evidence. In particular, to remain competitive, STICs will have to increase their focus on innovation and on improving analytical capacities. Indeed, other service providers exist that are able to process samples faster and at a lower cost; for instance, case study interviewees reported that for projects with a small budget (less than \$500,000), they used the services of foreign providers in China and Spain, where a variety of services are offered for a wider range of costs. In another case, a project chose to establish its own laboratory to develop new tools and technologies because the nature of the project required direct access to the instrumentation and modifications to standard operating procedures, which the STICs (and any other technology platforms) are not in a position to offer. Interviewees noted that STICs are unique in that they provide analytical expertise in addition to access to technologies, so they should further build on this strength to remain attractive to researchers.

Other areas of improvement of the STICs include the following:

- Policies and procedures on access, and guidelines regarding intellectual property are two aspects of the STICs that were not rated as highly as other features by surveyed PIs.
- Two of the cases examined highlighted a lack of bioinformatics capacity. In one case, researchers had to develop capacity in-house, while in the other case, researchers could not access bioinformatics infrastructure within each of the provincial institutions where the genome work was being conducted. Note that none of the case studies were in the health sector.
- The closing of the proteomics services of a STIC due to the non-renewal of Genome Canada funding generated delays in one of the cases examined. Researchers had to develop an in-house proteomics platform within the university they are affiliated with to allow the project to proceed as planned.
- The STIC International Review Committee (IRC) recommended that STICs focus on improving public data access and sharing. They also suggested that Genome Canada increases support to technology development and develops a training program for young investigators.⁴³
- A few interviewees suggested that, as larger STICs become self-sustainable, investments could be shifted toward building additional STICs in regions where none currently exist. This could also help reduce the pressure on existing centres that currently face a growing demand.

3.7 Management, design and delivery

This section examines various aspects of the management, design and delivery model of Genome Canada, with a view to discuss the mechanisms put in place to optimize the use of resources.⁴⁴

⁴³ Genome Canada Science and Technology Innovation Centre International Review Committee. (2013). *Chair's Report*.

⁴⁴ The following section discusses various topics related to the management, design and delivery of Genome Canada that are typically examined as part of an evaluation conducted in compliance with the requirements of the Treasury

Note that a comprehensive quantitative and/or comparative study of the cost-effectiveness of Genome Canada was not performed as part of this evaluation due to data and scope limitations.

As discussed below, there was a wide consensus on the need to maintain the regional model, despite inherent duplications associated with this model. Moreover, while Genome Canada has made efforts in the past few years to improve its cost-effectiveness, for ongoing improvements to its efficiency and effectiveness, particular focus should be put on clarifying Genome Canada's and the Centres' respective objectives, roles and requirements, to reduce duplication in the area of communications, streamline application and reporting processes, and improve its performance measurement practices.

Regional model

Internal and external interviewees agreed that Genome Centres are essential to ensure that regional and sectoral needs are identified and addressed. Some interviewees suggested that Centres should focus even more on regional strengths, instead of each covering all areas of strategic importance (e.g., Genome Quebec could further specialize in forestry; Genome Prairie and Genome Alberta in Agriculture, etc.). The Centres' primary function is also to raise co-funding for the projects, and they play a key role in attracting provincial funding. Surveyed PIs and co-PIs expressed positive views on the services provided by Genome Centres, highlighting their tailored support based on provincial characteristics, as well as their friendliness and cooperation. Other comments pointed to specific qualities of the Centres, such as their availability and responsiveness to researchers' needs, and their support in identifying outreach/networking opportunities.

Several challenges and issues are associated with this model. Completed surveys indicate that respondents across all groups had difficulty differentiating the respective features, responsibilities and requirements of Genome Canada, the Genome Centres and STICs. This suggests that the current delivery model employed by Genome Canada may be somewhat confusing for researchers. It is worth noting that the 2009 evaluation had already reported that the roles of the Centres were sometimes unclear⁴⁵. Moreover, evidence was found that the range of services offered is not consistent across Centres and that their ability to secure external support varies⁴⁶. In particular, interviewees stated that Centres covering several provinces tend to have more difficulties attracting provincial funding and the Centre Renewal Review indicated that "multi-province arrangements make it very difficult to capture the interest of provincial governments that are not where a Centre's primary staff base happens to be located, which has led one such Centre to propose expanding resources in its 'secondary' province"⁴⁷.

Board *Policy on Evaluation*. More specifically, it aims at addressing the Core Issue 5 of the *Directive on the Evaluation Function*, entitled "Demonstration of Efficiency and Economy".

⁴⁵ KPMG. (2009). *Evaluation of Genome Canada – Final Report* (Prepared for Genome Canada).

⁴⁶ Genome Canada. (2012). *Genome Centre Partnership – Genome Centre Funding Renewal*

⁴⁷ Genome Canada. (2012). *Genome Centre Partnership – Genome Centre Funding Renewal*

Duplication

The evaluation identified communications as the main area of duplication between Genome Canada and the Genome Centres that will require particular attention in the coming years. Indeed, many internal interviewees highlighted a need for a coordinated communication plan to ensure common messaging of the benefits of genomics research to external stakeholders (e.g., public, partners, end-users). Currently, each Centre is focused on its own region and existing structures remain insufficient to adequately coordinate efforts and avoid duplication of messaging. Efficiencies could be gained by sharing communication tools and expertise (e.g., in social media) across Centres. Note that the 2009 evaluation had previously identified an emerging need to improve the coordination and communication among the Genome Centres. The report stated that “although there is a ‘G7’ group that helps communication and coordination among the six Centres and Genome Canada”, survey responses tended to show that “even more coordination among Centres would be welcomed.”⁴⁸

Aside from these communication issues, the evaluation found some overlap across Centres, primarily related to the decentralized structure. There are mixed views among survey respondents about the extent to which there is duplication across Genome Centres. Less than 10% of survey respondents reported duplication to a large or great extent, while about one quarter reported some duplication; the remainder either reported no duplication or did not know. Interviewees noted that there is some duplication of administration and finance functions across Centres but stated that it is unavoidable given the decentralized model. Several interviewees further argued that only modest amounts of money would be saved by pooling resources.

Furthermore, survey respondents and interviewees saw relatively little duplication between Genome Canada and other granting agencies at the national and international levels. PIs expressed mixed views about the extent to which there is duplication with national or international genomics research centres. Given the lack of details provided by PIs in the survey, it is not possible to assess where this duplication occurs. As already discussed in the relevance section (i.e., on the need for a separate organization), many interviewees stated that the mandates of Genome Canada and other granting agencies are distinct enough to ensure that there is little duplication between them. Moreover, interview evidence suggests that Genome Canada and other funding agencies (e.g., CIHR, CFI) work closely together to avoid duplication when undertaking joint funding initiatives.

Efficiency/cost-effectiveness measures

Many interviewees noted that measures have been taken over the past five years to improve efficiency of Genome Canada’s governance structure (i.e., Board and committees). For instance, the Board of Directors performed a review of its governance structure. As a result, the mandate of the Board was clarified to ensure that it remains focused on strategic issues (i.e., oversight) and not on competition management-related activities (e.g., being a second level of peer review). Additionally, the structure of the committees governing Genome Canada was reorganized to cover all functions needed for effective implementation of the new strategic direction.

⁴⁸ KPMG. (2009). *Evaluation of Genome Canada – Final Report* (Prepared for Genome Canada).

Moreover, both Genome Canada and the Genome Centres have been proactively reducing their operating expenditures during the evaluation period. Between 2009-10 and 2012-13, Genome Canada's annual operating expenditures were at least 31% less than the \$9 million provided by Industry Canada for this purpose (Table 8). In 2013-14, planned expenses for operations were reduced to \$8 million, and Genome Canada's operating budget remained 14% below this amount. The resulting \$11.4 million in unspent operating funds was re-allocated to research funding. However, as illustrated in Figure 5, given the substantial decrease in research funding since 2010-11, the percentage of Genome Canada's operating expenditures (non-research projects) to total expenditure slightly increased from 7% to 11% between 2009-10 and 2012-13.

Table 8 Genome Canada Planned and Actual Operating Expenditures (in millions)

	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	Total 2008-09 to 2013-14
Initially Provided for Operations (Planned)	9.0	9.0	9.0	9.0	9.0	8.0	53.0
Actual Expenditures	8.9	5.8	6.2	6.2	6.2		33.3
Approved Budget as of October 2012						6.9	6.9
Unspent Operating Funds	0.1	3.2	2.8	2.8	2.8	1.1	12.8
Savings Percentage	1%	36%	31%	31%	31%	14%	24%
Transferred to Research Funding		3.3		7.0		1.1	11.4

Source: Genome Canada. (2014). Genome Canada Operating Funds. *Summary for Evaluation*.

As a further measure, Genome Canada reduced the annual base funding provided to the Genome Centres for their operations, from \$5.5M (2009-10 to 2011-2012) to \$4.8M (2012-2013) (see Table 1 in Section 2). However, it should be noted that individual Genome Centres also obtain operating funding from other sources, most notably from the provinces. The percentage of the Centres' operating budget that was provided by Genome Canada varies widely across Centres and from year to year, from a minimum of 23% to a maximum of 95% (about 40% on average between 2009-10 and 2012-13).⁴⁹

Between 2009-10 and 2012-13, the total operating expenditures for all Genome Centres combined have remained stable at roughly \$16 million per year (Figure 5). Similarly, there has been relatively little change in the percentage of Genome Centres' operating to total expenditures, which ranged between 14% and 18% during this period. .

⁴⁹ Genome Canada. (2014). Genome Canada Operating Funds. *Summary for Evaluation*.

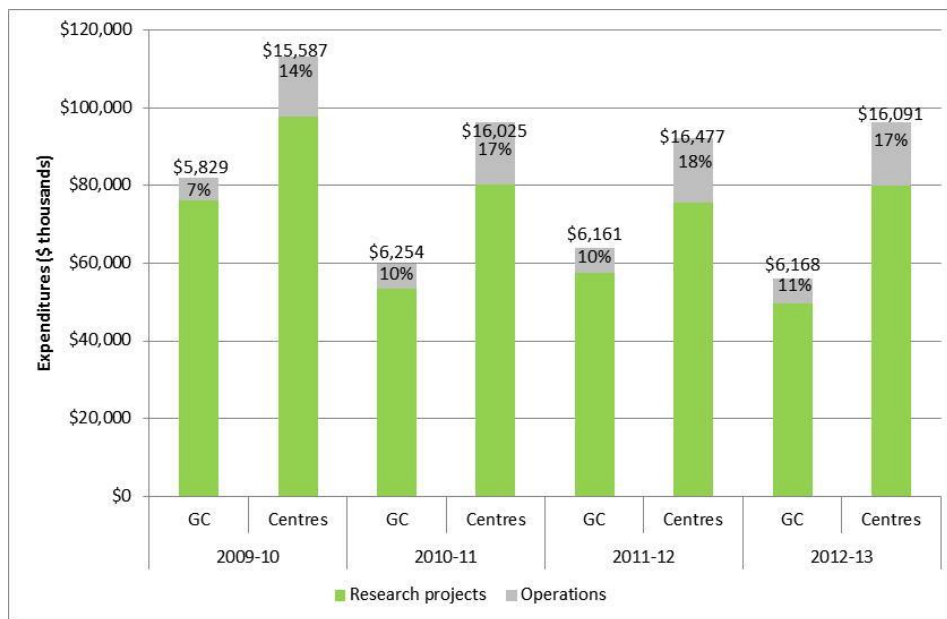


Figure 5 Genome Centres and Genome Canada operating and research expenditures, 2009-10 to 2012-13 (in thousands)

Source: Genome Canada. (2013). *Summaries of Centres Operating Expenditures Over Four Years*

However, the decision to reduce funding is controversial, given a tension between the need to improve efficiency and the level of resources necessary to deliver the Strategic Plan. In a 2012 review of the Genome Centres, the Centre Review Committee⁵⁰ recommended that Genome Canada should not continue to reduce funding allocated to the Centres, including the 12% cut in 2012-13. The authors of the review argue that Centres need additional support to cover operational costs related to “the expanded roles of the Centres as required by the new strategy.”⁵¹ Moreover, internal interviewees stated that the 12% cut required making changes in resource allocation that negatively affected the communication and business development functions. Others noted that governance costs should not be reduced at the expense of effective collaboration with the Centres (e.g., the Board no longer travels across Canada to visit the Centres).

Competition, project management and operational processes

Overall, the evaluation found that several aspects of the competition, project management and operational processes of Genome Canada could be improved; common issues were flagged through the survey, interviews and case studies. Evidence across all methods indicates that some administrative processes can be burdensome within Genome Canada and the Centres; interviewees and survey respondents in particular often pointed to the frequent and heavy reporting

⁵⁰ The Centre Review Committee was created in 2011 by the Board of Genome Canada to undertake an independent review of the Genome Centres and to provide recommendations and advice on improving the Genome Canada / Genome Centre Partnership. The Committee was comprised of six representatives from the academic, public and private sectors, including one member from a foreign university.

⁵¹ Genome Canada. (2012). *Genome Centre Partnership – Genome Centre Funding Renewal*

requirements. The quarterly reporting required by the Genome Centres is deemed overly burdensome, as only incremental progress can be made in three months. There was a consensus across cases examined that the frequency could be reduced without affecting accountability. Flexibility and moderate reporting requirements were also highlighted as best practices by a few international interviewees, including as a way to foster bold scientific discoveries. Genome Canada could also consider synchronizing reporting requirements and deadlines with those of other funding organizations, in the case of funding calls that include international or external collaborators. Finally, interviewees deemed the two-level reporting process between the Centres and Genome Canada to be redundant and time-consuming. Similar issues had previously been raised during the 2009 evaluation (e.g., stakeholders criticizing the extra layer of bureaucracy). Internal interviewees stated that the new approach whereby Genome Canada participates as an observer in reporting discussions at the Centre level is likely to accelerate the approval process.

Other key considerations or issues related to competition, project management and/or operational processes include the following:

- **Application process:** Less than half of PIs and GE³LS researchers (40% to 47%) were satisfied with their overall experience with Genome Canada's application process. In particular, less than one-third said there was adequate time allocated to complete the application. The majority of those who provided comments mentioned the need to reduce the size and/or simplify the application form. Case study evidence confirms that there is a need to streamline application processes. Nonetheless, several interviewees noted that guidance received from individual Genome Centres during the initial proposal stage helped them shape the research plan and establish partnerships with the private sector.
- **Funding approval process:** While the level of satisfaction is generally quite high regarding the transparency and equity of the funding approval process, only half of the surveyed PIs and one-third of GE³LS researchers considered it free from bias. Additionally, over half of PIs (52%) and 40% of GE³LS respondents disagreed or strongly disagreed that it was free from conflict of interest.
- **Interim review:** Surveyed respondents were overall satisfied with the interim review process. However, as was previously explained, many found the reporting requirements in general, including in the context of the interim review, to be excessive.
- **Project-level communications:** There was a wide consensus across cases examined that support from the Centres, both at the proposal stage and throughout the project, was a facilitating factor for all cases. However, interviewees across cases also said that coordination between Genome Canada and the Centres could be improved, especially with regard to synchronizing the timing of funding calls, streamlining application/reporting processes and reducing duplication (e.g., where approvals are required from more than one Genome Centre to authorize changes made to project design or management).

Genome Canada has already taken steps to address some of the above issues. In fact, documentary and interview evidence indicates that Genome Canada performs regular reviews of its management processes to ensure that they allow the organization to deliver its mandate effectively and efficiently. For instance, Genome Canada recently committed to replace quarterly reports by semi-annual or annual reports depending on project complexity. Less formal monitoring procedures

were also implemented, including through more direct linkages between the Project Manager and the centres. Advisory boards were also replaced by oversight committees which report to Genome Centres only. Where oversight committees are in place there will not be an interim review process.

Acknowledging that the preparation and review of project proposals can be costly and time consuming, Genome Canada introduced a pre-screening process and streamlined its Due Diligence process so that a full proposal review is performed only in the final stages of the approval process. In the future, face-to-face interviews may be replaced by videoconference meetings for competitions for smaller scale projects and Genome Canada no longer systematically conducts site visits and face-to-face meetings for the interim review of funded large-scale projects (e.g., 2010 Competition).

Performance measurement

Genome Canada recently updated its Performance Audit and Evaluation Strategy (PAES), which provides a high level framework addressing “the key elements that Genome Canada has put in place to ensure accountability in the achievement of objectives from the perspective of performance monitoring, audit, evaluation, risk and reporting.”⁵² The PAES details the various mechanisms in place, as well as the targets and indicators used to monitor the performance of Genome Canada and the Genome Centres.

Interview evidence indicates that Genome Canada has recently made efforts to improve performance measurement practices. First, following recommendations from the 2009 Performance Audit Report, a position of Director of Evaluation was created to fulfil the need for resources dedicated to performance measurement. Second, given the recent change in strategic direction, new metrics are being developed to better track socioeconomic benefits resulting from funded projects. Moreover, a new performance measurement database was implemented to allow for more systematic data collection on projects, including at the Centre level. The new system is expected to contribute to better decision-making on programming through evidence-based program assessments.

However, steps remain to be taken toward the implementation of a fully effective performance measurement system. First, regarding the new performance measurement database mentioned above, it is worth noting that not all Centres have started to use it systematically. A few interviewees explained that, in some cases, other systems already exist to capture performance information and that this information can only be entered in the new system once it has been entered in these existing systems. Second, several challenges also were encountered by the evaluation team while extracting information from the Genome Canada databases.

For instance, databases used by the finance and program units are not adequately linked (e.g., each uses different identifiers), which required additional manual validation steps to extract relevant data on projects (e.g., to confirm whether two projects with different identifiers were actually the same project). Furthermore, lists of co-funders and collaborators were very time-consuming to extract from the databases and ultimately limited the survey samples for this evaluation. Such lists are also

⁵² Genome Canada. (2013). *Performance, Audit and Evaluation Strategy 2012-2017*

critical for outreach and coordination purposes, such as efforts to seek out and/or create joint initiatives with a broader range of public and private organizations. A few interviewees explained that separate databases were initially created for different purposes and functionalities, but that the organization matures, there is a growing need to better integrate these systems to optimize the use of available information.

4 Annex 1 – Evaluation Background

4.1 Organization of the report

The various issues and questions that were addressed by the evaluation as per the evaluation design are aligned with three of the Treasury Board’s core evaluation issues (dark grey), and are presented as per key themes of interest for Industry Canada (light grey), as outlined in Table 9.

Table 9 Evaluation questions and issues

Relevance (Continued need for program) – Treasury Board Core Issue #1
Relevance (continued need) and sector identification
<ul style="list-style-type: none"> • Evaluation Question 1a) – Is Genome Canada’s rationale still valid? • Evaluation Question 1b) – Is there still a need for a separate organization to fund large-scale genomics research projects (and the necessary support technologies) in areas of strategic importance to Canada? • Evaluation Question 1c) – Would the research have been carried out if Genome Canada had not existed? • Evaluation Question 2a) – How effective has Genome Canada been in developing strategies to <u>identify</u> and focus on high priority strategic research themes?
Performance – Achievement of Expected Outcomes – Treasury Board Core Issue #4
Extent to which Genome Canada has contributed to enhanced support and capacity for genomics research
<ul style="list-style-type: none"> • Evaluation Question 2a) – How effective has Genome Canada been in developing strategies to identify and <u>focus</u> on high priority strategic research themes? • Evaluation Question 2b) – How effective has Genome Canada been in increasing coordination among the various national and international parties involved in genomics research? • Evaluation Question 3 – To what extent has Genome Canada to become a world leader in genomics research? • Evaluation Question 8 – How effectively has Genome Canada communicated the relative risks, rewards and long-term impact of genomics to its direct stakeholders (partners and end-users)? • Evaluation Question 9 – To what extent has Genome Canada’s investment been matched by additional resources from stakeholders, partners and collaborators through co-funding and leveraged funds?
Extent to which Genome Canada has contributed to Canada’s HQP in genomics
<ul style="list-style-type: none"> • Evaluation Question 10 – Has Genome Canada increased the supply of highly qualified persons to meet the evolving needs of genomic research?
Extent to which Genome Canada has contributed to increasing the breadth and depth of knowledge in genomics (including GE³LS)
<ul style="list-style-type: none"> • Evaluation Question 5 – To what extent has the research that has been funded by Genome Canada been transformative in areas of strategic importance to Canada? • Evaluation Question 6 – To what extent and how has Genome Canada demonstrated leadership in the area of ethical, environmental, economic, legal, social and other issues related to Genomics research (GE³LS)? • Evaluation Question 7a) – To what extent has Genome Canada’s model of embedding GE³LS research within projects facilitated the translation of genomics research? (effort) • Evaluation Question 7b) – What are the challenges and enablers that facilitate translation from the perspective of the different stakeholders and end-users? (effort)
Socio-economic benefits of the research that has been funded by Genome Canada
<ul style="list-style-type: none"> • Evaluation Question 11a) – What are the socio-economic benefits of the research that have been funded by Genome Canada? • Evaluation Question 11b) – To what extent has Genome Canada been the catalyst in translating genomics research into applications at a national and international level?
Extent to which Canadian genomics research is enabled through the provision of leading-edge technologies
<ul style="list-style-type: none"> • Evaluation Question 4 – To what extent has Genome Canada provided access to leading-edge technologies that have contributed to Canada’s world class competitiveness?

Performance – Demonstration of efficiency and economy – Treasury Board Core Issue #5**Management, design and delivery**

- Evaluation Question 12 – Are there alternative delivery models – or changes to the Genome Canada design to delivery process – that could improve its cost-effectiveness?
- Evaluation Question 13 – To what extent is there duplication of effort across the regional Centres and how effective has the use of resources been?
- Evaluation Question 14 – To what extent has Genome Canada implemented processes to maximize efficiency within the management of competitions, projects and operational needs?

4.2 Overview of the evaluation methods

Five data collection methods were used as part of this evaluation, including a survey, a management and delivery review, case studies, an international comparative review and bibliometrics. A brief overview of the approach used for each method is provided below. For more details regarding the data collection process and limitations associated with each method, see Appendix 1.

Management and delivery review: As part of the review, 24 interviews were conducted, and a document and file review of over 200 documents related to Genome Canada’s activities was performed. The purpose of the management and delivery review was to examine the history, processes and performance of Genome Canada across the evaluation period (2009–2014). Interviews were particularly useful to inform issues of continued need, efficiency and economy, whereas documents were one of the main sources of evidence – including quantitative evidence (i.e., financial and output data) – on the achievement of outcomes, as well as efficiency and economy issues.

Survey: Web surveys were conducted with five stakeholder groups, namely the Principal Investigators (PIs; n=53), co-applicants and other investigators (co-PIs; n=153), GE³LS PIs and leaders (n=52), highly qualified personnel (HQP; n=153) and other stakeholders (e.g., partners, collaborators, current and potential end-users; n=137) involved in Genome Canada-supported projects. These surveys mainly sought to collect information on performance issues to address data gaps relating to outcomes. Views regarding cost-effectiveness and delivery were also collected.

Bibliometrics: Using various indicators (e.g., scientific output; specialization, citation impact), Science-Metrix assessed the scientific performance of Genome-Canada’s funded researchers in genomics and in each of the strategic sectors, namely agriculture, health, environment, fisheries/aquaculture, forestry and energy/mining. This performance was also examined within the broader Canadian context (e.g., comparison to non-funded researchers, benchmarking with other countries), in an attempt to determine Genome Canada’s contribution to the national standing in genomics over the years. The level of national and international scientific collaboration of Genome Canada and of individual researchers was also measured, as an indicator of the organization’s effectiveness in coordinating genomics research efforts.

Case studies: Eight projects funded by Genome Canada were examined in depth as part of the case study method. The selection of case studies focused on emerging and natural resource sectors, namely agriculture, environment/energy/mining, fisheries, and forestry in order to address particular needs relating to the implementation of the 2012-2017 Strategic Plan. Each case involved conducting two or three interviews with relevant stakeholders (e.g., project contributors, partners and/or end users). A project-level document review was also conducted, examining applications,

quarterly, interim and annual reports as well as information such as collaboration agreements, scientific publications and any other related outputs as provided by Genome Canada and interviewees. The purpose of the case studies was to provide insight on key themes that span across projects and that relate to the success and impact of large-scale genomics projects. The resulting cross-case analysis is presented in Appendix 2.

International comparative review: The data collection and analysis for the international comparative review were based on two methods: a literature review of five organizations comparable with Genome Canada and targeted interviews with representatives from three of these organizations. The literature review component focused on identifying and extracting relevant information and data from the organizations' websites and other relevant sources such as grey literature, funding announcements, etc. A total of four interviews were also conducted with individuals knowledgeable about their organization and the country's overall support mechanisms for genomics research. This line of evidence was used to assess the continued need for national support of genomics research and contribution of Genome Canada to Canada's global leadership in this field, as well as to position Genome Canada in the global context according to elements such as operating environment, strategy development, design and delivery of programs or projects, and best practices.

Genome Canada Five-Year Evaluation Appendix 1 – Methods

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1 Overview of the evaluation approach

The evaluation approach was designed to assist Genome Canada in assessing its past performance for the five-year period from 2009 to 2014, but also sought to adopt a forward-looking perspective to help inform management and other stakeholders on how to best implement the organization’s new strategic direction.

Potential evaluation questions were identified by Genome Canada through a consultative process with Genome Canada’s Board of Directors and key stakeholders. A total of 14 questions have been aligned with three of the Treasury Board’s core evaluation issues¹:

- **Relevance: continued need** – *in line with Treasury Board core evaluation Issue #1*
- **Performance: achievement of expected outcomes** – *in line with Treasury Board core evaluation Issue #4*
- **Performance: demonstration of efficiency and economy** – *in line with Treasury Board core evaluation Issue #5*

These 14 questions were used to guide the development of the evaluation methods. These questions have also been grouped under key themes of interest for Industry Canada (as per the expected results in the funding agreement), as outlined in Table 1.

Table 1 Evaluation questions and issues

Relevance – Continued need – Treasury Board Core Issue #1
Relevance (continued need) and sector identification
<ul style="list-style-type: none"> • Evaluation Question 1a) – Is Genome Canada’s rationale still valid? • Evaluation Question 1b) – Is there still a need for a separate organization to fund large-scale genomics research projects (and the necessary support technologies) in areas of strategic importance to Canada? • Evaluation Question 1c) – Would the research have been carried out if Genome Canada had not existed? • Evaluation Question 2a) – How effective has Genome Canada been in developing strategies to <u>identify</u> and focus on high priority strategic research themes?
Performance – Achievement of Expected Outcomes – Treasury Board Core Issue #4
Extent to which Genome Canada has contributed to enhanced support and capacity for genomics research
<ul style="list-style-type: none"> • Evaluation Question 2a) – How effective has Genome Canada been in developing strategies to identify and <u>focus</u> on high priority strategic research themes? • Evaluation Question 2b) – How effective has Genome Canada been in increasing coordination among the various national and international parties involved in genomics research? • Evaluation Question 3 – To what extent has Genome Canada to become a world leader in genomics research? • Evaluation Question 8 – How effectively has Genome Canada communicated the relative risks, rewards and long-term impact of genomics to its direct stakeholders (partners and end-users)? • Evaluation Question 9 – To what extent has Genome Canada’s investment been matched by additional resources from stakeholders, partners and collaborators through co-funding and leveraged funds?

¹ Treasury Board of Canada Secretariat. (2012). *Directive on the Evaluation Function*. Annex A: <http://www.tbs-sct.gc.ca/pol/doc-eng.aspx?id=15681§ion=text>

Extent to which Genome Canada has contributed to Canada’s HQP in genomics
<ul style="list-style-type: none"> • Evaluation Question 10 – Has Genome Canada increased the supply of highly qualified persons to meet the evolving needs of genomic research?
Extent to which Genome Canada has contributed to increasing the breadth and depth of knowledge in genomics (including GE³LS)
<ul style="list-style-type: none"> • Evaluation Question 5 – To what extent has the research that has been funded by Genome Canada been transformative in areas of strategic importance to Canada? • Evaluation Question 6 – To what extent and how has Genome Canada demonstrated leadership in the area of ethical, environmental, economic, legal, social and other issues related to Genomics research (GE³LS)? • Evaluation Question 7a) – To what extent has Genome Canada’s model of embedding GE³LS research within projects facilitated the translation of genomics research? (effort) • Evaluation Question 7b) – What are the challenges and enablers that facilitate translation from the perspective of the different stakeholders and end-users? (effort)
Socio-economic benefits of the research that has been funded by Genome Canada
<ul style="list-style-type: none"> • Evaluation Question 11a) – What are the socio-economic benefits of the research that have been funded by Genome Canada? • Evaluation Question 11b) – To what extent has Genome Canada been the catalyst in translating genomics research into applications at a national and international level?
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Performance – Demonstration of efficiency and economy – Treasury Board Core Issue #5
Management, design and delivery
<ul style="list-style-type: none"> • Evaluation Question 12 – Are there alternative delivery models – or changes to the Genome Canada design to delivery process – that could improve its cost-effectiveness? • Evaluation Question 13 – To what extent is there duplication of effort across the regional Centres and how effective has the use of resources been? • Evaluation Question 14 – To what extent has Genome Canada implemented processes to maximize efficiency within the management of competitions, projects and operational needs?

The evaluation design, including the refinement of the methods and indicators used, was further informed by additional rounds of discussion with Genome Canada to clarify our understanding of the context, objectives and scope of the evaluation, as well as a preliminary scan of relevant information from and about Genome Canada. Input from the Evaluation Steering Committee (ESC) also played a key role in strengthening the approach. No need for additional or alternative questions was indicated in the development of the evaluation design. These questions were used to delimit the scope of the evaluation project.

Indicators were developed for each evaluation question to guide the collection and analysis of data across the methods to be used; these are presented in the full data collection matrix (DCM) which links evaluation questions, issues, indicators and methods. An overview of the methods used in this evaluation is presented in Table 2.

Table 2 Overview of methods (with comparison to the 2009 evaluation baseline data)

	★ New ● 2009 baseline
Management and Delivery Review	
Interviews (24 interviews)	
• Genome Canada Board of Directors and Scientific and Industry Advisory Committee members	★
• Genome Canada Management and Staff	★
• Genome Centres Management	★
• Key partners	★
• National experts	★
• Unsuccessful applicants	★
Document, file and database review (over 200 documents)	
• Genome Canada and Centres corporate documentation and data/databases (strategic plan, annual reports, financial and co-funding data, activity/output data, Centre renewal process, etc.)	●
• Past evaluations, audits and performance reviews of Genome Canada	●
• Additional internal and external documents (e.g., provided by beneficiaries/partners)	●
Surveys	
• 1. Principal investigators (PIs) – not GE ³ LS	●
• 2. Co-applicants and other investigators (co-PIs)	★
• 3. GE ³ LS PIs and leaders	●
• 4. Other stakeholders (partners, collaborators, current and potential end-users)	●/★
• 5. Highly qualified personnel (HQP from Competition III)	★
Bibliometrics	
• Benchmarking and positioning of Canadian genomics research (including sectors)	●
• Assessment of research funded by Genome Canada – effect of funding/statistical comparative analysis between supported papers and non-supported papers (Competition III), and Canadian genomics researchers	●/★
• Historical trends in Canadian genomics, including sectors and GE ³ LS	★
• Collaboration network analysis	★
• Patent analysis	★
Case Studies (8 projects)	
• Project-level interviews: 23 interviews (2-3 per case)	★
• Project-level document and file review	★
• Cross-case analysis	★
International Comparative Review	
• Literature scan and document review focused on 5 selected international organizations	●
• Interviews with representatives from selected organizations and international experts: 6 interviews	●

2 Detailed methods

2.1 Management and delivery review

The purpose of the management and delivery review was to examine the history, processes and performance of Genome Canada across the evaluation period (2009–2014). As part of this review, Science-Metrix conducted 24 interviews from September to November 2013 and performed a document and file review of over 200 documents related to Genome Canada’s activities.

Interviews were particularly useful to inform issues of continued need, efficiency and economy, whereas documents were one of the main sources of evidence – including quantitative evidence (i.e., financial and output data) – on the achievement of outcomes, as well as efficiency and economy issues.

The document and file review built on the baseline data collected from the 2009 evaluation, in order to provide evidence on longitudinal impacts and progress toward targeted outcomes. It is important to note that these longitudinal data were complemented by those collected in the web surveys, as well as by the bibliometric analysis.

2.1.1 Interviews

The list of interview candidates (primary and back-up) was developed with the input of program staff and the Evaluation Steering Committee (ESC). Modifications to the originally proposed distribution of interviewees were made in response to this input. The final interview distribution is presented in Table 3. Interview questions were developed with a view to ensure alignment with evaluation questions and indicators in the DCM. The resulting interview guides were reviewed and approved by the Project Manager at Genome Canada.

Interviewee responses were analyzed to identify common themes across all groups based on questions and indicators listed in the DCM. Because the interviewees who were consulted for this evaluation are not representative of the actual population of stakeholders, interview evidence is not presented as counts or percentages. Instead, the scale provided in Table 4 is used to indicate whether the views were reported by a given proportion of individuals, or whether they are anecdotal views.

Table 3 Distribution of interviewees across stakeholder groups

Stakeholder groups	# Interviews
Internal	
Board of Directors Members	2
Scientific and Industry Advisory Committee (SIAC)	2
Genome Canada Management and Staff	4
Genome Centres Management	6
Internal – TOTAL	14
External	
Key Partners	6
National Experts	2
Unsuccessful Applicants	2
External – TOTAL	10
GRAND TOTAL	24

Table 4 Scale to quantify interview responses

Term	Proportion of interviews
“Almost all” or “consensus”	Findings reflect the experiences, views and opinions of more than 85% of the interviewees.
“Most”	Findings reflect the experiences, views and opinions of more than 50% of the interviewees.
“Many”	Findings reflect the experiences, views and opinions of more than 25% but no more than 50% of the interviewees.
“Some”	Findings reflect the experiences, views and opinions of more than 10% but no more than 25% of the interviewees.
“A few”	Findings reflect the experiences, views and opinions of less than 10% of the interviewees.

2.1.2 Document review

Documentary materials reviewed included Genome Canada corporate files, such as annual reports, corporate plans and funding agreements, as well as financial databases including co-funding information. Past evaluations and audits were also reviewed and used to establish a baseline for several of the indicators examined in this evaluation. Additional internal and external documents identified in the course of the evaluation (including those identified/provided by interviewees) were also used to inform the findings.

Evidence collected during the course of the document review was analyzed in a systematic manner using the design report and data collection matrix to help structure and focus the findings. In short, data from the various sources were compiled and analyzed to identify pertinent findings for each evaluation question and indicator that was associated with this method.

2.2 Survey

Web surveys sought to collect information on all 14 of the evaluation questions, from different stakeholders; namely the principal investigators (PIs), co-PIs, GE³LS PIs and leaders, highly qualified personnel (HQP) and other stakeholders involved in GC-supported projects (e.g., partners, collaborators, current and potential end-users). While some data on relevance were collected via the surveys, the emphasis was placed on performance issues to address data gaps relating to outcomes. Views regarding cost-effectiveness and delivery were also collected. Importantly, these surveys built on the findings of the 2009 evaluation, which surveyed some of the same populations.

2.2.1 Survey design

Five different populations were consulted during this evaluation using five distinct surveys. Unless otherwise indicated, only those associated with projects from Competition III onward were included in the survey populations. The design and implementation of the surveys were based on lists provided by Genome Canada of potential survey respondents for the five populations.

- **Principal investigators (PIs; N=150).** This survey targeted all principal investigators supported by Genome Canada. The PI population was also consulted during the 2009 evaluation. As such, the survey questionnaire was designed to allow for a comparison over time. New questions were also drafted to address issues specific to this evaluation.
- **Co-applicants and other investigators (co-PIs; N=422).** This survey targeted co-applicants and other researchers involved in Genome Canada research projects but not included in the PI survey above (or the GE³LS survey). This population was not consulted during the previous evaluation. This survey used a similar but shorter version of the PI survey questionnaire.
- **GE³LS PIs and leaders (N=108).** This survey targeted PIs for large-scale GE³LS projects, as well GE³LS leaders and co-PIs for other large-scale projects supported by Genome Canada. As for the PIs, GE³LS PIs were consulted during the 2009 evaluation. The current survey questionnaire was composed of questions used previously and new questions specific to the current evaluation issues. Potential respondents involved in several Genome Canada-supported projects but with different roles (e.g., as PI, co-PI or GE³LS leader) were preferentially included in this survey.
- **Other stakeholders (N=290).** This survey targeted partner organizations directly or indirectly involved in Genome Canada-funded research. It included collaborators (and possibly co-applicants) not invited to the co-PI survey, current and potential end-users, and other unclassified stakeholders. The preliminary lists of potential participants were provided by Genome Canada staff and included participants from different workshops held by Genome Canada. Additional contact information for potential respondents for this group were obtained from the PI, co-PI and GE³LS surveys (snowball sampling technique): respondents were asked

to identify end-users involved in their GC-supported projects and to provide contact information.

- **HQP (N=435).** This short survey targeted HQP involved in Genome Canada research projects funded as part of Competition III. Answers provided were particularly useful to examine evaluation question 10 (Building capacity in HQP) but also helped inform other evaluation issues surrounding research environment, capacity and management.

Both Science-Metrix and Genome Canada staff were involved in drafting the survey questionnaires and in pre-testing the web surveys. To the extent possible, survey questions were designed with a view to ensure alignment with the 2009 survey. The survey questionnaire included both closed-ended (for example, multiple-choice or five-point scale) and open-ended questions for each group.

2.2.2 Response rates

The completion and response rates for the survey were calculated based on the number of respondents who completed the survey (Table 5). The completion rates are based on the number of individuals who were successfully contacted, while the response rates are based on the total population of potential respondents, including those who could not be contacted.

Although the response rate sometimes reached or exceeds the expected range for these populations, the margins of error remain slightly higher than 5% (between 6.1% and 10.5%). This was to be expected given the relatively small survey populations: to achieve margins of error of less than 5%, approximately 65% of the population would have needed to complete the surveys. The survey results should therefore be interpreted with caution as the margins of error are slightly higher than 5%, in particular for distributions that are close to 50-60%, and especially for PI and GE³LS results.

Table 5 Sample distribution and response rate for the five GC surveys

Survey	Initial sample	Valid sample	Completed	Partial*	Total valid responses (n)	Completion rate†	Response rate††	Margin of error‡
PI	142	137	53	3	53	38.7%	37.3%	10.5%
Co-PI	420	397	153	2	153	38.5%	36.4%	6.3%
GE ³ LS	109	103	52	0	52	51.0%	47.7%	9.9%
Stakeholders	290	281	137	8	137	48.8%	47.2%	6.1%
HQP	435	388	153	1	153	39.4%	35.2%	6.4%

Notes: *

Partial: Number of respondents who did not complete the entire survey.

†

Completion rate = Number of completed surveys, divided by the valid sample, which excludes unreachable potential respondents (invalid email address).

††

Response rate = Number of completed surveys, divided by the total sample (population), which includes unreachable potential respondents (invalid email address).

‡

Calculated for a response distribution of 50% (namely, 50% yes/50% no); 95% confidence level (19 times out of 20).

2.2.3 Survey analysis

Administrative survey data and survey responses were compiled in an Excel spreadsheet and basic qualitative and quantitative data analyses were performed. This included coding of qualitative (open-ended) questions, frequency tables, and appropriate statistical analyses (e.g., cross-tabulation, based on the type of question and level of response). Systat Software was used to perform statistical tests using quantitative data and MaxQDA for qualitative data analysis. Responses were analyzed overall as well as by selected and relevant descriptive characteristics of the populations (e.g., sectors, Genome Centres, project status, etc.) to help identify potential trends/outliers and contextualize the findings. The final dataset, including descriptive statistic tables for each survey, was subjected to additional validation and quality control to ensure an error-free dataset.

2.3 Bibliometrics

The selection of the bibliographic database for the constitution of the datasets used in producing reliable indicators of scientific production for Genome Canada’s funded researchers is discussed in Section 2.3.1. Section 2.3.2 addresses the construction of these datasets in detail, while Section 2.3.3 presents the bibliometric indicators used to quantify scientific outputs. Finally, Section 2.3.4 describes the statistical analysis performed on bibliometric indicators.

2.3.1 Database

Scientometrics

Access to a database containing the most complete bibliographic information on scientific serials published worldwide is essential for the gathering of data on scientific outputs. In this study, Thomson Reuters’ Web of Science (WoS), which includes three databases (the *Science Citation Index Expanded*TM [SCI Expanded], the *Social Sciences Citation Index*TM, and the *Arts & Humanities Citation Index*TM) covering the complete spectrum of scientific fields (e.g., natural sciences and engineering [NSE], social sciences and humanities [SSH]), was used to produce statistics on the scientific production of Genome Canada’s supported researchers.

Although the WoS lists several types of documents, only articles, research notes, and review articles were retained in the production of the bibliometric indicators, as these are considered to be the main types of documents through which new knowledge is disseminated in the NSE. In addition, these documents have been subject to peer review prior to being accepted for publication, ensuring that the research is of good quality and constitutes an original and robust contribution to scientific knowledge. In this report, articles, notes, and reviews are collectively referred to as “papers”.

Technometrics

Access to a database containing the most complete bibliographic information on patents is essential for the gathering of data on technological innovation. Patents are often used as a measure of invention. However, they are known to have a number of limitations, including:

- incompleteness: many inventions are not patented, since patenting is only one way of protecting an invention;
- inconsistency in quality: the importance and value of patented inventions vary considerably;
- inconsistency across industries and fields: industries and fields vary considerably in their propensity to patent;
- inconsistency across countries: inventors from different countries have different propensities to patent inventions, and different countries have different patent laws.

Despite these limits, patents are widely used to compare the level of technological development of different geographic and organizational entities. This report uses the US Patents and Trademark Office (USPTO) database. Its data are commonly used to measure invention, since the USPTO has one of the largest registers of patented inventions in the world. Because the US is the largest market in the world, the most important inventions tend to be patented there. Although the USPTO database presents an obvious bias towards the US, it is still a potent tool for country-level comparison. The analyses are exclusively based on utility patents that have been granted (and not patent applications).

2.3.2 Constitution of datasets

The dataset was constructed by querying genome-specific keywords in the titles of papers indexed in the WoS. The keyword set for the query was originally defined in 1999 by experts appointed by Genome Canada and by Science-Metrix analysts. The query has since then been revised to take into account the development of new topics, techniques, methods and vocabulary in the field. The resulting datasets comprise papers in core and peripheral genomics (such as papers in molecular biology that touch upon genome research), including GE³LS research. A similar approach was also used to build datasets of publications for the priority sectors (health, agriculture, environment, forestry and fisheries) and GE³LS, and to identify patents of relevance to genomics. Please note that the genomic publications in the mining and energy sectors were very limited. They are nevertheless partly covered in the environment sub-dataset (e.g. includes keywords such as “biomining”, “clean coal”, “renewable energy*”).

A bibliometric dataset for an institution is usually built by retrieving papers in which the name of the institution is found in the authors' address. Because Genome Canada is an organization that supports research as opposed to a research institute *per se*, its name is not expected to be found in the address field of papers published by the researchers it funds. This makes it virtually impossible to precisely identify the papers that had been produced with financial support from Genome Canada.

Instead, to build a dataset of papers supported by Genome Canada, a publication portfolio was built for each of the PIs and co-applicants who received funding from Genome Canada in Competition III. To do so, Science-Metrix used the listing provided by Genome Canada of individuals who were supported in Competition III. For the counterfactual analysis, Science-Metrix used a list of unsuccessful applicants for this competition.² Note that, for the social network analysis, portfolios were built for other Canadian genomics researchers (not only the ones who applied to Genome Canada's Competition III), so that this analysis covers the 500 most publishing (based on their publication record in the WoS) Canadian researchers in genome research. Due to ties, there were in fact 501 researchers presented in the collaboration network.

The identification of the different names used by an individual and the resolution of homographs is crucial to the production of statistics at the level of authors (i.e., researchers) and for linking financial support to scientific output. Science-Metrix has extensive expertise in author name disambiguation, having performed several contracts in which the names of thousands of researchers were disambiguated to assess the effect of various research funding programs. In brief, Science-Metrix used a combination of human expertise aided by powerful algorithms that examine author affiliations, fields of production, co-authors, co-citation patterns, and rare words used by the authors to accomplish this work.

2.3.3 Bibliometric indicators

Scientometrics

Using researcher portfolios (up to 2012 inclusively) built using the aforementioned methods as well as papers computed at the world and country (i.e., Canada; up to 2011) levels, the following indicators were calculated:

Number of publications: A count of the number of scientific papers written by authors associated with a funding organization (i.e., Genome Canada) based on author names or with a country based on author addresses. Full counting is used. This means that each author is counted once on a paper instead of being attributed a fraction of the paper based on the number of co-authors. At the country level, double counting is avoided; if there are two or more authors from Canada on a publication, it is counted only once for the country.

² Science-Metrix has a secret-level security clearance at the firm level and has a clearance for document safeguarding at the Protected B level. This means that Genome Canada can securely share these data with the firm. Only staff with appropriate clearance will have access to nominal data. Once on Science-Metrix servers, all data will be kept encrypted in their raw form and within Science-Metrix database system (Science-Metrix uses SQL Server 2012 for most of its data processing needs, and this relational database management system allows encryption at the column and table levels).

Specialization Index (SI): This measures the intensity of research of a given geographic or organizational entity (e.g., a country) in a given research area (e.g., domain, field) relative to the intensity of the reference entity (e.g., the world) in the same research area.

The SI can be formulated as follows:

$$SI = ((X_S/X_T))/((N_S/N_T))$$

Where,

X_S = Papers from entity X in a given research area (e.g., Canada in genomics)

X_T = Papers from entity X in a reference set of papers (e.g., Canada in the whole database)

N_S = Papers from the reference entity N in a given research area (e.g., world in genomics)

N_T = Papers from the reference entity N in a reference set of papers (e.g., world in the whole database)

An index value above 1 means that a given entity is specialized relative to the reference entity while an index value below 1 means the reverse. For example, if 10% of an organization's papers are in genomics, and the count for genomics papers at the international level represents only 5% of all papers, this organization is considered to be specialized in genomics and would have an SI score of 2.

Average of Relative Citations (ARC): The ARC is an indicator of the scientific impact of papers produced by a given entity (e.g., the world, a country, an institution, a researcher) relative to the world average (i.e., the expected number of citations). Because it is based on the citations received by the actual publications of an entity, it is said to be a *direct* measure of scientific impact.

The number of citations received by each publication is counted for the year in which it was published as well as for all subsequent years such that the citation window of papers published in different years differ (i.e., a 1996 paper accumulated citations over 17 years, whereas a 2005 paper accumulated citations over 8 years). To account for this variation in the citation windows of papers as well as for differences in the citation patterns across fields and subfields of science (e.g., there are more citations in Biomedical Research than in Mathematics), each publication's citation count is divided by the average citation count of all publications that were published the same year in the same subfield to obtain a Relative Citation count (RC). The ARC of a given entity is the average of the RCs of the papers belonging to it. An ARC value above 1 means that a given entity is cited more frequently than the world average, while a value below 1 means the reverse. The ARC was computed for all years covered in this study except 2012 since the citation window for papers published in that year is too short (publication year plus one). The minimal citation window required to obtain reliable scores for this indicator is of two years beyond the publication year (i.e., publication year + 2 years).

Percentage of publications in the 10% most cited world papers: The proportion of an entity's (e.g., the world, a country, a researcher) publications in the 10% most-cited publications in the database is determined using the relative citation (RC) scores of publications computed using a variable citation window (see above description of the ARC for the computation of RC scores). Because some publications are tied based on their RC scores, including all publications in the database that have an RC score equal to or greater than the 10% threshold, this often leads to the inclusion of slightly more than 10% of the database. To ensure that the proportion of publications in the 10% most-cited publications in the database is exactly equal to 10% of the database, publications tied at the threshold RC score are each given a fraction of the number of remaining places within the top 10%. For example, if a database contains 100 publications (i.e., the top 10% should contain 10 publications) and the 9th, 10th, 11th and 12th publications all have the same RC score, they are each given a quarter of the remaining two places in the top 10% (0.5 publications of the top 10% each). An institution whose publications rank second and ninth would therefore have 1.5 publications in the top 10% using whole counting (at the level of addresses). This indicator is computed for the same period as the ARC.

International Collaboration Rate (%): This is an indicator of the relative importance of international collaboration. For a given entity (e.g., a country or a researcher), the rate is calculated by dividing the number of papers written in collaboration with an author from a country other than that of the entity by the entity's total number of papers.

National Collaboration Rate (%): This is an indicator of the relative importance of national collaboration. For a given entity (e.g., a country or a researcher), the rate is calculated by dividing the number of papers written in collaboration by two or more authors from the entity's country by the entity's total number of papers.

Social Network Analysis: A collaboration networks were produced to help illustrate linkages between researchers based on co-authorship of scientific papers. Based on a matrix cross-linking the number of co-publications by the relevant entities, the GEPHI software program was used to produce a visual representation of the strength of the relationships between the selected 501 researchers. More specifically, a force atlas layout algorithm was used to establish the relative locations of the entities in the graphic representation.

In the network, each researcher is represented by a node of a size proportional to its scientific production in genomics. Individuals were not labeled using their names to keep the network anonymous. Yet, the nodes of GC-funded principal investigators (PI) and co-investigators (CI) were labeled to identify the sector(s) of the grant(s) awarded by GC to a given researcher (A = Agriculture, E = Energy, Env = Environment, F = Fisheries, FO = Forestry, G = GE3LS, H = Health and N = New Technology Development) as well as to appreciate their spread within the network. The health sector is dominant as is generally the case in the field of genomics in Canada and worldwide. The width of links is proportional to the number of co-publications between any pair of researchers. The following network indicators were computed:

- **Degree:** The degree of a node (a researcher) is the number of links that are adjacent to it. This represents the number of distinct researchers with whom a researcher collaborates in the network.
- **Weighted degree:** The sum of the links' width connected to a node (a researcher). This represents the number of non-distinct linkages to other researchers in the network. If a researchers as two-co-publications with another researchers, it will count twice in the weighted degree compared to once in the non-weighted degree.
- **Closeness centrality:** The average distance from a given node to all other nodes in the network. A node directly connected to every other nodes in the network would score 1, the highest possible closeness centrality score.
- **Betweenness centrality:** It measures how often a node appears on the shortest path between any two nodes in the network.
- **Eccentricity:** This score represents the distance between a node and the node that is furthest from it. A high eccentricity means that the furthest away node in the network is very far, and a low eccentricity means that the furthest away node is close. This is related to the network diameter measure as the diameter network is in fact the highest eccentricity score of any node in the network.

The network was produced for the 1998–2011 period. It was also produced (but not drawn) for three 4-year periods (i.e. 1999–2002, 2004–2007 and 2008–2011) to allow for a better understanding of the role GC played in structuring the network over time.

Technometrics

The statistics presented here concern utility patents that have been granted between 1996 and 2011 (and not patent applications). The dataset was used to produce detailed statistics based on the following indicators:

Number of patents (IP): Unlike scientific publications, patents possess two fields that contain bibliographic information relevant to the calculation of where a patent originates: the inventor field and the assignee field. These fields can be used to compute statistics on two different indicators—namely, invention and intellectual property (IP). The majority of patents are owned by corporations, and their addresses, which appear in the assignee field, are used to compute the geographical location of the ownership of IP. In some cases, where an individual owns the IP, the address of this owner is used to compute the location of the IP. For the sake of simplicity, this report presents data on IP only.

Specialization index (SI): This is an indicator of the concentration of IP in a given geographic or organizational entity relative to the overall IP for a given reference. For example, if the percentage of Canadian patents in the field of genomics is greater than the percentage of patents in this field at the world level (the reference), then Canada is said to be specialized in this field.

Average of Relative Citations (ARC): The number of citations received for each patent were counted for the year in which they were granted and all subsequent years. Thus, as for papers, patents issued in different years have citation windows of varying length. The number of citations of each patent was therefore normalized by the average number of citations of patents issued the same year in the same primary class (based on the USPTO classification) to obtain a relative citation count (RC). The ARC of a given entity is the average of the RCs of the patents belonging to it. An ARC value above 1 means that a given entity is cited more frequently than the world average, while a value below 1 means the reverse.

2.3.4 Statistical Analyses

To establish whether there were significant differences between various entities in terms of scientific production and scientific impact, a series of statistical tests were performed in SYSTAT. For each statistical test, the difference was considered to be significant at $p < 0.05$.

Because data on scientific production and impact are not normally distributed, non-parametric tests were used. In most cases, the Mann-Whitney U test was used to test a null hypotheses for significance.

2.4 Case studies

The purpose of the case studies was to provide insight on key themes that span across projects and that relate to the success and impact of large-scale genomics projects. As such, the eight case studies will help Genome Canada identify and understand how various elements, conditions and variables—such as coordination, partnerships, strategic sector focus, GE³LS integration, access to technology, or other design features—contribute to the achievement of Genome Canada’s strategic objectives.

As part of this method, Science-Metrix conducted 21 interviews from September to November 2013 and reviewed documents and files for each case including progress, interim and final reports. Key findings from both the document review and interviews were integrated and formed the basis of individual case studies. The findings on relevance and performance across the individual case studies were summarized for as part of a cross-case analysis.

2.4.1 Case selection

During the design phase of the evaluation, the ESC identified and articulated a rationale to focus the case studies on emerging resource sectors, namely agriculture, environment/energy/mining, fisheries, and forestry in order to address particular needs relating to the implementation of the 2012-2017 Strategic Plan. Because other lines of evidence identified GE³LS as a key priority for Genome Canada, it was also decided to review a stand-alone GE³LS project. Project selection considered particular characteristics and contexts (e.g. international or interregional collaboration,

technology development, etc.) and also considered cases that were perceived as highly successful and those perceived as more moderately successful, in order to better understand the factors that contribute to project success and impact. The focus was also on completed (or very advanced) projects, as these would provide more evidence towards longer-term impacts. The final choice of eight cases was validated by Genome Canada (Table 6).

Table 6 Case study projects

Project Full Name	Identifier used in reports	Sector (Focus)
Arborea phase II	Arborea-II	Forest
Atlantic cod genomics and broodstock development	Cod	Fisheries and Aquaculture
Consortium for genomic research on all Salmonids project (cGRASP)	Salmonids	Fisheries and Aquaculture
Designing oilseeds for tomorrow's markets	Oilseeds	Agri-Food
Environmental barcoding through massively parallelized sequencing	Barcoding	Environment/Energy/Mining (Technology Development)
Grape and Wine Genomics	Grape and Wine	Agri-Food
Value addition through Genomics and GE3LS (VALGEN)	VALGEN	Agri-Food (GE3LS)

2.4.2 Interviews

The list of interview candidates for the case studies was developed with the input of the ESC and the Genome Centres. Each case study comprised two to three interviews (for a total of 23) with relevant stakeholders, including one with the principal investigator, one with a co-investigator and one with a contributor, partner and/or end user. All 23 interviews were conducted by telephone. In addition, in one case, one partner consented to provide some input by email on a small selection of key questions.

Interview responses were analyzed in order to identify common views across key informants for each case, while ensuring that interesting but isolated statements are also captured. Findings were identified for each pertinent evaluation question and indicator and were used to complement information extracted from the document review.

2.4.3 Document review

A project-level document review was conducted for each case, examining applications, quarterly, interim and annual reports as well as information such as collaboration agreements, scientific publications and any other related outputs as provided by Genome Canada and interviewees.

2.5 International comparative review

The purpose of this review was to conduct an in-depth review will be conducted of five organizations that present key features of interest to help address specific evaluation questions. In particular, this review will be used to help assess the continued role for national support of

genomics research and the contribution of Genome Canada to Canada’s global leadership in this field, as well as to position Genome Canada in the global context according to elements such as operating environment, strategy development, design and delivery of programs or projects, and best practices.

The data collection and analysis for the international comparative review were based on two methods: a literature review and targeted interviews with representatives from the international organizations, as described in more detail below. Note that interviews were conducted only for three of the five organizations considered, given that contacts provided for the Beijing Institute of Genomics and for France Génomique did not respond to our invitations.

2.5.1 Selection of international organizations

The actual choice of comparable organizations was informed by discussions with Genome Canada Project Manager and ESC members. These consultations led to the selection of the following five countries:

- China – Beijing Institute of Genomics (BIG)
- France – France Génomique
- Norway – The Research Council of Norway
- UK – Wellcome Trust
- US – National Human Genome Research Institute (NHGRI)

Table 7 provides an overview of these five organizations to better illustrate the criteria used in this selection, which included:

- Key features of interest for comparison
- Relevant changes since 2008
- Available documents of interest
- Collaboration with Genome Canada

Key features of interest included strategy development, organizational structure, performance and funding, and collaborative practices – including collaboration with Genome Canada.

Table 7 Overview of international organizations selected for the comparative review

Organization	Country	Website	In 2009 eval	Key features of interest for comparison	Changes since 2008 (org structure, strategy, other)	Available documents of interest	Collaboration with GC
The Research Council of Norway	Norway	http://www.forskning.sradet.no/en/Homepage/1177315753906	Y	<ul style="list-style-type: none"> * Ethical, legal and social aspects (ELSA) * Financial performance and funding * International collaboration 	<ul style="list-style-type: none"> * FUGE replaced by BIOTECK2021, evolved from basic research to broader-based initiative with relevance and benefit to industry and society as additional key areas. * Recent increases in public investment in R&D - the Council's budget has increased by more than NOK 1.6 billion in last 5 years (growth rate of 30%). 	<ul style="list-style-type: none"> * Report of the Executive Board for 2010 * FUGE evaluation report (2011; summary in English) 	MOU with Genome Canada FUGE (Functional Genomics) collaboration with GC on All Salmonids Project
Wellcome Trust	UK	http://www.wellcome.ac.uk/	Y	<ul style="list-style-type: none"> * Partnership focus * Funding and investment * Strategy development * Organizational structure (independence) 	<ul style="list-style-type: none"> * Genomics key focus of 2010-20 Strategic Plan * Developed a cadre of research leaders, contributed to the creation, development and maintenance of major research resources, growth of centres of excellence * Since the last evaluation, they transformed their investment policy, combining aligned partnerships with the strongest external managers and building in-house resources to own selected assets directly. 	<ul style="list-style-type: none"> * Annual Report and Financial Statements 2012 * Strategic Plan 2010-20 	Partnership with Genome Canada
National Human Genome Research Institute (NHGRI)	US	http://www.genome.gov/	Y	<ul style="list-style-type: none"> * Organizational structure * Partnerships * Strategy development 	<ul style="list-style-type: none"> * In 2010, NHGRI launched the Genetics/Genomics Competency Center - online tool to help educators in their teaching * In 2012, NHGRI reorganized its institutional structure by dividing the Extramural Research Program into 4 new divisions, reflecting the expanding scope of genomics research. 	<ul style="list-style-type: none"> * Justification of Estimate for Congressional Appropriations Committee and Budget request (2003-2013) * Long-Range Planning Process 2008-2011 * 2011 vision for future of genomics research (health) 	Partnership with Genome Canada (e.g., 2011 North American Conditional Mouse Mutagenesis Project, funded by GC)
France Génomique	France	https://www.france-genomique.org/spip/	N	<ul style="list-style-type: none"> * Technology infrastructure * Strategy development 	<ul style="list-style-type: none"> * Founded in 2010 with government funding, consortium of major genomics platforms in France. Through technology development, expertise, services, and infrastructure capacity, aims to position and maintain France at the highest levels of competitiveness and performance, with state-of-the-art production and analysis of genomics data. * Funds some large-scale projects. 	Somewhat limited (website and program documents)	
Beijing Institute of Genomics (BIG)	China	http://english.big.cas.cn	N		<ul style="list-style-type: none"> * Part of the Chinese Academy of Sciences, founded in 2003, offers two platforms: Genomics/Bioinformatics and Cell Biology. * BIG was the first in China to finish the genome sequencing of SARS virus and to develop the diagnostic reagent kit for the virus. 	Limited (website only)	Partnership with Genome Canada/Genome Québec (HapMap project)

2.5.2 Literature review

The literature review component of the international comparative review focused on identifying and extracting relevant information and data from the organizations' websites and other relevant sources such as grey literature, funder announcements etc. This material helped contextualize the operating environment, provided insight into the relevance of the national role, and shed light on alternative models implemented in international jurisdictions to support genomics research.

In addition to the publically available sources, Science-Metrix asked international interviewees (see below) to provide any relevant non-public information that they could share. This approach did not yield many additional documents or insights.

2.5.3 Interviews

For each selected organization, individuals knowledgeable about their organization and the country's overall support mechanisms for genomics research were contacted to conduct targeted telephone interviews. These individuals were identified with the help of Genome Canada and contacted by Science-Metrix. Three interviews were conducted with representatives of the Research Council of Norway (RCN), the UK Wellcome Trust (WT) and the US National Health Genomics Research Institute (NHGRI). Given that 1) no interviews were conducted with representatives of the Beijing Institute of Genomics and France Génomique and 2) the US and UK have several funding bodies that support genomics research, representatives of other organizations in the UK and the US were invited to participate to complement other interviews. As a result, one additional interview was conducted with a representative of the Agricultural Research Services of the US Department of Agriculture. Moreover, two additional interviews helped draw a more complete picture of the genomics research funding context in other countries, specifically with international experts from the San Diego Center for Algae Biotechnology in the US and the Garvan Institute of Medical Research in Australia.

In addition to collecting key information on the context surrounding genomics research in the interviewee's organization/country, the interviews were used to help inform questions related to Canada's leadership in -omics research (evaluation question 3) and GE3LS (evaluation question 6), as well as Genome Canada's contribution to the country's world standing in this regard.

3 Challenges, limitations and mitigation strategies

The evaluation challenges and limitations and the corresponding mitigation strategies for each line of evidence are described in Table 3. Note that, generally, either specific mitigation strategies were identified or other lines of evidence were used to fill any gaps in information that may have resulted from these limitations, e.g. the survey of other stakeholders and case study interviews with partners, compensates for the limited number of interviews conducted with partners. These limitations have also led to a number of recommendations for future evaluations.

Challenge/limitation	Mitigation strategy and implications
Management and delivery review - Interviews	
<p>Relatively few individuals within each external stakeholder sub-group were interviewed; responses are thus not representative of the whole population. This is especially true for the unfunded group, as only two researchers were interviewed and no survey was conducted with this group.</p>	<p>Other lines of evidence at least partially compensate for the limited number of unfunded researchers interviewed. Surveys were conducted with PIs and co-PIs and bibliometric analyses have compared the output and impact for both funded and unfunded researchers.</p>
<p>Since Genome Canada provided the names of most of the internal and external stakeholders interviewed for this evaluation, this might have resulted in a possible selection/sampling bias (i.e., a systematic error due to a non-random sample of a population, causing some members of the population to be less likely to be included than others and resulting in a sample in which all population members are not equally balanced or objectively represented).</p>	<p>The impacts of a potential selection/sampling bias were minimized by framing interview questions and prompts in a manner that encouraged interviewees to provide verifiable examples/supporting documents in relation to their answers, wherever applicable. In the final evaluation report, this was also mitigated by triangulating multiple lines of evidence (e.g., case studies, surveys, review of internal and external documents) to identify and assess any concerns or opinions that might not have been reported/shared by internal stakeholders.</p>
<p>Scheduling of external stakeholders became somewhat challenging, as several partners, and unfunded researchers who were originally suggested as primary or back-up interviewees declined to participate or did not respond to invitations. The initial target number for these stakeholder groups was thus not reached.</p>	<p>Additional partner names were extracted from a list of potential survey participants. Only individuals who had not participated in the survey were solicited for an interview. Overall, 6 partners were interviewed, which is close to the target (9), and all major partner groups were covered (i.e. granting agency, private sector, federal department, not-for-profit organization). The comprehensive survey conducted with 'other stakeholders' includes partners, which will mitigate for the reduced number of partner interviews.</p>
Management and delivery review - Document and File Review	
<p>Data from the document/literature reviews did not always provide evidence to show the relationship between activities and outcomes (i.e., attribution), particularly when there may be other factors/players contributing to the outcomes (e.g. other funding organizations, international initiatives)</p>	<p>Information from the document and file review have to be considered in combination with primary data from the interviews consulted for this method, in order to gain a better understanding of the contribution of GC to outcomes.</p>

Challenge/limitation	Mitigation strategy and implications
<p>The financial analysis was somewhat affected by incomplete/unavailable data due to the timing of the evaluation. Available funding information provided did not fully cover the past as well as the current evaluation periods. For example, for the 2001-2008 period, co-funding information was based on the 2009 evaluation (covering until October 2008) and for the 2009-2014 period, until November 2013. Financial statements were available to 2012-13; these have not yet been produced for the final year (2013-14).</p>	<p>Following discussions with finance staff, it appears that numbers provided were not expected to change/ have changed significantly by year end. Therefore, the trends identified between the two periods can be considered as reliable to a large extent.</p>
<p>The project-level information available in existing databases and the lack of integration of different databases presented challenges in extracting or analyzing pertinent financial and performance data in a timely manner. In particular, the lack of common project identifiers between databases resulted in the need to manually validate some information (e.g., to confirm whether two projects with different identifiers were actually the same project). Other useful indicators that would be based on data that will be compiled in the forthcoming performance measurement database could not be prepared for this evaluation (e.g., patents) as this database is not yet fully functional.</p>	<p>Data was manually validated when possible (e.g., to determine the number of project funded by Genome Canada), which also helped support the analyses conducted in other methods (i.e., surveys, bibliometrics). In the case of missing information, this was known at the design stage, such that known gaps were filled whenever possible using other evaluation methods.</p>
Survey	
<p>The lack of complete contact information on co-funders resulted in the decision to pool potential respondents for this group with other stakeholders, rather than to conduct a standalone survey for this group as originally proposed.</p>	<p>Despite sustained effort on the part of Genome Canada to extract or compile complete contact information for co-funders (i.e., names, email addresses), the resulting list was too modest to allow for a standalone survey for this group. This group was therefore administered the same survey as for other stakeholders (i.e., collaborators, end-users, and snowball sampling results). In addition, some of the co-funders were identified by Genome Canada as key partners, and were consulted via a telephone interview instead of via the survey to collect more in-depth views.</p>
<p>Small sample size combined with low response rates may limit possible analyses for some surveys and/or questions.</p>	<p>Pre-notice emails were sent by GC to potential survey respondents. Reminders were also sent at regular intervals by Science-Metrix. Bounced back emails were verified manually in order to find other contact information. Nonetheless, the margins of error remain slightly higher than 5% (between 6.1% and 10.5%). The survey results should therefore be interpreted with caution, in particular for distributions that are close to 50-60%, and especially for PI and GE3LS survey results.</p>
<p>There was often overlap in the potential respondents between separate Genome Canada projects (i.e., same individual may be identified for more than one project, as PI, co-applicant and/or GE3LS leader), as well as between methods (e.g., interviews).</p>	<p>Care was taken to ensure that individuals were not invited to participate in more than one survey or to more than one method. Interviews took priority over surveys. For individuals found in more than one survey list, order of priority was GE3LS, PI and then co-PI survey.</p>

Challenge/limitation	Mitigation strategy and implications
<p>Early-fall grant applications may have limited the availability of researchers.</p>	<p>As the surveys were launched in late August/early September, the summer vacation period was avoided. However, some PIs mentioned they could not complete the survey because of their involvement in grant applications. The survey periods were extended to the maximum in order to allow them to complete the survey.</p>
<p>Analysis of survey results was sometimes hindered by the use of the same questions as the 2009 evaluation in order to support the longitudinal analysis.</p>	<p>Discussion and efforts took place during the survey design to assess whether the survey questions would adequately address the evaluation questions and some additions and modifications were made as a result. However, in some cases, the questions that were retained to support the longitudinal analysis did not provide the necessary level of detail or focus to allow for strong conclusions to be made on evaluation issues of interest to Genome Canada and its stakeholders.</p>
Bibliometrics	
<p>Certain analyses on Genome Canada-funded research were limited due to the small population size in some sector or groups (note that this was also the case for GE³LS; see below). Similarly, the social network analyses (i.e., collaboration network) only included the 500 most publishing Canadian researchers in genomics, as opposed to the top 1,000 as originally planned.</p>	<p>To mitigate this, some categories were combined (e.g., not previously funded and previously funded PIs), and other analyses were conducted only for the entire population (e.g., collaboration and social network analysis; sectors were identified in the network but not analysed separately). In cases where the results may be affected by population size, this is clearly indicated in the report.</p> <p>For the social network analyses, it was considered more meaningful to analyse the top 500 researchers in genomics as it became clear, while cleaning the data, that most researchers beyond this leading group did not have a production of a sufficient size to provide meaningful insights into the structure of the Canadian network in genomics (i.e. less than 2.2 publications per year on average over the past 14 years).</p> <p>Also, the analysis of collaboration network statistics at the sector level appeared unreliable in Forest Genomics, GE³LS and in Fisheries & Agricultural Genomics due to the small number of Genome Canada-funded PIs and co-PIs in these areas. For the remaining areas, statistics were produced but Science-Matrix recommends interpreting them cautiously due to potentially important fluctuations through time resulting from the rather small average number of connections of researchers in the Canadian collaboration networks in these areas. Adding more researchers might not prove to be a great solution since people with smaller outputs are likely to have fewer connections.</p> <p>Overall, it appears best to rely on the findings based on the aggregated statistics for Genomics as a whole.</p>
<p>Several limitations relating to bibliographic databases may have affected the findings related to GE³LS: the GE³LS output measured in the WoS is likely not comprehensive as is often the case in social sciences (i.e., books, grey literature, peer-reviewed literature not covered in main bibliographic databases). GE³LS outputs might appear more frequently in public media than in peer-reviewed scientific</p>	<p>Bibliometric data might not fully reflect the GC contribution to GE³LS research. It is also not impossible that other countries would rank better if we had more extensive bibliographic databases than those currently available. As such, these limitations are clearly stated in the report, along with the note that “further studies could help provide a more comprehensive analysis of the evolution of Canadian leadership in this area.”</p>

Challenge/limitation	Mitigation strategy and implications
<p>literature. In addition, bibliometric analyses of the social sciences could underestimate the production of non-English speaking countries.</p>	<p>Moreover, the statistics presented at the level of researchers (PIs) should be interpreted with caution. In particular, it was not possible to study trends in the scientific impact and collaboration patterns of PIs and UNPIs in GE3LS due to their small number of scientific papers in this area. The numbers were still too small even when co-investigators were included in the analysis.</p>
<p>The groups being compared might not be fully comparable. For example, senior researchers might be over- or under-represented among PI; this limits our ability to attribute the observed effect to Genome Canada funding since senior researchers do not exhibit the same pattern as emerging researchers in terms of growth in production/impact. In many instances, this limits the ability to attribute the observed effect to GC funding..</p>	<p>Wherever this limitation impacted on the question of attribution, the findings with regard to the effect of Genome Canada funding were nuanced; for example, only a partial effect was confirmed as likely.</p>
<p>Given the time required to prepare and issue a patent, the post-grant interval may have been too short to allow patenting activity to be adequately detected and measured.</p>	<p>This limitation could not be mitigated and so was clearly identified in the evaluation report. It could be of interest to study patent applications instead of issued patents to get a more up-to-date status on the inventiveness of Canada and of Genome Canada-supported individuals in genomics. In particular, this would allow circumventing a key limitation in assessing the effect of research funding on longer term socio-economic benefits such as patenting. Indeed, there are important delays between the date of application and issuance of patents at the USPTO (lags of 5 years are not unusual). Even before submitting an application there is a long time lag between research activities and the subsequent applications of research findings that could lead to patent application. Thus, monitoring patent applications instead of issued patents could reduce significantly the time that must elapse following the funding of research before such outputs can be measured and attributed to the given source of funds. Unfortunately, quality data on patent applications are not made publicly available by the USPTO as the publication of patent application is not mandatory.</p>
Case studies	
<p>Relatively few individuals for each case could be interviewed in the interest of time and level of effort required. In addition, some of the cases ended in 2010 while some are still ongoing. As such, interviewees either could not remember all the details or were only able to estimate future impacts.</p>	<p>To the extent possible, interview findings were verified against all available documentary material for each case. The cross-case approach also allows for common findings to be drawn out across multiple cases. Other lines of evidence will be triangulated with the case study findings for the analysis of the final report.</p>
<p>Three stakeholders each were interviewed for seven of the eight cases. For the eighth case, it was only possible to interview two stakeholders.</p>	<p>A third stakeholder for this project emailed responses to a few key questions. A deeper review of documents in this case mitigated for the lack of a third full interview.</p>

Challenge/limitation	Mitigation strategy and implications
<p>Organizations other than Genome Canada contributed funding and/or non-financial support to all of these cases. As such, it is often challenging to attribute all the outcomes of each case study directly to Genome Canada. Furthermore, the attribution of Canada-wide socio-economic benefits to a single case or organization is often difficult as other contextual factors may also have played a role (e.g., market or regulatory conditions).</p>	<p>To the extent possible, mitigation in this respect focuses on the contribution of Genome Canada to various outcomes and socio-economic benefits.</p>
<p>For ongoing projects, no final report was available and not all quarterly reports were provided. Final reports usually summarize all major outcomes achieved while quarterly only focus on realizations since the last quarterly report. Therefore, it was difficult to draw a complete picture of outcomes achieved by these projects.</p>	<p>Interviews were used to fill any gaps identified during the document review. Additionally, whenever the most recent quarterly report was not provided in the initial transmission of project documents by GC, a request was sent to the Centres to have access to this document.</p>
<p>International comparative review</p>	
<p>The literature review relied primarily on publically available sources, which resulted in a great variety in resources and information collected and analyzed for each organization. In particular, there was very little information available for most of the evaluation questions on the Beijing Institute of Genomics and France Génomique.</p>	<p>While additional search was performed to retrieve information from other sources than official websites of these organizations, these efforts did not result in a great enhancement of the material. Given that Science-Metrix did not succeed in scheduling interviews with representatives of these organizations due to a lack of response/interest, additional internal documents could not be requested. Issues with data availability and comparability (see below) also limited efforts to conduct a comparative assessment of efficiency and cost-effectiveness of Genome Canada with other delivery models to support genomics research, which had been envisioned in the original design.</p> <p>As a mitigation strategy, Science-Metrix identified additional organizations in other countries and following a consultation with Genome Canada conducted additional interviews with representatives of these organizations. Due to the timeline and scope of the project, an in-depth focused review of documents could not be performed for these additional organizations. However, the additional interviewees provided some valuable views that informed the evaluation questions.</p>
<p>None of the organizations included in this comparative review is a true comparable to Genome Canada due to its independent standing and the scope of genomic science it supports. In fact, several of the organizations limit their focus on genomics in health and medicine while other areas of genomics are also supported, albeit through other institutions in that country.</p>	<p>The selection of organizations for this review was conducted based on a set of criteria deemed important for Genome Canada and its five-year evaluation. Efforts were made to include diverse organizations representing different models of support to genomic research at a national level. This diversity in strategic management approaches as well as different contexts of the organizations was considered valuable for the review as it could provide innovative or inspirational information for Genome Canada. Nevertheless, caution is warranted when interpreting the findings of this report as the operating environment of each organization is significantly different from the one of Genome Canada.</p>

3.1 Considerations for future evaluations

At the end of the evaluation process, especially considering the list of challenges, limitations and mitigations strategies, Science-Metrix has also arrived at some lessons learned that may be of use for future evaluations or performance measurement studies.

International comparative review: Given observed challenges and limitations, this method would need to be seriously re-considered if used for the future evaluations. This may include advance planning and the involvement of senior Genome Canada representatives to ensure the engagement of a variety of international interviewees. In addition, in order to ensure that *comparable* information across countries or organizations could be gathered, a clear set of indicators or criteria should be mapped out and their feasibility assessed very early in the evaluation design phase.

Survey: A longitudinal analysis is not recommended for the next survey as this has the potential to constrain the survey question, especially since this analysis did not provide particularly rich information to track Genome Canada's progress over time. This was especially the case regarding application and translation questions. These questions should be reviewed in the next evaluation to more accurately capture impacts, rather than serving mainly to compare answers with the results of earlier surveys.

Social network analysis/bibliometrics: Given the highly technical nature of social network analysis, future efforts to conduct in-depth social network analyses should include transfer to a more specialized audience (e.g., program staff) that may derive more insight from the nuanced findings. In light of the study's findings, it would also be advisable, as is the case with any bibliometric methods, to focus more in-depth analyses on sectors or contexts where the number of researchers/papers is sufficient to draw robust conclusions. Some of these lessons also apply more generally to the bibliometric analyses, which provide valuable insights but are sometimes challenging to communicate to the broader audience that will consult the evaluation report. As such, Science-Metrix recommends to continue the practice of providing detailed bibliometric analyses and data separately (i.e., as a complement to the evaluation report) in order to meet the information needs of Genome Canada.

Patent analysis: As noted in the report, to date, simply not enough time has passed post-Genome Canada funding competitions to be able to track patent activity in any meaningful manner. However, patenting activity should be able to be assessed more adequately in the next five year evaluations, especially if the national performance measurement database provides project-level data on this activity, as expected upon its full implementation. In particular, having access to such a database would solve the important issue of attributing specific patents to GC funding which is more complex than for research papers.

Finally, as outlined in the recommendations, ongoing improvements to **Genome Canada's performance measurement practice's and tools, as well as better integration of its various information systems** will help support future evaluation efforts.

Genome Canada Five Year Evaluation

Appendix 2 – Cross-Case Analysis

Date:

February 28, 2014

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Acronyms

ABC	Competition in Applied Genomics Research in Bioproducts or Crops
BC	British Columbia
CFI	Canada Foundation for Innovation
cGRASP	Consortium for genomic research on all Salmonids project
DFO	Department of Fisheries and Oceans
ESC	Evaluation Steering Committee
GAPP	Genomic Applications Partnership Program
GDP	Gross Domestic Product
GC	Genome Canada
GE ³ LS	Genomics ethical, environmental, economic, legal or social aspects
ESC	Evaluation Steering Committee
HQP	highly qualified personnel
iBOL	International Barcode of Life Project
IP	Intellectual Property
NSERC	Natural Sciences and Engineering Research Council
SSHRC	Social Sciences and Humanities Research Council
STIC	Science and Technology Innovation Centre
UK	United Kingdom
US	United States
VALGEN	Value addition through Genomics and GE ³ LS

1 Introduction

The present technical report summarizes the findings from eight case studies conducted for the second five-year evaluation of Genome Canada. As part of this review, Science-Metrix conducted 23 interviews from September to November 2013 and reviewed documents and files for each case including progress, interim and final reports. Note that this is an internal report produced independently by Science-Metrix to summarize the findings of the case studies. Because this method represents one of several lines of evidence used to address the evaluation questions, **the data presented herein should not be interpreted as a comprehensive answer to each question.**

The purpose of this review was to provide insight on key themes that span across projects and that relate to the success and impact of large-scale genomics projects. As such, the case studies will help Genome Canada identify and understand how various elements, conditions and variables—such as coordination, partnerships, strategic sector focus, GE³LS integration, access to technology, or other design features—contribute to the achievement of Genome Canada’s strategic objectives

A brief review of the methodology and the limitations are presented in Section 2. Key findings on relevance and performance across cases (i.e., cross-case analysis) are presented in Sections 3 to 8. Note that the presentation of findings based on the original evaluation questions has been grouped as per the key themes of interest to Industry Canada as per the expected results of the funding agreement.

2 Methodology

The purpose of the case studies was to provide insight on key themes that span across projects and that relate to the success and impact of large-scale genomics projects. As such, the eight case studies will help Genome Canada identify and understand how various elements, conditions and variables—such as coordination, partnerships, strategic sector focus, GE³LS integration, access to technology, or other design features—contribute to the achievement of Genome Canada’s strategic objectives.

As part of this method, Science-Metrix conducted 21 interviews from September to November 2013 and reviewed documents and files for each case including progress, interim and final reports. Key findings from both the document review and interviews were integrated and formed the basis of individual case studies. The findings on relevance and performance across the individual case studies were summarized for as part of a cross-case analysis.

2.1 Case selection

During the design phase of the evaluation, the Evaluation Steering Committee identified and articulated a rationale to focus the case studies on emerging/resource sectors, namely agriculture, environment/energy/mining, fisheries, and forestry in order to address particular needs relating to the implementation of the 2012-2017 Strategic Plan. Because other lines of evidence identified GE³LS as a key priority for Genome Canada, it was also decided to review a stand-alone GE³LS project. Project selection considered particular characteristics and contexts (e.g., international or interregional collaboration, technology development, etc.) and also considered cases that were perceived as highly successful and those perceived as more moderately successful by representatives of the Genome Centres, in order to better understand the factors that contribute to project success and impact. The focus was also on completed (or very advanced) projects, as these would provide more evidence towards longer-term impacts. The final choice of eight cases was validated by Genome Canada.

Table 1 indicates the project name, sector and an identifying tag that will be used to refer to each project for the remainder of the report.

Table 1 Project Information

Project Full Name	Identifier	Sector (Focus)
Arborea phase II	Arborea-II	Forest
Atlantic cod genomics and broodstock development	Cod	Fisheries and Aquaculture
Consortium for genomic research on all Salmonids project (cGRASP)	Salmonids	Fisheries and Aquaculture
Designing oilseeds for tomorrow’s markets	Oilseeds	Agri-Food
Environmental barcoding through massively parallelized sequencing	Barcoding	Environment/Energy/Mining (Technology Development)
Genozymes for Bioproducts and Bioprocess Development	Genozymes	Environment/Energy/Mining
Grape and Wine Genomics	Grape and Wine	Agri-Food
Value addition through Genomics and GE ³ LS (VALGEN)	VALGEN	Agri-Food (GE ³ LS)

2.2 Data collection methods

2.2.1 Interviews

Each case study comprised approximately three interviews (total of 23; see limitations) with relevant stakeholders, including one with the principal investigator, one with a co-investigator and one with a contributor, partner and/or end user. All 23 interviews were conducted by telephone. In addition, in one case, one partner consented to provide some input by email on a small selection of key questions.

Interview responses were analyzed in order to identify common views across key informants for each case, while ensuring that interesting but isolated statements are also captured. Findings were identified for each pertinent evaluation question and indicator and were used to complement information extracted from the document review.

2.2.2 Document review

A project-level document review was conducted for each case, examining applications, quarterly, interim and annual reports as well as information such as collaboration agreements, scientific publications and any other related outputs as provided by Genome Canada and interviewees.

2.3 Limitations, challenges and mitigation strategies

Challenges and associated mitigation strategies for the preparation of this technical report are outlined in the table below.

Table 2 Challenges, limitations and mitigation strategies

Challenge/limitation	Mitigation strategy
Relatively few individuals for each case could be interviewed in the interest of time and level of effort required. In addition, some of the cases ended in 2010 while some are still ongoing. As such, interviewees either had issues with recall (e.g., could not remember all the details of the project under review) or were only able to estimate future impacts .	To the extent possible, interview findings were verified against all available documentary material for each case. The cross-case approach also allows for common findings to be drawn out across multiple cases. Other lines of evidence will be triangulated with the case study findings for the analysis of the final report.
Three stakeholders each were interviewed for seven of the eight cases. For the eighth case, it was only possible to interview two stakeholders .	A third stakeholder for this project emailed responses to a few key questions. A deeper review of documents in this case mitigated for the lack of a third full interview.

Challenge/limitation	Mitigation strategy
<p>Organizations other than Genome Canada contributed funding and/or non-financial support to all of these cases. As such, it is often challenging to attribute all the outcomes of each case study directly to Genome Canada. Furthermore, the attribution of Canada-wide socio-economic benefits to a single case or organization is often difficult as other contextual factors may also have played a role (e.g., market or regulatory conditions).</p>	<p>To the extent possible, mitigation in this respect focuses on the <i>contribution</i> of Genome Canada to various outcomes and socio-economic benefits.</p>
<p>For ongoing projects, no final report was available and not all quarterly reports were provided. Final reports usually summarize all major outcomes achieved while quarterly only focus on realizations since the last quarterly report. Therefore, it was difficult to draw a complete picture of outcomes achieved by these projects.</p>	<p>Interviews were used to fill any gaps identified during the document review. Additionally, whenever the most recent quarterly report was not provided in the initial transmission of project documents by Genome Canada, a request was sent to the Centres to have access to this document.</p>

3 Relevance (Continued need for program)

Summary: The case studies show a clear continued need for Genome Canada to support genomics research: a strong consensus across all eight case studies indicated that there was very little likelihood of projects proceeding in the absence of Genome Canada funding. The organization and its funding remain relevant to facilitate large-scale projects, to help attract other funders, and to support research that is not funded through other means.

Evaluation Question 1c) – Would the research have been carried out if Genome Canada had not existed?

A strong consensus across all eight case studies indicated that there was very little likelihood of projects proceeding in the absence of Genome Canada funding. The majority of interviewees said that outcomes could not have been achieved without Genome Canada. Only a few cases could have found funding to proceed through other sources, and if they had, it is likely that they would have proceeded at a significantly smaller scale or a slower pace. In particular, Genome Canada's support was instrumental in:

- Facilitating aspects of large-scale projects (e.g., multi-stakeholder collaboration, national or international scope, enabling access to multiple technology platforms, etc.).
- Providing a springboard to establish co-funding agreements. While project co-funding is mandatory, many interviewees noted that it was easier to attract other potential funders with Genome Canada funding in hand.
- Supporting research that is not widely funded through other mechanisms (e.g., emerging sectors, GE³LS research). Similarly, in Canada, there are few private foundations (unlike in the United States) supporting large genomics projects, such that Genome Canada support is critical.

4 Extent to which Genome Canada has contributed to enhanced support and capacity for genomics research

Summary: Genome Canada's contribution to genomics research support and capacity was explored by examining the focus on high priority research themes and the extent of co-funding across cases. Generally, all the cases were highly aligned with both Genome Canada's strategic plan and the individual sector strategies. Nevertheless, unmet needs still exist (examples detailed below).

Cases achieved a 1:1 co-funding ratio and some anecdotal evidence of additional leveraging exists. It appears that, moving forward, there is a need to increase investment in genomics from both the private and government sector, although there were mixed views on this topic and few suggestions on how to do so. Notably, the mandatory co-funding model can affect the ability of researchers to conduct innovative/higher-risk research, as partners from the private sector are generally reluctant to support such research.

Evaluation Question 2a) – How effective has Genome Canada been in developing strategies to identify and focus on high priority strategic research themes?

While the Genome Canada 2012-2017 Strategic Plan was launched after the start of the individual projects chosen for this case study, all are generally well-aligned with the Plan's main objectives,

especially to accelerate translation, attract investment from a wider range of stakeholders, and enhance GE³LS opportunities. Similarly, while all of the cases began before the Genome Canada Sector Strategies were officially launched, it is clear that each case is in fact well-aligned with key priorities outlined for each sector.

- **Arborea-II** (Forest) – role of genomics in mitigating sector challenges and creating opportunities;
- **Cod and Salmonids** (Fisheries) – development of genomics tools, species sustainability, breeding programs;
- **Oilseeds, Grape and Wine, VALGEN** (Agri-food) – improving human and animal health, boosting Canada’s competitiveness through food quality, smoothing out the regulatory path for agricultural biotechnologies;
- **Barcoding** (Environment/Energy/Mining) – focus ongoing development of genomics applications on critical broad-interest challenges;
- **Genozymes** (Environment/Energy/Mining) – integrate genomics into energy operations and regulations to generate environmental, industrial and broader societal benefits.

Despite this alignment with the key priorities for Genome Canada, interviewees across cases indicated that opportunities still exist to fill other ongoing needs such as:

- Capacity-building for transfer and application in all sectors; this encompasses training and support for projects that will result in products to serve both science and end-user needs;
- Long-term genomics support to maintain project “momentum” (see next question);
- Increased bioinformatics/applied statistics/mathematical modelling capacity; and
- Increased capacity, coordination and awareness-building for GE³LS.

Evaluation Question 9 – To what extent has Genome Canada’s investment been matched by additional resources from stakeholders, partners and collaborators through co-funding and leveraged funds?

Table 3 shows that Genome Canada’s investment was generally matched by co-funders in an approximate 1:1 ratio, with only slight variations among projects. The documents also provided some evidence of additional leveraging for projects (also indicated in the table), although amounts are difficult to quantify as direct project leveraging is not systematically reported.

Table 3 Project funding contributions and additional leveraging

Identifier	GC contribution	Partner Contribution*	Other evidence of leveraging
Arborea-II	50%	50%	>\$500,000 from the CFI and Fonds Québécois de la Recherche sur la Nature
Cod	49%	53%	Funding acquired to hold a debate on development of Canadian aquaculture capacity – results published in a book
Salmonids	49%	54%	Created opportunities for other projects now operating with provincial funding
Oilseeds	45%	53%	Created opportunities for other projects now

			operating with provincial funding
Barcoding	44%	56%	>\$300,000 leveraged from five different organizations for various projects
Genozymes	45%	55%	None found
Grape and Wine	74%	53%	Additional funding for salaries was secured through various sources
VALGEN	47%	53%	>\$300,000 from a SSHRC Insight Grant
TOTAL AVERAGE	50%	53%	

*Note: Partner contribution amounts are current as of Nov 2013. Not all amounts total 100% as partners sometimes added in funding after the total budget had been approved, or projects are still ongoing thus the total amount has not yet been reached.

While it is clear that Genome Canada’s investment has been matched, there may be opportunities to further explore and improve both co-funding and leveraging. The following issues were raised by interviewees:

- A few interviewees found that the mandatory co-funding model has the potential to place limits on the amount of innovative research that can be pursued, especially as it can be harder to find willing partners to support higher-risk or non-traditional research (e.g., the use of genomics in wine-making, the use of oilseeds as feed, fuel or both).
- A few interviewees across projects said there was increased pressure from the federal government to the provinces to rely more heavily on industry as a driving funding source for applied research. In this respect, while the Genome Canada GAPP program was cited as useful for short projects, there is still a continued need for longer-term genomics support. Especially as several sectors encompass complex regulatory processes, sustained funding is required to allow ongoing research activities as products go through regulatory approval.
- In one case, the removal of members of the project team also meant a loss of the funding sources brought in by that individual. In this case, the team found it very challenging to bring in new co-funders to meet the mandatory requirement.
- Both aquaculture cases (Salmonids and Cod) noted that there have been no projects funded by Genome Canada for this sector since Competition III (launched in 2004). They stressed the importance of ongoing federal funding to complement projects that are currently running with provincial funding (Salmonids) or to move research projects solely from the academic sphere into the industry sphere (Cod).
- Finally, one international collaborator interviewed said that, from the perspective of the international canola community, funding for canola research in Canada has been decreasing in favour of wheat research. The interviewee was concerned that if the trend continued, it would result in not only a loss of Canadian expertise in canola, but also a decrease in international collaboration and funding in this area.

5 Extent to which Genome Canada has contributed to Canada's HQP in genomics

Summary: Case studies indicate that Genome Canada has been very effective in contributing to Canada's HQP in genomics. Over 260 HQP were involved in the cases examined. They were offered opportunities (e.g., access to technology, exposure to large-scale project governance) that may not have been afforded on smaller projects. HQP also moved on to a variety of positions after working on Genome Canada funded projects, transferring skills to the academic, private and government sectors.

Evaluation Question 10 – Has Genome Canada increased the supply of highly qualified persons to meet the evolving needs of genomics research?

A conservative estimate indicates that over 260 highly qualified highly qualified personnel (HQP) were involved across the eight cases examined. Per project, the number ranged from about 15 to upwards of 60. HQP generally included all levels of students (from undergraduate to post-doctoral fellows), research assistants, and technicians, as well as database and computer administrators. Across every single case, it was noted that projects enabled great opportunities for HQP, including activities they may not necessarily have experienced by working on smaller projects. Examples include:

- Experience with multi-stakeholder project management, project governance, industry relations and GE³LS;
- Access to advanced technologies, equipment or infrastructure;
- Scientific or technical experience (biostatistics, fish/plant breeding, modelling and data analysis etc.); and
- Exposure to national and international colleagues and opportunities to present research at genomics conferences, colloquia, seminars etc.

Because of this experience, HQP were able to move on to other positions after working on the Genome Canada projects, transferring their skills and knowledge. Examples from individual cases include:

- **Cod** – former HQP are now in charge of fish breeding programs and microarray work for several Canadian universities;
- **Barcoding** – former HQP were offered positions in China, France and Brazil working on the international iBOL project; and
- **Arborea-II, Salmonids, Oilseeds, Genozymes, Grape and Wine, VALGEN** – former HQP are now working in a variety of sectors including academic (as professors, researchers, postdocs), private (pharmaceutical), and government (provincial policy work, Canadian Forest Service).

6 Extent to which Genome Canada has contributed to increasing the breadth and depth of knowledge in genomics (including GE³LS)

Summary: The case studies provide detailed evidence that Genome Canada has contributed to increasing the breadth and depth of knowledge in genomics. Some examples include new genetic mechanisms for plant/animal disease resistance; development of innovative genetic tools, methods and techniques with a variety of applications; and sequencing large parts of the genomes of organisms with commercial value (e.g., salmon, cod, canola). While the discoveries to date are notable, it is difficult to conclude that these have more broadly transformed the wider scientific community.

As seven of the eight case studies included a GE³LS component, it was also found that a contribution was made to increasing the breadth and depth of knowledge for GE³LS. However, there was a consensus that scientific work and GE³LS work continues to function largely in silos. Further awareness of the benefits of GE³LS is needed to achieve true integration and to allow GE³LS to become a more effective enabler for translation of genomics research.

Identified barriers to the application and uptake of results included poor knowledge/benefits translation to the end-user, complex regulatory processes, and other contextual factors. Enablers were the inclusion of end-user ideas from project inception, as well as targeted communication and outreach efforts.

Evaluation Question 5 – To what extent has the research that has been funded by Genome Canada been transformative in areas of strategic importance to Canada?

As shown in Table 4, the eight cases met all or most of their intended scientific outcomes. Moreover, discoveries from each case do represent a potential for transformation in areas of strategic importance to Canada, although it is difficult to conclude that widespread transformative effects of these discoveries have occurred among the larger scientific community. There is however, evidence of progress because ‘trigger points’ for transformation have been identified in all cases (e.g., using genomics, projects enabled new question to be asked, or changed ways that research is conducted by developing new methods). More details for each project are provided after the table.

Table 4 Project level of achievement and transformational potential

Identifier	Intended objectives	Transformational trigger point
Arborea-II	Met all	Changed ways to conduct research through new methods/technologies
Barcoding	Met all	Shift in research paradigm
Cod	Met all	Enabled new questions to be asked or addressed using genomics
Genozymes	Met most*	Changed ways to conduct research through new methods/technologies
Grape and Wine	Met most	Enabled new questions to be asked or addressed using genomics
Oilseeds	Met most	Enabled new questions to be asked or addressed using genomics
Salmonids	Met all	Enabled new questions to be asked or addressed using genomics
VALGEN	Met most*	Changed ways to conduct research through new methods/technologies

*Note: Project still ongoing

Arborea-II

- Discovered a genetic mechanism for natural resistance against the spruce budworm.
- Developed a new approach to genomic selection which, according to one interviewee, is much more promising than the previous approach based on association studies in terms of application for the forest industry.
- Developed genetic testing methods for field material. These high accuracy, high precision genetic testing methods which have been validated at the operational front with industry partners such as JD Irving and the Quebec Ministry of Natural resources.
- Note that as white spruce plantations in eastern Canada have a rotation age of 35 years or more, transformative impacts will truly begin to materialize 5 to 10 years post-project.

Barcoding

- Developed technology to sequence and analyze genetic information of biota in bulk environmental samples as opposed to single specimen analysis.
- Represents a significant shift in the type and amount of information gathered and can be used for monitoring variations species that indicate the overall health of an ecosystem, such as aquatic insects.
- Major advantage over simplistic measurements of physical and chemical variations in natural habitats, which lack sensitivity and specificity required to accurately predict ecosystem change.

Cod

- Produced broodstock that had been selected based on developed genetic markers and phenotype for favourable market traits. (At this point the project ended so that validation and commercial use of the genetic markers was not possible).
- Developed genomics tools to identify fish directly from the wild that already have the genes for desired traits, thus avoiding the longer timeframe and challenges associated with traditional selective breeding methods.
- Produced the best cod gene sequence map available at the time and contributed to about 85% of what is currently known about Atlantic cod genomics.
- Based on the work in this project, a collaborating research group in Norway (FishGen) was then able to sequence the entire cod genome.

Genozymes

- Applied functional genomics and other techniques (e.g., proteomics, bioinformatics) to sequence the genome of 30 fungal decomposers. Sequencing work has begun on five additional species to produce high-quality reference genomes that will benefit the fungal genomics community.
- Cloned close to 4000 novel enzymes; the project focus has now turned to identify those enzymes with the most potential for direct industrial applications (e.g., lignin degradation, animal feed that is easier to metabolize, and other commercial applications).
- Elucidated nine protein structures that show promise in yielding important functional information for scientific and practical pay-off (e.g., turning plant material into biofuels).

Grape and Wine

- Note: Project was divided into two research components, viticulture and yeast. Planned outcomes for viticulture were mostly met while the research on yeast has not been completed. This component received a no-cost extension that will end in 2014.
- Genomics research has been applied to viticulture to gain a better understanding of grape breeding and wine fermentation under particular conditions (dry/humid climate).
- Built a prototype for a hand-held genomics-based tool (protein extraction and antibody detection) that is expected to assist growers in irrigation management and to improve the economic and environmental sustainability of grape production. This work is ongoing with alternative funding.
- Transcription of the yeast genome during wine fermentation allowed the discovery of new genes with an as yet undiscovered function, the ongoing goal is to determine function for these genes which probably play an important role during the fermentation process.

Oilseeds

- Succeeded in reducing anti-nutritional factors in canola seeds by 60-97% (different for each factor).
- Generated transgenic seed with a 185-fold increase in beta-carotene and a 42-fold increase in total carotenoid content. These lines will be tested in the field and resulting material analyzed in feeding trials to determine the extent of the nutritional benefit.
- Generated and field tested >2,300 recombinant lines of an elite canola line with good yield potential, high oil, protein and sucrose contents, resulting in a large amount of field data and seed available to the scientific community.
- Attempted a variety of techniques to lower the fibre content of the canola seed coat (which is undigestible by animals), but finding the critical genes proved elusive and little reduction in fibre content was achieved by the end of the project.

Salmonids

- Created a genetic map framework for the Atlantic salmonid genome and a comprehensive gene set for other salmonids.
- Laid the essential foundation for an ongoing project to sequence the complete Atlantic salmon genome.
- Developed genetic tools to assess toxicology, immune response, temperature tolerance and growth which allows for more sophisticated research on fish physiology, aquaculture, conservation, and genome evolution.

VALGEN

- Note: project is ongoing with some research activities still left to complete.
- Generated and tested innovative models and metrics for new conceptualizations of intellectual property and technology transfer, social network models and agent-based models of research systems and regulatory systems, used for GE³LS.
- Revisited methodologies to identify commercial opportunities of developed technologies. Results have been shared with regulators in many countries and diffused in scholarly journals.
- This work will also shed light on the regulatory system function and democratic engagement structures for GE³LS.

Evaluation Question 7a) – To what extent has Genome Canada’s model of embedding GE³LS research within projects facilitated the translation of genomics research? (effort)

Six out of eight cases—excluding VALGEN, which was a large-scale GE³LS project, and Genozymes, which cited good integration—found it difficult and time-consuming to fully integrate GE³LS aspects into the project. Most interviewees across cases recognized and appreciated the value of GE³LS, however, there was a clear cross-case consensus that the science and the GE³LS components were functioning in individual silos, with neither truly supporting the other. In one case where integration seemed to pose the least issue (Arborea-II), professors with GE³LS expertise were recruited at the earliest stages of the project and were included in all major project decisions. Similarly, interviewees on the Genozymes case said that integration was facilitated by close physical proximity (adjoining offices for the science and GE³LS PIs) and daily formal and information communication between the two teams.

As barriers to integration, interviewees across the other cases pointed to a lack of awareness on their part, geographical distance between researchers, and the fact that GE³LS research was often too general to have any tangible application to the specific research activities being conducted. One interesting example from the Oilseeds case speaks to this latter point. Frustrated with his experience on the Oilseeds project, but recognizing the value of GE³LS, one principal investigator decided to use a different approach to incorporate GE³LS aspects into a new project on bioactive oils, but not funded by Genome Canada. In his words,

“It started out the same way, they [GE³LS researchers] were doing IP analysis in a very general sense. And then we began to ask, ‘what is this really doing for our project?’ So we had a meeting with them, brought in a consultant and said, ‘how can we make you more engaged with the science?’ So then they began to focus more on what were the IP obstacles in the bioactive program, and how can we overcome them? What were the biotech issues with the specific oils we were trying to develop? How could we better sell this to our particular consumer? And then it became better, as the GE³LS began to complement the science, helping it to move forward.”

VALGEN was a project seeking to act as the hub for Canadian GE³LS researchers involved in projects funded under the Competition in Applied Genomics Research in Bioproducts or Crops (ABC), to identify and address GE³LS overarching issues related to intellectual property management, regulation and governance and democratic engagement. This project was reportedly very successful in linking GE³LS and genomics researchers of most ABC-funded projects to identify and address barriers to technology commercialization. As a result, Genome Canada decided to build on the success of VALGEN to shift its approach toward integration of GE³LS research. Genome Canada is now more focused on increasing GE³LS capacity through HQP training and building a strong network of GE³LS researchers across projects and regions, in addition to directly funding GE³LS research within stand-alone and integrated GE³LS projects. There is also increased recognition by Genome Canada of the need to engage early on with regulators and consumers to facilitate technology approval and adoption.

Overall, case study evidence supports the need for ongoing GE³LS capacity building, networking and awareness-raising, not only among the scientific community but also within the general public.

Evaluation Question 7b) – What are the challenges and enablers that facilitate translation from the perspective of the different stakeholders and end-users?

The translation and uptake of results are described in detail in later in this report. This discussion is focused on the barriers and enablers to translation in the view of the project stakeholders. Across cases, the challenges to translation were described as follows:

- From the industry perspective, scientists were sometime lacking in their ability to transfer knowledge, or to make project results ‘accessible’. It is likely that uptake would be improved if results could be quickly and easily understood and/or made available through outreach and knowledge transfer activities. A few interviewees across projects also said they could have made more effort to disseminate research results to end-users and the general public.
- Several of the projects experienced negative contextual factors (e.g., significant market crash for Cod, resistance to genomics in the commercial wine industry) presenting a serious challenge for the translation and uptake of results.
- Similarly, regulatory or policy contexts can also present a challenge. On the Oilseeds project, restrictive IP policies from one federal partner prevented the timely release of information at a conference where many industry representatives and other stakeholders were present. Furthermore, the regulatory context for agricultural import or export crops such as canola is complex and end-users seek a certain ‘threshold’ of product benefit before they will invest in navigating this regulatory context.
- Some projects also experienced challenges on a project-level, most commonly, rapid team turnover and trying to keep up with the accelerated development of technology. While these do not directly hinder translation per se, they do present obstacles before a project can reach the translation stage.

Alternatively, cases also presented clear examples of enablers to translation:

- A key success factor for translation, best exemplified in the Arborea-II and Barcoding projects (and to some extent in the Genozymes project) was the conscious effort made to include the ideas and opinions of end-users and potential product consumers at every step of the way from project inception to final result. This facilitates translation of knowledge into practical applications. This was also noted specifically in the international component of the Oilseeds project. International collaborators had great success with industry uptake but noted that their Canadian colleagues on the project had some difficulty. In the collaborator’s words:

“I got the impression that the interaction with the industry did not take place as strongly within the research project as we are used to in Germany. In Germany we really have an environment where the companies themselves—not only bilaterally with researchers, but also in research consortia—join forces and collaborate in order to develop tools. When they are involved immediately in the research, then the tools that will be developed will be more applied for their own commercial usage.”

- Another key enabler was communication and outreach, best exemplified in the Salmonids project. Possibly because this project was part of a larger international collaboration with three other major salmonid groups from Norway, the US and the UK, extensive outreach efforts were made. Examples include participation in regional, national and international conferences, workshops aimed at introducing government and industry stakeholders to the benefits of genomics in aquaculture, and dozens of media appearances. Interviewees said

that this targeted effort, in addition to the traditional scientific channels of publications, helped engage end-users.

7 Socio-economic benefits of the research that has been funded by Genome Canada

Summary: Considering well-recognized barriers to translation (e.g., lack of funding, contextual factors, etc.) there is some evidence that practical applications were developed in the cases examined (examples detailed below). However, uptake by end-users was moderate in at least three of the seven cases, and it is clear that more work remains to be done to translate genomics research into everyday applications.

Following from this, it was difficult to quantify direct and widespread socio-economic benefits although there is evidence of much potential for benefit (e.g., through patents, improved environmental monitoring, improved tree/fish growth, more nutritional canola, etc.) In addition, every single case provided examples of indirect socio-economic benefits (e.g., increased collaboration, provision of HQP).

Evaluation Question 11b) – To what extent has Genome Canada been the catalyst in translating genomics research into applications at a national and international level?

Note that evaluation question 11b (translation into applications) is presented here before evaluation questions 11a (socio-economic benefits). This is to allow the reader to become familiar with the various examples of translation in each project, before examining wider socio-economic benefits.

All projects were able to provide examples of how genomics research has been translated into practical applications, although some had more moderate uptake (e.g., Cod, Grape and Wine, VALGEN) than others. Uptake of results must also be considered in light of the challenges and enablers to translation discussed earlier. Overall, the cross-case evidence suggests that Genome Canada has catalyzed some practical applications although more work remains to be done. Specific case examples are provided below.

Arborea-II

- Launched a new project (SMarTForests), with funding from Genome Canada and various Genome Centres, to develop diagnostic genetic markers to advance Canadian spruce breeding. Marker systems are aimed at identifying trees and seedlings with improved growth, wood properties, and insect resistance. Estimates are that marker assisted selection could translate into a potential GDP increase of \$300 million.¹
- Led to international collaborations^{2,3} supported by the European Union to prepare coordinated research plans (North America and Europe) regarding adaptation of forest trees to climate change.

Barcoding

¹ For more information, <http://www.smartforests.ca/>

² For more information, see <http://www.foresttrac.eu>

³ For more information, see http://ec.europa.eu/research/bioeconomy/agriculture/projects/procogen_en.htm

- The developed barcoding technology is being used by Environment Canada and Parks Canada for their biomonitoring program in the Wood Buffalo National Park, an ecologically unique area spanning Alberta and the Northwest Territories.
- The project recently expanded to a monitoring plan for the oil sands. The tools will allow for large sampling of the oil sands region of Alberta with the information gained being used to implement a comprehensive, scientifically credible environmental assessment program for the oil sands industry.⁴
- Ontario’s Ministry of Environment is currently exploring the use of the barcoding technology for monitoring mining areas like the Northern Ontario Ring of Fire site.

Cod

- Developed many genomics tools and markers for selecting fish that continue to be used by various university groups for research, as well as in international industry projects (on fish species other than cod in Saudi Arabia and Chile).
- Transferred 90% of the genetically superior cod broodstock resulting from this project to commercial partners (Canadian and American) at project termination.⁵ However, because of a large market crash for cod, industry partners are currently pursuing other opportunities. Nonetheless, cryopreservation of elite broodstock sperm ensures that should the market rebound they will not have to “start from scratch.”

Genozymes

- Identified 25 candidate ‘enzyme cocktails’ for improving ways of creating biofuels from plant based material. Commercial application is current being investigated by an industry partner with global reach (DSM Innovations Inc.).
- Although still in the early stages, Agriculture and Agri-food Canada has noted interest in working with the Genozymes team to develop more nutritious cattle feed supplements that would allow cattle to absorb more nutrients from grass and corn.
- For the pulp and paper industry, the amount of chlorine required can be significantly reduced by pre-treating paper with fungal enzymes rather than with bleach. Potential enzyme candidates have been identified and the research partner, FP Innovations Pulp and Paper Research Institute, are currently testing for potential use.

Grape and Wine

- Prototype development of a hand-held biomarker detection device which can monitor vine water status to detect drought stress in leaf samples prior to visible symptoms.
- Subsequent refinements to monitor fruit ripening have the potential to improve wine quality but will depend on ease of use, reproducibility and grower/industry acceptability.

⁴ <http://ibarcodes.org/steve/wordpress/index.php/archives/135>

⁵ Genome Canada. Interim Review of Competition III projects. ISRC summary report. October 2007.

- Field testing is still necessary, so the application has not yet achieved widespread use.

Oilseeds

- The international collaborators in this project said that the technologies developed from the collaboration (e.g., near- infrared spectrometry calibrations) and the scientific results “were immediately translated and used in the commercial breeding sector in Germany.”
- Results also triggered ongoing work in Canada on improving the nutritional content of canola supported with provincial funding. According to interviewees, these new canola lines have the potential for commercialization.

Salmonids

- Developed resources are being currently used by DFO and Environment Canada to evaluate fish response to pollution and to identify health fish stocks.
- Data generated in this project is being used to compare transgenic and domesticated fish with the aim to inform federal regulatory processes.
- Spurred at least four other ongoing projects for genomics in aquaculture, supported by provincial, NSERC and university funding.

VALGEN

- According to interviewees, this project was instrumental in building a network of communication between policymakers and the private sector and increased public awareness of the benefits of agricultural biotechnologies.
- Contributed to shifting Genome Canada’s way of approaching and promoting GE³LS research (see discussion in Section 6).
- Work on the comparative costs of regulatory approval of agricultural biotechnologies in different regulatory regimes is already expected to have a direct impact on the commercialization plans of three large-scale genomics projects. Nevertheless much work needs to be done before this work will become policy.

Evaluation Question 11a) – What are the socio-economic benefits of the research that has been funded by Genome Canada?

Following from the previous question, socio-economic benefits stem from the translation and uptake of genomics research into real-world applications. As such, the specific examples noted in the bullets below are somewhat moderate and/or represent the *potential for* socio-economic benefit rather than direct benefits.

Nevertheless, several cross-case indirect benefits were noted. For example, through publication of peer-reviewed articles and by depositing research results in various public databases (e.g., Genbank) all the cases contributed to an indirect socio-economic benefit by expanding the body of scientific work in genomics that can be taken up by the R&D community. Similarly, notable contribution to the production and training of HQP (see Section **Error! Reference source not found.**) is also a clear indirect socio-economic benefit arising from these cases. Finally, all cases included some national or international collaboration. These networks and contact often expand to spin-off

projects and when they then reinforce old collaborations or help build new ones. Specific examples for each case are described below.

- **Arborea-II:** Using genetic markers to identify the best trees for culture at an early stage will greatly reduce the length of the selection process and increase the value of the trees. Taken together these factors will lead to a significant increase in economic benefit per hectare. For example, the identification of predictive markers for the best trees has the potential for annual economic gains of \$200 million, assuming only 25% of reforestation in the near term. Tree breeding also holds the potential to produce more wood on the same land, freeing up space for conservation.
- **Barcoding:** As noted in question 11b, technology developed in this case has provided environmental assessment and monitoring tools for several different projects in Canada. By extension, these should contribute to improved ecosystems and improved monitoring programs. The online software developed during this project has been made available as an open-source system that can be freely accessed by Canadian and international users. One additional potential avenue for exploration on the socio-economic front is community engagement. By being able to run bulk sequencing samples, the collection process can be simplified and local community stakeholders can contribute. This could result in community empowerment and in a better understanding, thus stewardship of their environment
- **Cod:** One patent resulted from this project for markers that are important for selected traits of industry value. The protection of intellectual property will be useful especially if there is a resurgence in the cod aquaculture market. This project also implemented two small side-projects (i.e., a formal debate and a workshop) to discuss the potential benefits of genomics in aquaculture, thus raising awareness among the stakeholders involved.
- **Genozymes:** The research undertaken in this project aims to take advantage of Canada's abundance of cellulosic biomass; the potential replacement of petrochemical fuels with biofuels represents major strides for both economic gains and environmental protection. Such socio-economic impacts have come even closer to fruition in the pulp and paper industry, as enzyme capacities to pre-treat paper have already allowed for chlorine reductions for the bleaching processes. Interviewees indicated, however, that while the potential industrial applications of this research are demonstrably viable, it will take some time before they make their way into actual industrial processes. In one example, an enzyme delivered to a biofuels partner proved to be about 20-25% more efficient than the product currently used. However, the enterprise noted that actually adopting this development into their production would not be cost-effective as it would incur costs for changing production lines, as well as for advertising and marketing.
- **Grape and Wine:** As noted in the project documentation, the project focused on fairly fundamental studies and so direct, specific benefit to Canada are not obvious. However, aspects of the project are still ongoing. More generally, having a strong research base in viticulture and fermentation will be important for the Canadian wine industry. For example, an improved understanding of the fermentation process will improve the quality of wines produced in Canada. The ability to produce better local wines can also increase local

consumption, reducing a reliance on imports. One license was produced during this project for the mutation of a gene regulating acetic acid during wine fermentation. Once fully commercialized, there is a potential that royalties will be paid out to the research organizations.

- **Oilseeds:** From an economic standpoint, canola is an important cash crop for Canada, so any success in increased crop yields or value (e.g., more nutritional animal feed) will have benefits in terms of export income and possibly employment. As this project also resulted in patents, there is potential for commercialization of research results. This project also raised awareness of where the obstacles were in terms of commercializing canola traits. The interviewees said that they gained much insight into how to deal with the consumer and the negative perceptions about genetic engineering.
- **Salmonids:** Research results are already being used for fish conservation and monitoring purposes as noted in the question above (11b). In addition, this project generated multiple spin-off projects, thus enhancing collaboration and contributing greatly to the larger body of scientific work.
- **VALGEN:** The highest impact will result from the diffusion of highly qualified researchers in the economy, as they become critical thought leaders, industrial leaders or regulatory leaders and apply their skills to advance the effective and efficient use of technology. VALGEN investigators also expect that the adoption and use of the business processes and regulatory and evaluation tools will help remove the barriers associated with the current system and facilitate the commercialization of biotechnologies. Finally it is worth noting that the GE³LS models developed as part of VALGEN can be applied outside of agriculture (e.g., health, forestry, mining, etc.) to facilitate the achievement of socio-economic benefits in these sectors as well.

8 Extent to which Canadian genomics research is enabled through the provision of leading-edge technologies

Summary: Access to enabling technologies was found to be adequate and sufficient in all cases examined. Projects used a variety of technology platforms, both those funded and those not funded by Genome Canada, depending on the needs of each case. Within individual cases, areas for improvement were noted; however, no overarching issue or challenge was identified through this line of evidence.

Evaluation Question 4 – To what extent has Genome Canada provided access to leading-edge technologies that have contributed to Canada’s world class competitiveness?

Of the five Genome Canada Science & Technology Innovation Centers (STICs) currently operating, three were used by five projects, as shown in Table 3. Six of the projects used various other technology platforms, both previously funded and not funded by Genome Canada. Three projects built their own platforms with Genome Canada project funding.

For the majority of cases, access to technology was not a limiting factor overall. Generally, interviewees found that all of the facilities used (STICs or otherwise) were of high quality and the supporting staff was cited as knowledgeable and helpful. However, some specific limiting factors were noted in the individual cases as follows. These were not perceived by interviewees as major

barriers but rather presented areas for improvement with respect to the provision of enabling technologies.

- **Arborea-II:** Bioinformatics structures were lacking at the beginning of the project (2006) and had to be developed in-house. Interviewees noted that the availability of such platforms has increased with time.
- **Barcoding:** Due to the nature of this particular project, it was critical for the research team to have the flexibility to modify and adapt instrumentation according to their needs. The STICs or other technology platforms are not meant to accommodate such needs thus the team established its own Next Generation Sequencing laboratory.
- **Cod:** One interviewee noted that, because of the mandatory co-funding arrangement, there was “pressure” to use one of the service providers, rather than another external group who may have been more qualified for the job.
- **Genozymes:** About midway through the project, Genome Canada funding ended for certain components of two platforms (bioinformatics and mass spectrometry, see table below). This caused major delays in deliverables although the team was able to translate these challenges into opportunities. Namely, the investigators decided to develop these lost capacities in-house, thus in the long run, cost and time associated with shipping and communications was significantly reduced.
- **Grape and Wine:** No limiting factors regarding STICs were mentioned in the documents or interviews.
- **Oilseeds:** One interviewee commented that the project would have benefitted from using bioinformatics capacity within each of the provincial institutions where the genome work was being conducted. Instead, one off-site central resource (at the University of Calgary) did not meet the everyday needs of the researchers who would have preferred ongoing access to bioinformatics expertise as the project progressed at different sites. The same interviewee also said that compared to the international competitors, the state of Canada’s genome sequencing centres and overall bioinformatics capacity is lagging.
- **Salmonids:** It was noted that for smaller scale projects (less than \$500,000), access to STICs or large technology platforms is not possible because of budget limitations. This then forces researchers to work with genomics centres from abroad (e.g., China, Spain, etc.) where a variety of services are offered for a wider range of costs.

Table 5 Enabling technologies used in the eight cases

Project	STICs (as of 2013) used	Other technology platforms used	Built technology
Arborea-II	McGill University and Genome Quebec Innovation Center; University of Victoria – Genome BC Proteomics Center	N/A	N/A
Cod	McGill University and Genome Quebec Innovation Center	Atlantic Genome Center (sequencing services); ¹ Atlantic Cancer Research Institute; NRC Atlantic Bioinformatics Laboratory; Research and Productivity Council	Built two broodstock facilities

Salmonids	Genomics Innovation Center at the BC Cancer Agency Genome Sciences Center	Vancouver Prostate Centre	N/A
Oilseeds	N/A	Vancouver Prostate Centre; ² University of Calgary Bioinformatics Facility; ³ A variety of other technology platforms (e.g. facilities for sequencing, microarrays, TiLLing, feed analysis and more) were also employed (e.g., at AAFC, NRC, and local universities)	N/A
Barcoding	N/A	N/A	Established a sequencing facility at the Biodiversity Institute of Ontario
Genozymes	McGill University and Genome Quebec Innovation Center (mass spectrometry facility) ⁴	University of Calgary Bioinformatics Facility; ³ University of Missouri DNA Core Facility	Developed in-house proteomics platform located at the Concordia Centre for Structural and Functional Genomics
Grape and Wine	University of Victoria – Genome BC Proteomics Center	Microarray Facility (part of the Vancouver Prostate Center) and Wine Research Center at University of BC	N/A
VALGEN	N/A	Used existing university-based infrastructure (e.g., telephone survey labs, computer simulation equipment)	N/A

1 ended as a GC STIC in 2005

2 ended as a GC STIC April 2011 – still active as the Laboratory for Applied Genomics

3 ended as part of integrated and distributed bioinformatics GC STIC April 2011

4 GC funding to proteomics activities at the center (including mass spectrometry) ended in the latter half of 2006

9 Management, design and delivery (demonstration of efficiency and economy)

Summary: None of the large-scale projects examined in this study encountered major problems with project management or duplication, indicating fairly efficient delivery of scientific results overall. While communications between Genome Canada and the Genome Centres could be improved, interviewees appreciated the support from the Centres during competitions. There was also a strong consensus to reduce the overall reporting burden for large-scale projects.

Evaluation Question 14 – To what extent has Genome Canada implemented processes to maximize efficiency within the management of competitions, projects and operational needs?

Each project experienced its own individual challenges in terms of efficiency (e.g., team turnover, change in research direction, delays, competition with the research team). These are detailed in a separate Appendix and are not presented here. Across cases, it was clear that the project management approaches varied widely, from informal meetings to very structured governance committees. More importantly, as project objectives were largely met across all projects (see Section 6), it may be concluded that a flexible, customized project management approach for individual projects, with engaged and competent project leaders, made efficient use of resources.

Each case also explored efficiency with regards to communications with Genome Canada, competition management and reporting processes. Cross-case summaries on these topics are presented below.

Communications: At a project-level, no major communication issue was raised with either the Genome Centers or Genome Canada. There was a consensus that support from the Centers, both at the proposal stage and throughout the project, was a facilitating factor for all cases. However, interviewees across cases also said that coordination between Genome Canada and the Centers could be improved, especially with regards to synchronizing the timing of funding calls, streamlining application/reporting processes and reducing duplication (e.g., where approvals are required from more than one Genome Center to authorize changes made to project design or management).

Competition management: At least three cases received guidance from individual Genome Centers during the initial proposal stage. This was seen as a useful step to help shape the research plan and also to help establish partnerships with the private sector in the regions where the work was to be carried out. The letter of intent, submitted before the formal application was also seen as useful to orient the project before too much work went into the application. Aspects of competition management that could be improved included ensuring continuity of funding opportunities and ensuring that if funding calls include international or external collaborators, considerations are made for synchronized reporting and milestone delivery.

Reporting: Many interviewees across a majority of cases indicated that the quarterly reporting required by the Genome Centers is overly burdensome, as only incremental progress can be made in three months. There is also the possibility that co-funders will ask for progress reports in addition to the required interim and final reporting processes from Genome Canada. Overall, the utility and necessity of reporting was not questioned, rather there was a consensus that the frequency could be reduced without losing any of the project accountability.