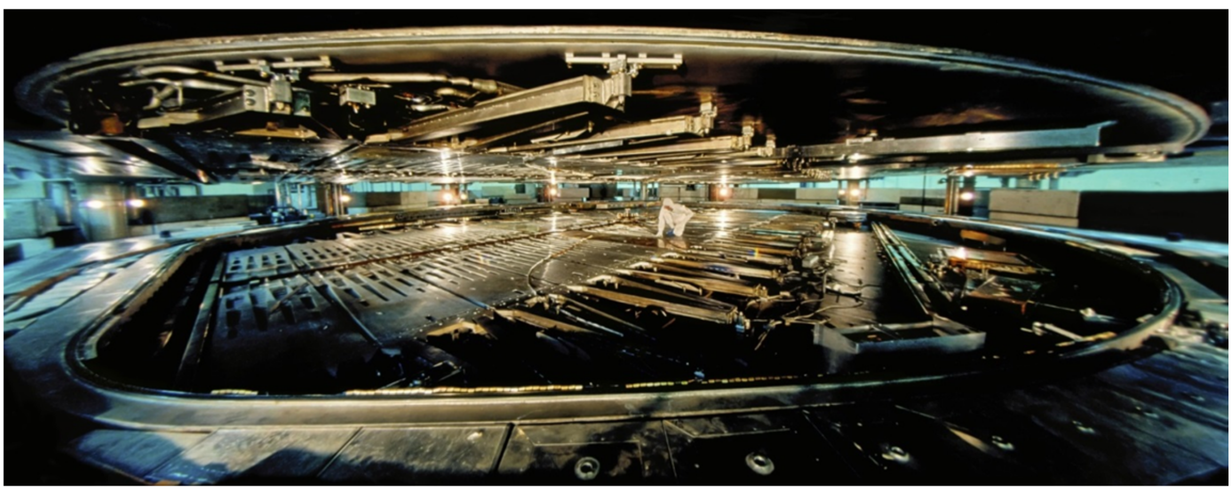
# Examining international approaches to research infrastructure support



TRIUMF LAB – INSIDE THE CYCLOTRON

Science-Metrix

# Examining international approaches to research infrastructure support

## FINAL REPORT

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# Executive Summary

This study report examines the balance between infrastructure support and direct research funding in Canada, relative to four other jurisdictions, namely Australia, Germany, the United Kingdom (UK) and the United States (US). In Canada, a primary source of federal funding for research infrastructure is the Canada Foundation for Innovation (CFI), a not-for-profit corporation that funds research infrastructure to strengthen the capacity of Canadian universities, colleges, research hospitals and non-profit research institutions. In support of an ongoing evaluation of the CFI, Industry Canada—the arm's length delivery agent of funding for the CFI—determined it useful to examine issues related to balancing direct research and infrastructure support.

This project used four data collection methods: 1) a comprehensive review of approximately 120 documents; 2) a quantitative scan of financial figures and expenditure data on direct research spending and infrastructure support in the five countries examined; 3) an online survey of actively publishing researchers in each of the five countries; 4) 23 interviews (Canada-7, Australia-5, Germany-4, UK-4, and US-3) were completed with management individuals at national funding agencies, government departments or research councils.

There are noteworthy limitations with the data collection methods. The principal limitation of the quantitative scan is the limited availability of financial data for research spending. There was a scarcity of financial data regarding research infrastructure and, within the available data, numerous issues considerably hindered comparability between each of the five countries. Regarding the online survey, the availability of survey respondents was a challenge given the short, intense data collection period (approximately 1 month during the summer vacation). Similarly, the availability of interviewees presented a challenge given the short data collection period and the summer vacation season.

This study addressed six specific research issues; the key findings are presented below.

Issue 1: There is clear pressure from researchers to increase research infrastructure spending across all five countries examined. However, the collected evidence also indicates that pressure to increase direct research support is perceived as at least equally important. Often, a cyclical demand emerges whereby funding for cutting-edge infrastructure tends to increase the need for research projects (i.e. direct funding) that will then make use of that infrastructure. The influence of research discipline on infrastructure spending similarly cannot be discounted. Thus, optimal decision-making must take into account many contextual factors, which vary from country to country, when determining the need for both types of support.

Issue 2: In the five countries examined, federal research infrastructure funding grew on average two times faster than direct funding between 2008 and 2013. However, it is imperative to note that serious limitations exist around the availability and robustness of data that has been compiled by government or national statistics offices on research infrastructure and as such, these statistics are broadly indicative rather than definitive.

Of all countries, Canada showed the lowest growth for infrastructure funding (2%), followed by the UK (3%). The overall average for the four comparator countries (i.e. excluding Canada) was 6.5%. Though a causal link should not necessarily be inferred, it is noteworthy that Canadian survey respondents were the least satisfied that their need to access research infrastructure over the last decade had been fulfilled.

Issue 3: Considered together, these countries devoted around 10% of federal research funding to research infrastructure between 2008 and 2013. For Canada, the spending ratio was 12% (16% when infrastructure operating funds are included). The UK allocated a comparable 12% of total R&D funding to research infrastructure and Australia allocated 15% (including operating funds), while the US and Germany both spent 9% of their total R&D budget on research infrastructure for the period (US based on NSF "plant" data only).

Issue 4: All countries examined in this study conduct peer-review of infrastructure proposals and/or carry out periodic evaluations of existing infrastructure schemes to address questions of appropriate funding allocation. A distinction can be made between two types of approaches to planning for infrastructure. The top-down, systemic, strategic approach reflects varying needs by research discipline and takes into account national research priorities. Regular roadmapping processes are engrained in Germany, the UK and Australia, which are all countries that appear to take a more top-down approach. On the other hand, a bottom-up, à la pièce, tactical approach (more common in the US and Canada) reflects funding demands by researchers and often embodies strategic vision publications, developed by scientific community organizations that are oriented toward specific thematic fields of science.

Issue 5: Determining an ideal balance between new and existing facilities is a necessary part of the prioritization processes. Surveys are another common tool to help governments determine whether to continue funding existing infrastructures and identify the need for new infrastructures. While the majority of interviewees in Germany, the UK and the US spoke of a clear need to consider both types of infrastructure, Canadian and Australian interviewees noted a focus that has actually shifted from new to existing over the last ten years. In the countries examined, methods to determine an adequate balance vary from formal procedures to non-existent.

Issue 6: The collected evidence suggests that operating costs vary anywhere from 10-30% annually of total project costs. However, accurate and comparable definitions of operating costs are not readily available. Internationally, the OECD acknowledges the difficulty in properly accounting for operating costs and observes systemic difficulty with estimating infrastructure costs for roadmapping purposes. Moreover, any discussion of funding for maintenance and operation of research infrastructure must also take into account the age of the facilities or equipment and the highly qualified personnel trained to run and maintain it.

Survey data suggests that Canadians are more dissatisfied than others with funding available for operation and maintenance of existing infrastructure. Compared to an average of around 40%, some 60% of Canadian researchers who use infrastructure are dissatisfied with the financial means available for their maintenance.

Balancing direct research and infrastructure support is complex and there is currently a lack of qualitative and quantitative evidence to help guide decision makers. It appears that one-ratio-fits-all solutions do not exist. The scarcity of data and the robustness of the available data strongly suggest that ratios such as balance of infrastructure funding to direct research funding are not commonly used by national governments to make decisions on R&D spending. With research infrastructures constituting a tangible portion of OECD member countries' research expenditures, and constituting an increasingly crucial element of the research system, precise statistics are dearly needed.

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# 1 Introduction

This study report examines the seemingly simple question of the balance between federal infrastructure support and direct federal research funding in Canada, relative to four other jurisdictions, namely Australia, Germany, the United Kingdom (UK) and the United States (US). This report shows that due to the lack of available data, and to the large variation in countries' current needs that reflect the different historical path taken by each research system, this question is everything but simple.

Research infrastructures (RI) are key elements in science and innovation systems, helping boost scientific knowledge generation, accelerate technology development, and provide advanced training for new generations of scientists and science managers.[1] The Canadian Expert Panel on the state of science and technology (S&T) has noted that the nation's S&T performance is critically dependent on access to research infrastructure and facilities[2] alongside the more direct forms of support provided to researchers.

In Canada, the primary source of federal funding for research infrastructure is the Canada Foundation for Innovation (CFI), a not-for-profit corporation that funds research infrastructure to strengthen the capacity of Canadian universities, colleges, research hospitals and non-profit research institutions. Conversely, grants for direct research are available from the Tri-Council, comprised of the Natural Sciences and Engineering Research Council (NSERC), the Social Sciences and Humanities Research Council (SSHRC) and the Canadian Institutes of Health Research (CIHR). Tri-Council policy specifies that these funds must be used for costs directly attributable to the approved research projects.

In support of an ongoing evaluation of the CFI, Industry Canada, the arm's length delivery agent of research funding for the Tri-Council and CFI, determined it useful to examine issues related to balancing direct research and infrastructure support.

This report focuses on the main federal sources of funding for all five countries examined. While many non-federal sources (e.g., the European Union, regional development agencies, states, provinces, the academic and private sectors etc.) and even other science-based government departments and agencies, all play an infrastructure funding role, the report presents information on only the key federal funding sources.

The report is presented in eight sections. Following the present introduction, research findings for six different issues are presented subsequently. Section 8 provides the principal conclusions of this research and makes suggestions in support of future policy- and decision-making. Finally, appendices at the end of this report provide the list of organizations consulted for this study, limitations, quantitative data by country and references.

## 1.1 Methods

This project used the following four data collection methods:

**1. Literature review:** A comprehensive review of approximately 120 documents was undertaken for this study. The review provided contextual data on each country's research funding systems and identified gaps and issues to be explored through other lines of evidence. For each country, documents included national science investment plans and roadmaps, strategic plans for research infrastructure investments, government policy and program documents, and academic works regarding the research funding landscape. Literature on the global context (e.g., from sources such as the European Commission, the Organisation for Economic Co-operation and Development [OECD] and the World Bank) were also consulted as necessary.

**2. Tally of Quantitative Evidence:** A quantitative scan identified financial figures and expenditure data on direct research spending and infrastructure support in the five countries examined. Data were tallied for several variables including extramural R&D expenditures, percentage of operating and maintenance costs of existing versus new infrastructure and the evolution of these expenditures over the 2002 to 2014 timespan (depending on availability per country). Using Canada as a baseline, these financial data were analyzed to produce comparable ratios regarding national direct research spending and infrastructure support in Australia, Germany, the UK and the US. Once the preliminary analysis was completed, data was sent for verification and subsequently validated by experts in the US, the UK and Germany. Note that the experts in Australia did not validate the series but gave some explanation regarding the categories of expenditures. All country experts made reference to many of the limitations mentioned in the next section.

**3. Survey:** A sample of actively publishing researchers in each of the five countries completed an online survey regarding their own access to research infrastructure and funding for direct research support. From an initial population of approximately 900,000 researchers, invitations were sent to 22,060 according to a stratified sample by country and subfield. From the valid sample 17,049 reachable potential respondents, a total of 530 surveys were completed with an additional 91 partially completed surveys. Potential survey respondents could complete the survey in English, French or German. Initial scoping questions were posed to identify each respondent's major national funder and to assess the extent to which they used research infrastructure in their daily work. Any respondents indicating that they did not receive the majority of their funding from one of the five countries under analysis or who did not use research infrastructure at all were eliminated from the survey sample. Importantly also, only users of research infrastructures could actually complete the survey. Survey results were re-weighted and analyzed by country and, in pertinent cases, by subfield.

**4. Interviews:** In total, 23 interviews were completed for this project (Canada-7, Australia-5, Germany-4, UK-4, and US-3). Since the academic opinion was polled via the survey, the interview method sought to consult management individuals at national funding agencies, government departments or research councils. This stakeholder group provided a strategic perspective of the issues and was well-placed to identify best practices or lessons learned. In addition to the 23 formal interviews, several informal exchanges were made with various country representatives to validate quantitative data or answer targeted follow-up questions. A list of organizations consulted is presented in Appendix A.

## 1.2 Limitations

**Quantitative Scan:** The principal limitations of the tallied data are directly related to the limited availability of financial data for research spending. There was a scarcity of sector-disaggregated financial data for extramural research infrastructure, particularly outside Canada. Of the available data, numerous issues hindered comparability between each of the five countries. For example, UK funding data were based on allocations instead of expenditures, as presented in the other countries. The German federal expenditures on R&D data series includes the Business Sector (even if its contribution is marginal), which was not included for the other countries. It should also be noted that research expenditures figures for the US are substantially higher than what are presented in this report. This is because data for the National Health Institutes (NIH), the largest source of funding for research in the US, had to be excluded due to due to the absence of comparable data. Thus quantitative data on the US is taken only from the National Science Foundation (NSF). Additionally, the leveraging of infrastructure funding is highly variable from country to country. Wide variations in terminology across countries also presented compatibility issues as the inclusion and exclusion of various assets associated with each term varied greatly. Finally, accounting for operating costs and indirect funding alone presented particular challenges as statistics on research and infrastructure funding often encompass both direct and indirect costs. A full discussion of limitations is provided in Appendix B.

**Survey**: The availability of survey respondents presented a challenge given the short, intense data collection period (approximately 1 month). This challenge was further aggravated by the fact that the fieldwork phase coincided with the summer vacation season. It is possible that contextual factors (e.g., several survey reminders sent out in a short span of time, to a respondent pool that is highly solicited on a daily basis) may have negatively affected response rates. The survey was closed at the end of the data collection phase in order to complete the analysis of results. It is also important to consider the potential response bias in the final survey population. Respondents who indicated they did not use infrastructure at all were excluded from the survey through a routing question. Thus, respondents were all infrastructure users and therefore had a vested interest in research infrastructure funding. The use of comparisons across countries palliates the potential biases of this methodological choice.

**Interviews:** As for the survey, the availability of interviewees was a challenge given the short data collection period and summer vacation season. The deadline for accepting and completing interviews was extended slightly past the end of the data collection phase to ensure that the targeted number of consultations (minimum 20) was achieved.

# 2 Issue 1—Pressure to increase infrastructure funding

There is clear pressure to increase research infrastructure spending across all five countries examined. However, the collected evidence also indicates that pressure to increase direct research support is perceived as at least equally important. Thus, optimal decision-making must take into account contextual factors surrounding the need for both types of support, which vary from country to country. Furthermore, the influence of research discipline on infrastructure spending cannot be discounted. These findings are discussed in more detail below.

**Forcing a decision:** If forced to choose between an increase in either type of funding, the surveyed community of research infrastructure users would clearly prefer an increase in direct research support (83%, Table 1). Survey evidence further suggests that 43% of the research infrastructure users in the five examined countries do not think that direct research expenditures have kept pace with such expenditures in other countries.[i] On the other hand, survey respondents generally agreed (51%) that access to research infrastructure in their own country and for their own research area was currently adequate.[ii]

Table 1 Researcher preference for increased funding over the next three years

| | Australia n=45 | Canada n=94 | Germany n=59 | UK n=51 | US n=185 | Totals |
|---|---|---|---|---|---|---|
| Direct research | 89% | 84% | 75% | 76% | 86% | 83% |
| Research infrastructure | 11% | 16% | 25% | 24% | 14% | 17% |

Source: Computed by Science-Metrix, weighted percentage by country (n=434)

While it is important to consider the perspective of the research community, a complete portrait of infrastructure needs must also examine the influence of research policy and the availability of funds. This context is presented below for each of the five countries.

**Country context:** In 1997, the Canada Foundation for Innovation (CFI) was created to develop research infrastructure based on Canadian research priorities. From its creation, combined direct research and infrastructure spending initially accelerated and then stabilized around 2002 (discussed further under Issue 2 and 3).[3] In spite of CFI's funding, a particularly high proportion of Canadian survey respondents (48% compared to the average of 24%) did not think that their current access to research infrastructure was adequate. In addition, interviewees were concerned that a lack of long-term planning and no predictable multi-year funding for future infrastructure investments could jeopardize the operation of existing facilities (discussed further under Issue 5 and 6). Finally, it is interesting to note that in Canada, pressure to increase both types of funding may be due to a cycle of demand. With the CFI directing much of the funding for infrastructure, early emphasis was placed on new and emerging fields.[4] As explained by interviewees, this allowed Canadian researchers to be more productive, resulting in an increased demand for direct research funding to support these new areas, and ultimately, placing pressure on the infrastructure to remain cutting-edge. A similar cycle was mentioned by one interviewee each in Australia, the UK, and the US. The general

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[i] Survey response breakdown by country: Australia 64%, Canada 53%, Germany 27%, UK 37%, US, 44%
[ii] Survey response breakdown by country: Australia 44%, Canada 39%, Germany 59%, UK 51%, US 52%

consensus was that once new infrastructure is built, projects that make use of that infrastructure, 'take on a life of their own', thus increasing the pressure for more direct research grants.

In Australia, several mechanisms for infrastructure funding exist, including the Department of Education's Research Infrastructure Block Grants and the Australian Research Council's (ARC) Linkage Infrastructure Equipment and Facilities scheme. In addition to these, in the early 2000s the Australian government made significant efforts to address national infrastructure needs and emerging gaps with the pivotal creation of the National Collaborative Research Infrastructure Strategy (NCRIS) and an accompanying budget.[5] NCRIS was provided with $542 million from 2005-06 through to 2010-11, when funding ended.[6] It was intended to fund "capability areas that are of a national scale and generally require investment in the order of $20-100 million over five years."[7] In the 2013-14 Budget, the Government announced it would provide $185.9 million over two years to continue the NCRIS, allowing the most critical existing research facilities to continue to serve the needs of the research community. This funding terminates on June 30, 2015.[8] As the NCRIS is approaching the end of its mandate, there is pressure to reprioritize funding renewal for already funded infrastructure.[9] However, interviewees cautioned that research infrastructure renewal should not occur at the expense of reducing funding for direct research.

The UK awards public research funding (both direct and infrastructure support) via seven research councils, grouped collectively as the Research Councils UK (RCUK). Four Higher Education Funding Councils (England, Scotland, Wales and Northern Ireland) distribute additional university research funding. To complement these existing funding streams, with a total investment of more than £25 million or 10% of a Research Council's annual grant in-aid (whichever is less), the UK Department of Business Innovation and Skills launched a Large Facilities Capital Fund in 2002 to support projects that could not be implemented through the RCUK budget alone.[10] However, after a 2010 Government Spending Review, the overall infrastructure budget in the UK (called the 'capital budget') was reduced by about 40%. The largest reductions were in the Research Councils' capital budgets which were halved from 2010 to 2014.[11] Recently the government announced a new long term commitment to invest £1.1 billion funding for science and research infrastructure, starting in 2015.[12] Interviewees from the UK thought that there will be pressure for direct research to keep up with infrastructure after the forthcoming investment there. Additional concerns were raised on how exactly the future funding was to be prioritized (e.g., expansion of small regional facilities vs. ongoing operation of existing facilities vs. brand new facilities). Public consultations on how to prioritize this new funding are currently ongoing and discussed under Issue 4.

In the US, in general, the federal government's overall support for academic R&D is the combined result of numerous discrete funding decisions made by the R&D-supporting federal agencies, with input from the White House and Congress. There is little centralized direction concerning instrumentation and infrastructure, and each agency prioritizes infrastructure programs or funding based on their own priorities. Generally, overall expenditures for the top six funding agencies have remained relatively stable over the last decade.[13] Interviewees note that the varying missions and objectives of the different agencies, as well as the broad geographic distribution of research capabilities make it difficult to determine whether there is overall pressure to increase one type of funding support over the other. However, there were concerns that without continued investment in infrastructure capabilities, the US would fall behind in global science leadership.

In Germany, the primary federal sponsors of research and research infrastructure at universities and research institutions are the German Research Association (DFG) and the Federal Ministry of Education and Research (BMBF). As part of its Research Infrastructure Programme, the DFG defines major instrumentation as equipment with a gross purchase price of €50,000 or higher. The instrumentation must primarily serve research purposes and must not be included in the core support available at the respective institute.[14] The BMBF, on the other hand, does not stipulate an investment amount but rather that research infrastructures are defined as wide-ranging instruments, resources or services […] which stand out due to national signification, and to a certain longevity (more than 10 years)."[15]

Of all the countries examined for this study, researchers in Germany appear to be the most satisfied with their level of research funding. German survey respondents agreed in much higher proportions than the four other countries that funding for direct research expenditures has kept pace with the funding available to their colleagues in other countries, (37% versus 19% overall). Furthermore, a 2012 survey on innovation funding trends found that German country correspondents estimated that 'Infrastructure for Research and Innovation' equalled 23% of all research and innovation funding in 2011, among the highest share reported by any country correspondents. [16] Traditionally, the country's research infrastructures existed primarily in the natural sciences, particularly in chemistry as well as in physics and astronomy. However, the German federal government has worked to extend the definition of research infrastructures to incorporate knowledge resources of humanities and social sciences which have been chronically underfunded.[17] Although interviewees from Germany do not think the country is facing increasing pressure to fund infrastructure, the efforts in recent years to support research infrastructures in the humanities and the supply of digital information to other web-based tools represents an expansion of infrastructure priorities.[18]

**The influence of research disciplines:** The question of finding the right infrastructure to direct research funding balance is further complicated when trying to establish an appropriate distribution across research disciplines. The interview consensus across all countries was that research discipline does indeed influence pressure to increase infrastructure spending. This can become especially challenging when minorities or "lobbies" of a certain disciplines are very vocal, or when disciplines with lighter needs for infrastructure (e.g., social sciences) feel they are subsidizing infrastructure-heavy disciplines (e.g., astronomy).

Survey results corroborate this, suggesting that researchers from the following subfields would prefer to have a larger proportion of research infrastructure funding rather than direct support: Enabling & Strategic Technologies; Information & Communication Technologies; and Clinical Medicine.[19] In contrast, researchers from General Science & Technology, Mathematics & Statistics; and Psychology & Cognitive Sciences indicated a greater preference for increased direct researcher spending.

# 3 Issue 2—Pace of direct vs. infrastructure support

In the five countries examined, federal research infrastructure funding grew on average twice as fast as direct funding between 2008 and 2013.

Before further discussing this finding, it is imperative to note that serious limitations exist around the availability and robustness of data that has been compiled by government or national statistics offices on research infrastructure. For example, in Canada the analysis presented herewith is limited to data from the Tri-Council and the CFI, while data for the US is limited to the National Science Foundation (NSF), as these represented the most reliable quality data that could be used. Other limitations include the scarcity of sector-disaggregated data, numerous data comparability issues, variations in terminology, and the lack of standard methods to account for operating costs. A full discussion of limitations is presented in Appendix B. More detailed data by country are presented in Appendix C.

In order to determine growth rate, it was first necessary to compile the federal extramural expenditures for R&D in the higher education and non-profit sector for each country over the 2008-2013 period. This is presented in Figure 1 at purchasing power parity (PPP). The full federal expenditure series is presented in Appendix C, Table 6.

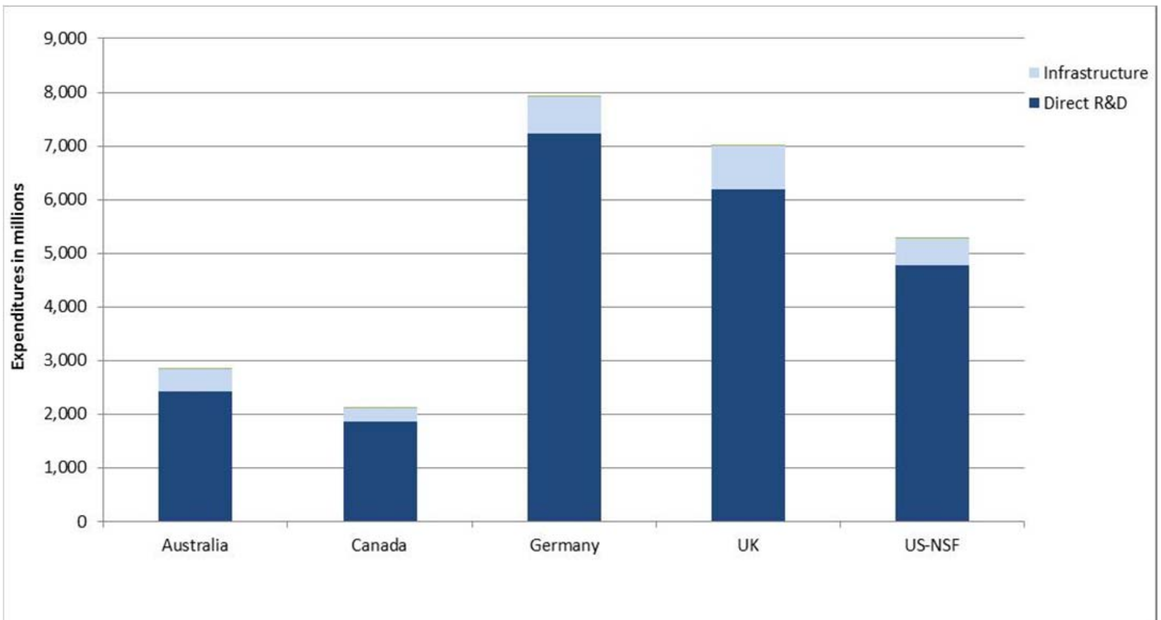


Figure 1 Federal expenditures on direct R&D and infrastructure, 2008-2013 average in PPP

Source: Data compiled by Science-Metrix from Statistics Canada, CFI, NSF, Government of Australia Department of Industry, UK Office for National Statistics, UK Department for Business, Innovation & Skills, Federal Statistical Office of Germany.

Using this information, the average annual growth rate was calculated for the studied period. Overall, direct federal R&D funding grew by 3% between 2008 and 2013, while the growth rate for federal infrastructure funding was 6% during the same period (Table 2).

Table 2 Average annual growth rate of federal direct funding and research infrastructure funding between 2008 and 2013

| Average annual Growth rate | Australia | Canada | Germany | UK | US -NSF | Average | Average (excluding Canada) |
|---|---|---|---|---|---|---|---|
| **Direct R&D** | 6% | 1% | 6% | 0.4% | 4% | **3%** | **4%** |
| **R&D Infrastructure** | 11% | 2% | 8% | 3% | 4% | **6%** | **6.5%** |

Source: Data compiled by Science-Metrix from annual tables on federal extramural expenditures on R&D, in higher education and non-profit institutions, by major departments or agencies of the governments of Canada, the US, Australia, the UK and Germany.

Of all countries, Canada showed the lowest growth for infrastructure funding (2%), followed by the UK where research infrastructure spending grew by an average 3%, and direct research funding growth was also slow at 0.4%. Alternatively, in Australia, infrastructure funding grew by an average 11% per year, almost twice its average annual growth rate for direct funding (6%). In the US, the NSF increased direct research and infrastructure funding at about the same rate for the 2008-2013 period (3.8% and 4.1% respectively). In Germany, research infrastructure funding between 2008 and 2013 grew by an average 8.5% per year, compared to a 5.6% annual growth rate of direct research funding. Note that excluding Canada from the average demonstrates that federal funding is well below the average relative to the other four countries. Because of the limitations previously discussed, these figures should be seen as indicative rather than definitive. Not surprisingly in light of these data, of all survey respondents, Canadians were the least satisfied that their need to access research infrastructure over the last decade had been fulfilled (Table 3).

Table 3 Researcher satisfaction regarding access to research infrastructure over the last decade

| | 1 - Very dissatisfied or 2 - dissatisfied | 3 - Neither satisfied nor dissatisfied | 4 - Satisfied or 5 - very satisfied |
|---|---|---|---|
| Australia (n=47) | 15% | 26% | 60% |
| Canada (n=97) | 32% | 24% | 44% |
| Germany (n=63) | 19% | 21% | 60% |
| United Kingdom (n=52) | 15% | 33% | 52% |
| United States (n=194) | 19% | 21% | 61% |
| **Totals** | **19%** | **23%** | **58%** |
| **Totals (excluding Canada)** | **17%** | **25%** | **58%** |

Source: computed by Science-Metrix, weighted percentage by country, (n=453)

# 4 Issue 3—Proportion of R&D spending devoted to infrastructure

Subject to caveats in data quality, these countries devoted around 10% of research funding on average to research infrastructure between 2008 and 2013. Average annual ratios were calculated comparing research infrastructure spending to total federal extramural expenditures on R&D in higher education and non-profit institutions. Figure 2 presents the national average as well as the yearly trend for all five countries examined in this study. Note that the 10% average does not include Australia, as its operating costs are included in its ratio.

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Average | Ratio of Annual Infrastructure to Total R&D Spending |
|---|---|---|---|---|---|---|---|---|
| **Australia*** | 10% | 11% | 18% | 20% | 16% | 13% | 15% | |
| **Canada** | 10% | 11% | 12% | 11% | 14% | 11% | 12% | |
| **Germany** | 7% | 10% | 9% | 9% | 9% | 8% | 9% | |
| **UK** | 7% | 15% | 18% | 11% | 10% | 9% | 12% | |
| **US (NSF)** | 7% | 11% | 18% | 6% | 7% | 7% | 9% | |

Figure 2 Annual ratio, federal infrastructure spending over total federal R&D spending 2008-2013
Note*: Australia series includes infrastructure operating programs (or indirect costs)
Source: Data compiled by Science-Metrix from tables on federal extramural expenditures on R&D, in higher education and non-profit institutions, by major departments or agencies of the governments of Canada, the US, Australia, the UK and Germany

For Canada, the spending ratio was 12% (16% when infrastructure operating funds are included). The UK allocated a comparable 12% of total R&D funding to research infrastructure and Australia allocated 15% (including operating funds), while the US and Germany both spent 9% of their total R&D budget on research infrastructure for the period (US data for NSF only).

Between 2008 and 2013, the infrastructure to total R&D spending annual ratio has been relatively stable for Canada and Germany, with the rate varying by three percentage points, between 11% and 14% in Canada, and between 7% and 10% in Germany.

It is also interesting to note that 45% of the surveyed researchers across all countries (total n=402) rated Germany as having the best ratio of investment in infrastructure compared to direct research support. The US was rated second by 24% of the surveyed population.

# 5 Issue 4—Policies to address the balance

While there is little evidence of a robust method to determine the share of direct research funding vs. infrastructure funding, all countries examined in this study conduct peer-review of infrastructure proposals and/or carry out periodic evaluations of existing infrastructure schemes to try to address questions of appropriate funding allocation. Common findings of such evaluations are as follows.

- Even modestly early access to information on which to base infrastructure investments is of high value because of the propensity for design features being "locked in" for many years.[20]
- Resource allocation should be done with a view to eliminate uncoordinated duplication of key research facilities. Efficient allocation is often supported by an independent, yet collaborative consultation process and informed long term, rather than *ad hoc*, planning[21] (e.g., see roadmap discussion later in this section).
- Foundations or private sponsors can play a critical role in the funding of research infrastructures. However, their involvement is often limited to the early stages as they cannot and/or do not want to provide permanent commitments[22] (see also the discussion in Issue 5 on co-ownership).

In addition, all countries examined participate in international fora to increase international cooperation relating to global research infrastructures (Box 1).[23]

**Box 1 International examples**

In 2008, a Group of Senior Officials (GSO) was formed encompassing government representatives from more than 14 countries and the European Commission. The GSO created a framework to take stock of and explore cooperation on global research infrastructures. The framework was furthermore adopted at a meeting of the G8 Science Ministers in 2013, as the reference terms under which G8 countries will consider cooperation on global infrastructures. Other major fora for such discussions include the International Conference on Research Infrastructures (which has been taking place in some form since 2000) and the European Strategy Forum on Research Infrastructures (ESFRI). Established in 2002, the ESFRI has put forward regular roadmaps (2006, 2008, 2010, and 2015 pending) to facilitate multilateral initiatives leading to a better use and development of research infrastructures.

Despite these commonalities, one can distinguish between two types of approaches to planning for infrastructure. The top-down, systemic, strategic approach reflects varying needs by research discipline and takes into account national research priorities. On the other hand, a bottom-up, à la pièce, tactical approach reflects funding demands by researchers (and sometimes research lobbies).

**Top-down:** Regular roadmapping processes are engrained in Germany, the UK and Australia, which are all countries that appear to take a more top-down approach. Roadmaps allow for investment planning across disciplines within a national framework. They can also support decisions on participating in infrastructures abroad, financed multilaterally based on clearly defined national priorities.[24] Roadmapping is often initiated by a government department, includes some form of expert advice and stakeholder consultation, and is sometimes linked to a defined funding scheme; some examples follow.

**Germany:** Based on roadmapping that takes place at the EU level (e.g., ESFRI—see box), Germany has produced its own research infrastructure roadmaps, which typically describe, almost exclusively, large-scale infrastructures to which many countries contribute funding and services; however, science policy in

Germany is increasingly focusing on medium-sized and small research infrastructures.[25] For example, in 2013 the Federal Ministry of Education and Research (BMBF) presented its National Roadmap for Research Infrastructures in Germany.[26] The purpose of the strategy is to support and guide political decisions related to research infrastructures, as well as to lay a foundation for the joint planning of infrastructures at the Länder (state) Federal, and international levels.[27] The Helmholtz Association of German Research Centres (HGF), which operates large equipment and complex infrastructures, also developed and published a roadmap for research infrastructures in 2011, to be updated at regular intervals. Consulting with experts in various research disciplines, its purpose is to list those research infrastructures that are most strategically relevant for the HGF. The roadmap aims to help determine strategies for funding, implementing and operating the research infrastructures using "already-formulated evaluation criteria and processes (i.e. using precise timescales and budgets, summary cost estimates, setting priorities, including the planning for closures/switch-offs and [new] structuring of the management for these infrastructures)."[28]

**UK:** As of 2003, the RCUK has prepared a large facilities roadmap with updated versions published in 2005, 2008, 2010 and 2012. These roadmaps help prioritize the project proposals that are eligible and are good candidates for LFCF funding (discussed under Issue 1). To prepare the roadmap, each Research Council proposes facilities in its field of expertise, which is followed by a collective prioritization exercise that involves the following stages:

- Selection of facilities for inclusion in the Large Facilities Roadmap, taking into consideration the views of their communities;
- Short-listing of facilities eligible first by each Research Council and then collectively;
- Prioritization of facilities using an agreed set of criteria.

The final decision on the prioritized list is approved by the RCUK Executive Group that then makes recommendations to the Department for Business, Innovation and Skills (BIS). The recommendations are also followed by consultations with other stakeholders (over 300 for the 2012 roadmap), with further discussion between the BIS Department and the Research Councils. The final funding decisions are taken by the BIS Department and require ministerial approval.[29]

Note that BIS is currently conducting a public consultation for a new Science Capital Roadmap (consultation closed as of May 2014, analysis now in progress).[30] This is to set out a "long-term strategic vision for world-leading science and infrastructure" with results expected in autumn 2014. The plan is backed by a forecast £1.1 billion in 2015-16, which is to grow in line with inflation each year up to 2020-21.[31]

**Australia**: As described earlier, the National Collaborative Research Infrastructure Strategy (NCRIS) is an Australian Government program for the development of large national research infrastructure. There have been three instalments of the NCRIS Roadmap (2006, 2008, and 2011). A 2010 Evaluation of the NCRIS noted that decision-making in the implementation of the program has always been based on a roadmapping process "that provided a firm foundation for the allocation of funding. The systematic and consultative approach to resource allocation ensured that the highest national priority capabilities were addressed. With appropriate, regular updates, this process is recommended for future research infrastructure funding programs."[32] For example, the latest roadmapping process encompassed advice from six Expert Working Groups on research infrastructure priorities, the circulation of a Discussion Paper for stakeholder feedback

(>200 responses) and subsequent circulation of an Exposure Draft (>150 responses) before preparing the final Roadmap.[33]

**Bottom-up:** While roadmapping processes also take place in Canada and the US, they more often occur at the institutional rather than national level and encompass a much longer timeframe. Some examples include the Canada Foundation for Innovation Strategic Roadmap 2012-2017[34] and the US Department of Energy's Facilities for the Future of Science 20 Year Outlook (2003) and a subsequent Interim Report (2007).[35]

Additionally, a more bottom-up approach often embodies strategic vision publications, developed by scientific community organizations that are oriented toward specific thematic fields of science. This includes a vision for the field from the scientific community point of view (the users of the infrastructures) and comes with a coherent picture of the relevant scientific landscape.[36]

As indicated by US interviewees, each of the main science agencies (e.g. DOE, NSF, NIH, NASA) has the flexibility to follow its own policy-making processes based on the needs of their individual scientific communities. As one interviewee said, "there are not a lot of top-down, one size fits all, centralized policy directives that come from the central executive authority, the Office of the President."

**Informed policies:** Forty per cent of survey respondents who used research infrastructure thought their country had informed polices that reflected their needs (total n=433). This did not discriminate between top-down and bottom-up approaches, as the percentages were highest in the UK (45%, n=51) and the US (42%, n=184), and lowest in Australia and Canada (31%, n=45 and 26%, n=93 respectively). Here, some explanation for the lower end can be offered. Notwithstanding the utility of the roadmapping process for identifying Australia's capability areas and for providing a strategic framework for investment, interviewees point out that sporadic funding for the NCRIS after 2011 somewhat undermined prioritization efforts. In addition, there have been challenges in integrating the NCRIS on a continuous spectrum with the various other funding mechanisms in Australia (e.g., university block grants for research infrastructure or the Infrastructure, Equipment and Facilities scheme of the Australian Research Council).

In Canada, interviewees were not convinced that a "national infrastructure plan" was appropriate in the current context, as many factors may challenge the creation of such a plan (e.g., no champion organization, multiple funders with multiple visions, no dedicated staff or resources in a climate of fiscal restraint, and decision-making that may have to involve competing stakeholders such as universities and industries). Instead, interviewees thought that any infrastructure planning should be within the context of an overall national research strategy (one interviewee pointed to the European Commission's Horizon 2020 as an example), which could act as a catalyst for overall innovation and would help guide funding allocations.

More specifically, under Horizon 2020's 'Excellent Science Pillar', a category for European Research Infrastructure has been designed to support three key activities: 1) development of new world-class research infrastructures, 2) optimising the use of national facilities by integrating them into Europe-wide networks, 3) development and deployment of ICT-based e-infrastructures. Two other lesser objectives (fostering human capital and policy cooperation) are also included in the design. The total budget for this activity in Horizon 2020 is €2.5 million.[37] The Work Programme for the Infrastructure activity outlines proposal calls for specific topics, include the challenge each proposal must address, its overall scope and its expected impact.[38]

# 6 Issue 5—Balancing new versus existing facilities

Determining an ideal balance between new and existing facilities is a necessary part of the prioritization processes described for all countries under Issue 4. Surveys are another common tool to help governments determine whether to continue funding existing infrastructures and identify the need for new infrastructures (Box 2).[39] While the majority of interviewees in Germany, the UK and the US spoke of a clear need to consider both types of infrastructure, Canadian and Australian interviewees noted a focus that has actually shifted from new to existing over the last ten years (as per the particular context of these countries explained in Issue 1). In practice, however, targeted methods for trying to determine the balance vary from formal procedures to non-existent. Examples below from Germany and the UK illustrate the opposite ends of the spectrum particularly well.

**Box 2 Surveys—a tool for decision-making**

The 2007 pan-European Survey of Research Infrastructures was jointly prepared by the EC and the European Science Foundation (ESF). It listed 598 existing, large European research infrastructures and compared them with projects planned for the future. The success and results of the survey led to the development of the European Portal on Research Infrastructures Database. In Germany, a 2011 government-led survey of 36 German scientific societies asked about the importance of existing research infrastructures and the desire for the creation of new research infrastructures. In the US, the 2010 Astronomy decadal survey carried out by the National Research Council included a section on planning for new telescopes, instruments and facilities, accounting for costs and future priorities.

**German procedure for the assessment of new/existing research infrastructures:** Prior to 2010, new large-scale facilities in Germany were traditionally selected for funding following an intensive peer-review process.[40] Infrastructure proposals were drafted by the specialist scientific communities, reviewed by the members of the German Council of Science and Humanities (WR) who are worldwide experts in their respective fields, and followed up by the respective departments of the BMBF.[41]

However, a new detailed procedure for the science-driven assessment of research infrastructure has been created by the WR in an attempt to make the best use of the existing infrastructures and to fully exploit the capabilities of new ones. This procedure was implemented by the BMBF in its 2013 roadmap and is meant to support policy and investment prioritization, so that policy decisions of the BMBF Ministry concerning research infrastructures are made systematically.[42] The new procedure dictates that research infrastructures be assessed in two stages:

1) *A science-based assessment of the projects.* Evaluation dimensions of the scientific process include scientific potential, utilization, feasibility, and significance for Germany as a location of S&T development. This evaluation includes an individual qualitative assessment of each project, followed by a comparative overall assessment.
2) *An assessment of economic aspects.* An independent circle of technical and economic experts is appointed to conduct cost estimates of each proposed infrastructure. Project implementation efforts are estimated and possible implementation risks are assessed.[43]

Projects are then prioritized based on the results of this process, and successful plans are subsequently taken up in the roadmap.

For existing infrastructures, no such assessment process is in place, although there are clear recommendations from the WR indicating that research-driven infrastructure projects can be terminated if:

evaluations are negative; if applications for external funding fail; if they do not fulfil the expectations attached to them; if they lose their relevance in a changed environment of disciplinary and interdisciplinary topics; or if they lose their connection to the further development of research methods.[44]

**Balance between new and existing in the UK:** Strong and ample evidence from a 2013 UK House of Lords report on scientific infrastructure articulates that new initiatives often come at the cost of under-exploiting existing facilities to their full potential. In the UK, this problem stems from the fact that capital investment for infrastructure and operational costs are governed and allocated differently, without a process for determining their interrelationship. Tangible negative consequences include reduced scientific output and a consequent decline in competitiveness. The committee stated that "balancing the requirement to provide operational costs against the requirement to invest in new infrastructure is far from straightforward." Furthermore, the disconnect between the two was described as "damaging" with no "ideal solution" yet coming to light. As such, the committee recommended that the BIS Department review the situation to determine how capital investment and the funding for operational costs can be tied together in one sustainable package.[45] Accepting the recommendation, the BIS is seeking views on the sustainability of capital investments and operational costs during its current consultation for the new science and innovation strategy to be released by the end of the year.[46]

**The benefits and drawbacks of co-ownership**: When considering any capital investments, it is also worthy to note that there are both advantages and disadvantages to shared ownership of facilities. Each country/organization must take its own particular context into account. For example, in Australia, various infrastructure funding programs have required differing levels of co-investment as a condition of Australian Government funding. Mandated requirements for co-investment have ranged from zero (NCRIS), 25% (ARC's Linkage Infrastructure, Equipment and Facilities program), 50% and beyond (Major National Research Facilities program). Co-investment shares the cost and risks of establishing and operating infrastructure and also represents a tangible demonstration of participants' priorities. Indeed, the 2010 NCRIS evaluation showed that even though there was no co-investment obligation, 30% of overall funds were from cash co-investment and 28% were from in-kind co-investment. Thus, the leveraging of public money was achieved and the benefits maximised. Another important lesson from the evaluation was that allowing flexibility for State and Territory Governments to deliver on their co-investment commitments over time encouraged greater overall leverage than would have been achieved by requiring co-investment up-front. As such, the Australian Innovation and Industry Department concluded that co-investment in research infrastructure is desirable but no specific requirement for co-investment should be stipulated at the framework level.[47]

Conversely, the US DOE can be seen as embodying the philosophy that "co-ownership is no-ownership" as it can be difficult to establish responsibility for costs and risks if primary ownership is not clearly defined when two or more group invest in an asset. As such, the DOE's Office of Science is the primary steward for all its user facilities (>20 large infrastructures, serving >29,000 users), meaning it completely owns, manages and oversees the facility in addition to providing funds for operations.[48]

**A note on mid-sized infrastructures:** Finally, the choice to make capital investments in brand new infrastructure, versus investing to upgrade existing facilities also applies to mid-sized infrastructures (M-RI). While not a perfect definition, M-RI tend to be shared by many users at one institution and require substantial investments, but several similar pieces of equipment are likely to exist at different locations within a country (e.g. sophisticated microscopes, DNA sequencers, nuclear magnetic resonance facilities). During this study, interviewees in the US, the UK and Germany, indicated that funding for M-RI often falls into a gap as small infrastructure costs may be eligible under a variety of research funding mechanisms while federal infrastructure funding often specifically targets large-scale facilities. Some documentary evidence also suggests that the issue is being raised. For example, the German Research Foundation (the DFG) was mandated by the European Heads of Research Councils to lead an exploration on M-RI in Europe. Suggested goals were to achieve a clear and usable definition of M-RI, to discuss standards that M-RI should fulfil, to determine how best to inventory M-RI in Europe (including updates) and to enable/encourage wider networking and access to M-RI. This work is ongoing.[49]

In the US, the latest NSF strategic plan (2014-2018) explicitly notes that M-RI "are increasingly critical for enabling fundamental research in the experimental sciences; there is an urgent need to adequately provide this category of instrumentation."[50] Similarly, the 2013 UK House of Lords report on scientific infrastructure found evidence of "some difficulties in the funding of mid-range scientific infrastructure". The report indicated that the establishment of university consortia and equipment-sharing initiatives is a welcome step forward in terms of improved access to mid-range infrastructure. [51]

# 7 Issue 6—Funding for maintenance and operation

Continued funding for the maintenance and operation of existing infrastructure was raised as a key ongoing issue by all interviewees. Such funding must consider not only the age of the infrastructure stock in question, but also the highly qualified personnel (HQP) required to maintain and operate the facilities. The collected evidence suggests that operating costs vary anywhere from 10-30% annually of total project costs. However, accurate and comparable definitions of operating costs are not readily available. Similarly, there are very few standardized practices guiding or dictating the allocation of operating costs in the countries examined for this study.

**Existing infrastructure challenges:** Interview and documentary consensus across the five countries revealed two key themes regarding funding for maintenance and operation.

**1. Aging Stock:** Essentially all interviewees noted that as existing infrastructure ages, it costs more to operate. Although this may seem obvious, the nuances of this challenge are well-explained in a 2014 report from the Canadian Association of University Business Officers. The study says that the majority of Canadian universities are not able to put sufficient resources into capital renewal. For all building types and functions examined in the study (e.g., complex to simple, administrative, to residential, to science-based) the backlog in the system is increasing to the tune of $8.4 billion in deferred maintenance as a whole. About a quarter of that amount ($2 billion) is specifically deferred maintenance for buildings with science research or medical functions. The report notes that there may be "a higher risk associated with the scientific research and medical space: while alternatives may be available for academic and administrative space, it is very difficult to quickly replace a laboratory or medical facility that has been unexpectedly closed by system failure." [52]

According to the report, there are a number of drivers for such a deficit, namely an increase in the total size of campuses, inflation in the cost of construction, funding and resource allocation models in place and the age profile of Canadian campuses, with a large number of buildings now being at the age where the need for systems renewal increases dramatically. The report recommends a dual approach to address the issue. First, on a shorter-term, more tactical basis, capital plans should address the immediate building needs that are already past due and are having a negative impact on the performance of the buildings. Secondly, more strategic, longer term planning is necessary to balance the need to continue to address any remaining deferred needs, while also anticipating new life cycles as they come due.[53]

Similarly, subsequent to a 2012 study in the US estimating that NASA may have as many as 865 unneeded facilities with maintenance costs of over $24 million a year, the agency held a hearing on efforts to manage its facilities and infrastructure. The hearing testimony indicated that NASA is coordinating a 20-year Agency Master Plan that prioritizes facilities for both replacement and demolition, as well as identifies cross-Center consolidation opportunities to reduce duplicative infrastructure. It was estimated that such efforts decreased the deferred maintenance costs by 5.7% in the first year of implementation.[54]

**2. Highly Qualified Personnel (HQP):** Allocations for existing infrastructure must consider the training, salary and retention of the HQP who operate the equipment. Such technical support is critical for several reasons. Not only does it facilitate researcher access, but it can also contribute to attracting industry partners, supporting student training and, ultimately, building a competent workforce.

In Australia, interviewees and documents note that uncertainty about the provision of funding for operating costs and specialized staff that run existing infrastructure creates management difficulties for the country's current science capabilities and places the country at risk of losing highly-skilled workers.[55]

Similarly, the UK House of Lords Committee Report on infrastructure was harsh in its criticism, stating that "operational costs and the development of skilled technicians with well plotted career paths have been deemed second order issues and have been relegated by the lure of new projects." The report stresses that a failure to address these issues means that the UK's infrastructure is not being exploited to its full potential.[56]

In Canada, one of the key findings from an evaluation of the Canada Research Chairs program (a program meant to strengthen Canadian research performance in universities), indicated that a barrier to attraction and retention of leading researchers is not only the availability of research infrastructure but also the availability of associated research staff.[57] Similarly, in the latest CFI annual report, issues related to HQP and the acquisition and updating of equipment were identified as important challenges.[58] One interviewee indicated that, with respect to existing infrastructure, "talking just about the equipment and ignoring the people that operate that equipment is perhaps too narrow a view".

As such, allocations for existing infrastructures and deliberations on the balance with new investments must necessarily consider HQP as part of the equation.

**Level of satisfaction:** Survey data suggests that Canadians are more dissatisfied than others with the funding available for the operation and maintenance of existing infrastructure (aligning well with the evidence presented above on Aging Stock). Compared to an average of around 40%, a total of 59% of Canadian researchers who use infrastructure are dissatisfied with the financial means available for their maintenance (Table 4) and 62% for their operation (Table 5). Again aligning with earlier evidence, Germany stands out at the opposite end of the spectrum, in that 46% of survey respondents are satisfied with the means available for maintenance, compared to the average of 31% (Table 4).

Table 4 Financial means to maintain research infrastructure are adequate

| | 1 - Strongly disagree or 2 - Disagree | 3 - Neither agree nor disagree | 4 - Agree or 5 - Strongly agree | Don't know/Not applicable |
|---|---|---|---|---|
| Australia (n=45) | 40% | 24% | 33% | 2% |
| Canada (n=94) | 59% | 12% | 24% | 5% |
| Germany (n=59) | 22% | 27% | 46% | 5% |
| United Kingdom (n=51) | 51% | 18% | 29% | 2% |
| United States (n=184) | 44% | 24% | 28% | 4% |
| **Totals** | **43%** | **22%** | **31%** | **4%** |
| **Totals (excluding Canada)** | **39%** | **23%** | **34%** | **3%** |

Source: Computed by Science-Metrix, weighted percentage by country (n=433)

Table 5 Financial means to operate research infrastructure are adequate

| | 1 - Strongly disagree or 2 - Disagree | 3 - Neither agree nor disagree | 4 - Agree or 5 - Strongly agree | Don't know/Not applicable |
|---|---|---|---|---|
| Australia (n=45) | 36% | 29% | 33% | 2% |
| Canada (n=94) | 62% | 15% | 20% | 3% |
| Germany (n=59) | 36% | 25% | 32% | 7% |
| United Kingdom (n=51) | 39% | 25% | 33% | 2% |
| United States (n=185) | 39% | 28% | 31% | 2% |
| **Totals** | **41%** | **26%** | **31%** | **3%** |
| **Totals (excluding Canada)** | **38%** | **27%** | **32%** | **3%** |

Source: Computed by Science-Metrix, weighted percentage by country (n=434)

To complement the survey data, some contextual information for each country is presented below, but any percentages should be used with great caution.

**Internationally**, the OECD acknowledges the difficulty in properly accounting for operating costs and observed systemic difficulty with estimating infrastructure costs for roadmapping purposes.[59] Nonetheless, several interviewees said their institutions relied on guidance from the OECD 'rule of thumb' for large research facilities, where the annual cost of operations is about 10% of the total construction cost. The OECD's definition includes:

- "staff of the collaboration, including their benefits;
- the 'non-scientific' infrastructure: buildings/offices and their maintenance, vehicles, roads, grounds-keeping, insurance;
- utilities, notably electricity, expendables, and replacement components;
- maintenance and replacement of defective equipment;
- R&D for new instruments, prototyping and upgrades;
- educational and outreach activities."[60]

As noted earlier in Figure 2, Australia does not distinguish its indirect costs from its total R&D expenditures. Little could be found in the way of percentages allocated specifically to operating costs for infrastructure and interviewees confirm that it would be difficult to estimate this proportion, as it is highly facility and project-dependent.

In Canada, the CFI's Infrastructure Operating Fund (IOF) allocates 30% of the maximum CFI amount approved at award finalization.[61] However, some interviewees point out that, as the CFI provides only 40% of total project costs (with the remainder required from other sources), the allocated operating funds only account for 12% of the cost overall (30% of 40%). As of November 2013, the CFI has also launched a searchable online directory of facilities across Canada that are open to working with businesses. Known as the *Research Facilities Navigator*, partnerships formed through this platform may help offset some maintenance or operation costs. Another government initiative, the Indirect Costs Program, uses a funding formula to help eligible institutions with indirect research costs (e.g. salaries for those providing research administration support, workplace health and safety training, maintenance of libraries and laboratories, and administrative costs associated with patenting).[62]

Similarly, in Germany, some operating costs are funded at the federal level. For example, the German Research Foundation (DFG) provides about 20% annually in overhead funding for the research projects it funds to cover indirect research costs, such as "maintenance costs for test facilities, the renting of laboratory space, software licenses, general administrative costs and other expenses that have an indirect relation to the research project."[63] Interviewees indicate that, in some cases, usage fees may be charged to cover the operating costs on a pro-rated basis. Hosting organizations may also refinance from other sources to cover part of the operating costs. International funding sources are also important although the European Commission has stated "EU financial support should never exceed 20% of the annual operating costs of the infrastructure to prevent it from becoming dependent on the EU contribution."[64]

Documentary evidence suggests that, in the UK, between 17 and 30% (depending on institution type) is spent on building depreciation, maintenance, equipment, energy and utilities costs in the higher education sector.[65] Indeed, interviewees used the term 'case-by-case' to describe operating cost allocation. They explained that for mid-sized institutional infrastructure, operating costs for the initial few years will be identified explicitly within the overall grant at the outset of the investment. For very large infrastructures of national importance, the responsible Research Council determines on a periodic basis how much to spend on operating costs from their overall recurrent funding, and may also have a cost recovery model which ensures that some operating costs are covered through direct charges. Furthermore, universities receive a block grant allocation for research capital and a separate block grant for recurrent research costs, and thus make their own decisions about how to invest in capital infrastructure and its on-going operation/maintenance/upgrade. Interviewees also noticed a visible culture shift in the last five years towards clusters of shared equipment to help distribute operating costs among various users. A notable example is the *N8 Research Partnership*, a group that has created a searchable online database to locate and request access to research equipment across the UK. As of March 2013, over 10,000 items have been catalogued and the group is working with the BIS department toward policy recommendations regarding barriers and current best practices for equipment and cost sharing.[66]

Finally, the US has a different system than other countries. The federal government reimburses universities for facilities and administrative (F&A) costs that they have already spent, up to a cap of around 26-28% annually. These F&A costs are necessary to support research but cannot be readily identified with an individual research project. Examples of these costs are facilities operation and maintenance, utilities, library facilities, and administrative expenses. F&A rates are calculated in accordance with federal guidelines issued by the White House Office of Management and Budget (OMB). F&A rates vary slightly from institution to institution because construction, maintenance, utilities, and administrative costs vary by institution and by region. The rate for each university generally is re-negotiated every three years based on documented historical costs and cost analysis studies.[67]

# 8 Conclusions

Canada and other countries examined during this study (Australia, Germany, the UK and the US) are facing pressure to increase the share of funding devoted to both research infrastructure and to direct research. The former is influenced by research discipline and science policies, while the latter reflects the preferences of the scientific researchers themselves. Additionally, funding for cutting-edge infrastructure tends to increase the demand for research projects (i.e. direct funding) that will subsequently make use of that infrastructure. There is no sound universal approach and as such, decision-making must take into account many specific country factors such as, time lag between infrastructure implementation and demand for direct research grants, research funding landscape and strategic science priorities, when determining the need for both types of support. Even within a country, the factors to consider are not always stable and thus appropriate funding policies should be responsive to varying needs and changing priorities.

Across the five countries, the pace of federal research infrastructure funding grew twice as fast as that of direct funding between 2008 and 2013 (average annual growth rate of 6% vs. 3%, or 6.5 vs. 4 when excluding Canada from the average). Canada showed the lowest growth for infrastructure funding (2%) and second lowest for direct funding (1%) after the UK. Because of the many limitations of the data, these figures should be seen as indicative rather than definitive. Importantly, the exercise of trying to determine funding pace illuminated the fact that none of the consulted government or national statistical offices compile robust data on research infrastructure spending.

For all countries over the 2008-2013 period, an average of 10% of total federal research funding was devoted to infrastructure. Canada's spending was slightly higher than the average, with 12% of its total research funding on infrastructure (or 16% when infrastructure operating funds are included). Due to data quality and comparability issues, this should not necessarily be construed as a significant difference.

While there is little evidence of a robust method to determine the balance between direct research and infrastructure support, all countries examined in this study address questions of appropriate funding allocation through peer-review, periodic evaluations and participation in international fora. Additionally, infrastructure planning is approached in one of two ways, top-down (most often encompassing roadmapping) or bottom-up. Forty per cent of survey respondents who used research infrastructure thought their country had informed polices that reflected their needs. Responses did not discriminate between top-down and bottom-up.

Methods specifically addressing the balance between new and existing facilities vary from formal procedures (Germany) to non-existent (UK). Capital investments that are made jointly (i.e. co-ownership of infrastructure facilities) may also be subject to certain benefits and drawbacks. Any decisions regarding capital investments should also consider mid-sized (in addition to large) infrastructures.

Accurate and comparable definitions of operating costs are not readily available across the countries examined. In general, operating costs vary from 10-30% annually of total project costs. The OECD has recognized a systemic difficulty in estimating infrastructure costs and suggests a rule of thumb where the annual cost of operations is about 10% of the total construction cost. Funding and operation of existing infrastructure also encompasses two complex challenges that all countries are facing, namely, making considerations for aging equipment, and provisions for highly qualified personnel.

Research infrastructures play an increasingly important role in the research funding landscape of all five countries examined. In spite of this, true best practices remain to be defined. Undeniably everyone is grappling with the same recurring questions:

- Is there an ideal funding percentage that can adequately provide for operation and maintenance?
- Who should pay these costs?
- How should infrastructure planning integrate the need for HQP?
- What are the ideal mechanisms to guide decisions on decommission, upgrading or investing anew?

There are implications for Canadian science policy and investment strategies. For example, the study revealed that despite sizeable investment for research infrastructure in Canada over the last decade, Canadian researchers who use this infrastructure appear to be more dissatisfied than their colleagues in other countries. This might indicate that the right mix of funding for new research infrastructure, renewal, maintenance and operation has not yet been found. Perhaps more importantly, this is likely a reflection of the comparatively low level of funding growth during the 2008-2013 period, especially compared to competing countries. During the last decade, although Canada has managed to maintain its standing in the international scientific community, there is a risk that the future of Canada's research system competitiveness will be compromised if tangible re-investments fail to materialize soon. This is the case for research in general as there is a sizeable time lag between initial investments, discoveries, and the use of that knowledge in industry, government and civil society. The lag is clearly more considerable when research requires large scale infrastructure as it entails careful acquisition, set up, and fine tuning before starting to produce useable data.

With respect to research discipline, it is interesting to note that two of the areas where researchers would prefer more funding for infrastructure (ICT and Clinical Medicine) correspond with Canadian research priorities named in the national S&T strategy. Future infrastructure investment strategies may want to consider that some fields are more heavily dependent on infrastructure than others.

The research also revealed three key areas that warrant further study.

1. There are several complex issues associated with infrastructure operation. The uncertainty that pertains to estimating actual costs of operations before a project begins, and the challenge of how to plan and provide for the skilled personnel who operate research infrastructure are two key examples. Although this report was limited in its ability to examine operating funds of all five countries in detail, this appears to be an increasingly important issue and warrants further study in the Canadian context, as well as elsewhere.
2. Generally two types of approaches are applied to infrastructure planning, top-down and bottom-up. While Canada leans towards a bottom-up approach, it may be a valuable exercise to dig deeper into the pros and cons of each.
3. This report focused on the main sources of federal funding. Nevertheless, it must be recognized that in all the countries examined, many other government and non-government sources contribute to the research funding landscape. Given this variability, a key take-away from this report is that it

would not be sensible at this stage to develop a policy of federal infrastructure spending as a share or percentage of federal research spending simply by applying a seemingly universal optimal ratio. Indeed, any optimal Canadian federal funding ratio could not be determined without a painstakingly meticulous analysis of all direct research funding and all infrastructure funding derived from all federal and non-governmental sources.

Balancing direct research and infrastructure support is highly complex. It would appear that one-ratio-fits-all solutions do not exist. If countries were determining their needs for infrastructure funding based on a ratio between research infrastructure and direct funding, data would be available on both of these. Yet, the scarcity of data and the robustness of the data available on infrastructure support strongly suggest that extrapolating ratios such as balance of infrastructure funding to direct research funding is not part of the usual methods used by national governments to view or make decisions on R&D spending. While infrastructure spending strategies cannot be dissociated from direct spending strategies, nearly all interviewees were uncomfortable with the premise of an ideal ratio for which every country should aim. Rather, it was suggested that research infrastructure funding should, in addition to current level of direct research investments, reflect several variables such as the country's pattern of research specialization, priorities, age of current infrastructure and fiscal context.

The world over, governments invest billions in new and existing research infrastructures yet, as repeatedly mentioned in this study, there is a dearth of data to account and plan for infrastructures. With research infrastructures constituting a tangible portion of OECD member countries' research expenditures, and constituting an increasingly crucial element of the research system, precise statistics are dearly needed yet broadly absent, even in countries with fairly detailed research spending accounts. This is clearly a void that only the OECD could fill by providing standard definitions and methods to compile data on research infrastructures. This could be added to the Frascati manual (for example in a chapter on "Measurement of expenditures devoted to R&D infrastructure") or made available in a new manual.

# Appendix A: List of organizations consulted

| | Formal Interviews | Informal Consultations and Data Validation |
|---|---|---|
| Australia | Australian Government Department of Education, Research and Higher Education Infrastructure Branch | Australian Bureau of Statistics, Innovation and Technology Statistics |
| | Australian Government Department of Education, Mission to the European Union, education and science | Australian Government, Department of Education |
| | Australian Research Council (ARC), Strategy Branch | Australian Government, Department of Industry, Strategic Data & Innovation Statistics Team, Economic and Analytical Services Division |
| | Commonwealth Scientific and Industrial Research Organisation (CSIRO), National facilitates and Collections Team | Australian Government, Department of Industry, Commercialisation Policy Branch, Portfolio Strategic Policy Division |
| | CSIRO, Science Excellence Team | Australian Research Council , Policy and Governance |
| | | Australian Research Council, Research Excellence Branch |
| Canada | Canada Foundation for Innovation (CFI), Executive | Canada Foundation for Innovation (CFI), Evaluation |
| | Canadian Institutes of Health Research, Science, Knowledge Translation and Ethics | |
| | Industry Canada, Science Partnerships | |
| | National Research Council Canada, Audit and Evaluation (formerly at CFI) | |
| | Natural Sciences and Engineering Research Council of Canada (NSERC), Research Partnerships | |
| | NSERC, Research Grants and Scholarships | |
| | Social Sciences and Humanities Research Council of Canada, Corporate Affairs Directorate | |
| Germany | German Research Foundation (DFG), Collaborative Research Centres | Fraunhofer Institute for Systems and Innovation Research ISI, Competence Center Policy and Regions |
| | German Research Foundation (DFG), Research Infrastructures and Life Sciences | |
| | Helmholtz Association of German Research Centres, Research Infrastructure and Spending | |
| | Leibnitz Association, Central Administration | |
| United Kingdom | Engineering and Physical Sciences Research Council, Research Infrastructure | Department for Business, Innovation & Skills, Economics and Markets |
| | Higher education Funding Council for England, Research Policy | Department for Business, Innovation & Skills, Research and Innovation Statistics |
| | Research Councils UK (RCUK), Research Group Executive | Department for Business, Innovation and Skills, Research Funding Unit |
| | Science and Technology Facilities Council, Programmes Directorate | Office for National Statistics, Business Outputs Division |
| United States | Department of Energy (DOE), Office of Science | National Science Foundation, National Center for Science and Engineering Statistics |
| | National Institutes of Health (NIH), Office of Planning and Communication | |
| | National Science Foundation (NSF), Major Research Instrumentation Program | |

# Appendix B: Quantitative data limitations

Quantitative tables were compiled for the 2008-2013 period, using available data on federal extramural funding for R&D and research infrastructure in the higher education non-profit research sectors. Data was publically available on government websites and websites of the statistical agencies for each of the countries examined (Canada, Australia, Germany, the United Kingdom [UK] and the United States [US]).

**Comparability challenges:** As stated in the initial work plan for this project, the definitions presented in the CFI's Policy and Program Guide were used to determine what constitutes "infrastructure". The main conclusions drawn from the cross-examination is that definitions of both infrastructure and direct research vary so widely that direct comparisons are not valuable.

Indeed, countries often referred to the OECD definition of Research and development (R&D) and related concepts published in the Frascati manual (OECD, 2002) to define the activities "(which) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications."

Countries also differed on what they considered extramural or intramural expenditures. According to the OECD (Frascati Manual, 2002, OECD), extramural expenditures are sums that a unit, organisation or sector reports having paid or committed to pay to another unit, organisation or sector for the performance of R&D during a specific period. This includes acquisition of R&D performed by other units and grants given to others for performing R&D. Intramural performers, on the other hand, are usually agencies and departments of the federal government.

Finding existing data series on research infrastructure funding, especially extramural and disaggregated by sector (e.g., business, federal agencies, academic or non-profit organizations) thus proved to be a large challenge.

For instance, the data series for the UK federal research infrastructure funding presents resources allocated instead of resources spent. The German federal expenditures on R&D data series includes the Business Sector (even if its contribution is marginal) and this country's expenditures on Research Infrastructure do not include non-profit institutions, which are counted in the R&D data. In Canada, the Statistics Canada data series on R&D does not differentiate between R&D and research infrastructure funding (or capital expenditures) made by extramural performers (higher education, non-profit institutions and business sectors).

**Terminology:** The use of different terms for "research infrastructure" in each of the countries was another important challenge. The diversity of terms includes "R&D Plant" in the US, "Capital" in the UK, and "Infrastructure programs" in Australia and Germany.

**Operating costs:** The inclusion of infrastructure operating costs in the funding data in Australia and Canada presented another challenge. R&D data series in Australia did not disaggregate operating costs from their infrastructure funding data. The Canadian departments and agencies, other than the CFI and the Tri-Council, also do not make this distinction.

**Country-specific considerations and data sources**

**Australia**: Data on R&D in the higher education and non-profit sector were collected from the Research and Innovation Budget published by the Department of Industry, Science of the Government of Australia: *Extramural Expenditures on Science, Research and Innovation to Universities and Colleges and Multisector*. "Multisector" was defined as "programs that may be accessed by several sectors, especially research hospitals and non-profit research institutions and other performers, including Australian Government agencies (but not the Business Sector)". More disaggregated data were not available to refine the data series.

The research infrastructure data series were collected by selecting infrastructure programs from the same Government Budget Tables, especially *R&D Granting Programs and Other Support for Science, Research and Innovation through the Budget* and *R&D Granting Programs and Other Support for Science, Research and Innovation through Special Appropriations and Other Measures*.

The main Australian infrastructure programs selected were: the Research Infrastructure Block Grants, the National Collaborative Research Infrastructure Strategy (NCRIS), the Education Investment Fund - Round 1, - Round 2, - Round 3, the Education Investment Fund - Super Science, the Education Investment Fund - Sustainability Round, the Collaborative Research Infrastructure Scheme (CRIS), the Giant Magellan Telescope and the ARC program.

**Canada**: Tables on direct research and infrastructure support for Canada were compiled from Statistics Canada data (CANSIM 358-0164) on federal extramural expenditures on science and technology, by performance sector and major departments and agencies, and data from the CFI's annual reports on research infrastructure funding.

The main analysis centered on data from the Tri-Council for direct research funding and data from CFI for research infrastructure funding, mainly because R&D data collected from other departments and agencies were not sufficiently disaggregated to differentiate between the two flows of funding, i.e. direct funding and research infrastructure funding. Nevertheless, these two categories of expenditure from the Tri-Council and the CFI form a very representative sample, amounting to 87% of all federal spending on R&D and research infrastructure in Canada.

**Germany**: Data were collected from the Federal Statistical Office of Germany and from the German Research Council (DFG) Jahresberichte 2012 and 2013. The websites of the four large research organizations in Germany (Max-Planck-Gesellschaft, Fraunhofer-Gesellschaft, Leibniz Association and Helmoltz) were also consulted.

**UK**: Data were compiled from the publication of the Office National of Statistics, the GERD Gross Domestic Expenditure on Research and Development Table and from the publications of the Department of Business Innovation and Skills, Science allocations 2011-12 to 2014-2015 and former Department of Trade and Industry, Science Budget and Allocation, 2005-2006 to 2007-2008, May 2005.

**US:** Tables were compiled from the Survey of Federal Funds for Research and Development. The survey is an annual census completed by the federal agencies that conduct R&D programs. The NSF's National Center for Science and Engineering Statistics is responsible for the management of the survey. The survey of Federal Funds for Research and Development presents data on "R&D Plant", which was the closest definition to the CFI's definitions of Research Infrastructure.

In the United States, the analysis was performed only with data from NSF because of the quality of the collected data and the fact that the NSF is the major source of federal funding in many fields, such as mathematics, computer science and the social sciences, accounting for 24% of all federally supported basic research conducted by America's colleges and universities. According to the NSF expert who manages the survey, many of the agencies have trouble reporting their R&D Plant, especially the National Health Institutes (NIH) which is the largest source of funding for research in the US. For instance, grants or contracts for R&D that also contain some funding for Plant end up being reported as research or development because of the difficulty in separating out the obligations that fall under the "Plant" category.

**Analysis and validation:** The main analyses conducted for this report focused on two measures: 1) the Average Annual Growth Rate (AGR) and 2) the proportion of R&D funding devoted to Research Infrastructure.

The measure of the AGR gives an average growth rate for each time interval given past and present figures, assuming a steady rate of growth. The AGR is a classic economic measure that gives a summary of broad trends, but must be interpreted with caution since it calculates the growth between the two most distanced points: the value of the last year of the series (2013) and the first (2008), assuming that the values are stable and growing.

The annual percentage ratio was calculated for each country series, expressing the proportion of research infrastructure spending on total federal extramural expenditures on R&D in higher education and non-profit institutions in Canada, United States, Australia, UK and Germany between 2008-2013.

Considering the numerous comparability issues and the scarcity of data on extramural research infrastructure funding, the evaluation team sought data validation from country experts. Specifically, an excel spreadsheet with the compiled data and definitions was sent for review to the relevant statistical contacts in each country. All country experts referred to the limitations that were previously mentioned, namely the lack of accuracy of the US Federal Survey's data, and the fact that statistical data series in Australia, Canada, UK, and the USA often include both direct research and infrastructure funding as well as indirect costs, without distinguishing between these categories.

# Appendix C: Quantitative data by country

Table 6 Federal extramural expenditure series on R&D in higher education and non-profit institutions, by major departments or agencies, in five countries, annual 2008-2013 (in millions of local currency)

| Country | | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total |
|---|---|---|---|---|---|---|---|---|
| Australia (Australian dollars) | Total R&D (Include Operating Costs Programs) | 3 310 | 3 663 | 4 243 | 4 734 | 4 989 | 4 695 | 25 633 |
| | Research Infrastructure | 327 | 388 | 754 | 927 | 819 | 623 | 3 836 |
| Canada (Canadian dollars) | Tri-Council R&D | 2 248 | 2 250 | 2 320 | 2 331 | 2 332 | 2 331 | 13 812 |
| | CFI Research Infrastructure | 261 | 266 | 319 | 298 | 382 | 302 | 1 827 |
| Germany (Euro) | Total R&D | 5 382 | 5 737 | 6 288 | 6 462 | 6 405 | 7 457 | 37 730 |
| | Research Infrastructure | 374 | 597 | 553 | 589 | 547 | 609 | 3 269 |
| UK (Pound sterling) | Total R&D | 4 594 | 4 952 | 4 871 | 4 800 | 4 698 | 4 712 | 28 627 |
| | Research Infrastructure | 342 | 730 | 873 | 514 | 449 | 416 | 3 323 |
| US-NSF Only (American dollars) | NSF R&D | 3 911 | 5 808 | 4 522 | 4 715 | 4 745 | 4 973 | 28 673 |
| | NSF R&D Plant | 286 | 731 | 974 | 312 | 349 | 358 | 3 010 |

Source: Data compiled by Science-Metrix from Statistics Canada, CFI, NSF, Department of Industry, Science of the Government of Australia, UK Office National of Statistics, UK Department of Technology and Innovation (DTI); Federal Statistical Office of Germany.

Notes:
1) In Canada, the Canadian Foundation for Innovation (CFI) separately finances investments in large infrastructures and the Tri-Council refers to the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada. Both flux represent near 90 % of R&D.
2) The National Science Foundation (NSF) finances a quarter of R&D federal expenditures in United States.

Table 7 Australian Government expenditures on R&D, in higher education and private non-profit institutions, by category, Annual (Australian dollars, millions)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total | Average Annual Growth Rate | |
|---|---|---|---|---|---|---|---|---|---|
| Total R&D (Include Indirects Costs | 3 310 | 3 663 | 4 243 | 4 734 | 4 989 | 4 695 | 25 633 | 6% |  |
| Research Infrastructure | 327 | 388 | 754 | 927 | 819 | 623 | 3 836 | 11% |  |
| % on Total R&D devoted to Research Infrastructure | 10% | 11% | 18% | 20% | 16% | 13% | 14,6% | | |

Source: The Australian Government's 2013-14 Science, Research and Innovation Budget Tables. Retrieved from: http://www.industry.gov.au/innovation/reportsandstudies/Pages/SRIBudget.aspx

Notes:
1) Research Infrastructure funding is the summation of the following main Australian infrastructure programs: the Research Infrastructure Block Grants, the National Collaborative Research Infrastructure Strategy (NCRIS), the Education Investment Fund - Round 1, - Round 2, - Round 3, the Education Investment Fund - Super Science, the Education Investment Fund - Sustainability Round, the Collaborative Research Infrastructure Scheme (CRIS), the Giant Magellan Telescope and the ARC program.
2) Note that Research Infrastructure series include infrastructure programs which finance Indirect Costs such as the Research Infrastructure Block Grants Scheme (which focuses on the indirect costs associated with Australian Competitive Grants.)
2) Definition of Total R&D: creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man [human kind], culture and society, and the use of this stock of knowledge to devise new applications (OECD definition).
3) Research infrastructure means assets, facilities, services, and coordinated access to major national and/or international research facilities or consortia which directly support research in higher education organizations and more broadly and which maintain the capacity of researchers to undertake excellent research and deliver innovative outcomes. Funding Rules for schemes under the Linkage Program 2015 – Linkage Infrastructure, Equipment and Facilities, February 2014

Table 8 Canadian federal extramural expenditures on R&D, in higher education and Canadian non-profit institutions, by major departments and agencies, Annual (Canadian dollars, millions)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total | Average Annual Growth Rate |
|---|---|---|---|---|---|---|---|---|
| **Canada Foundation for Innovation (CFI Infrastructure Funding)** | 373 | 380 | 455 | 426 | 545 | 431 | 2 610 | **2,4%** |
| **Canadian Institutes of Health Research** | 885 | 882 | 914 | 902 | 898 | 901 | 5 382 | **0,3%** |
| **Natural Sciences and Engineering Research Council of Canada** | 836 | 845 | 880 | 897 | 895 | 889 | 5 242 | **1,0%** |
| **Social Sciences and Humanities Research Council of Canada** | 527 | 523 | 526 | 532 | 539 | 541 | 3 188 | **0,4%** |
| Agriculture and Agri-Food Canada | 16 | 19 | 35 | 18 | 26 | 27 | 141 | |
| Atomic Energy of Canada Limited | 0 | 1 | 0 | 1 | 1 | 1 | 4 | |
| Canadian International Development Agency | 1 | 1 | 2 | 1 | 1 | 1 | 7 | |
| Canadian Space Agency | 15 | 12 | 13 | 18 | 12 | 12 | 82 | |
| Environment Canada | 13 | 18 | 21 | 19 | 7 | 7 | 85 | |
| Fisheries and Oceans Canada | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Health Canada | 10 | 10 | 12 | 4 | 5 | 5 | 46 | |
| Industry Canada | 46 | 51 | 42 | 7 | 33 | 45 | 224 | |
| International Development Research Centre | 0 | 0 | 0 | 0 | 64 | 0 | 64 | |
| National Defence | 7 | 4 | 3 | 4 | 13 | 12 | 43 | |
| National Research Council Canada | 46 | 52 | 52 | 47 | 42 | 47 | 286 | |
| Natural Resources Canada | 14 | 13 | 25 | 25 | 15 | 14 | 106 | |
| Statistics Canada | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Other Departments and Agencies | 221 | 230 | 222 | 270 | 237 | 283 | 1 463 | |
| **Total CFI & Tri-Council R&D** | 2 621 | 2 630 | 2 775 | 2 757 | 2 877 | 2 762 | 16 422 | **0,9%** |
| **Total CFI (excluding IOF) & Tri-Council R&D** | 2 509 | 2 516 | 2 639 | 2 629 | 2 714 | 2 633 | 15 639 | |
| **Total Tri-Council R&D** | 2 248 | 2 250 | 2 320 | 2 331 | 2 332 | 2 331 | 13 812 | **0,6%** |
| **% of Tri-Council and CFI R&D Devoted to CFI Infrastructure Funding** | **14,2%** | **14,4%** | **16,4%** | **15,5%** | **18,9%** | **15,6%** | **15,9%** | |
| CFI Infrastructure Funding (excluding Infrastructure Operating Funding-IOF) | 261 | 266 | 319 | 298 | 382 | 302 | 1 827 | |
| **% of Tri-Council and CFI R&D Devoted to CFI Infrastructure Funding (excluding IOF)** | **10,4%** | **10,6%** | **12,1%** | **11,3%** | **14,1%** | **11,5%** | **11,7%** | |

Source: Statistics Canada, CANSIM Table 358-0164 - Federal extramural expenditures on science and technology, by performing sector and major departments and agencies, annual (dollar), Retrieved from: http://www5.statcan.gc.ca/cansim/pick-choisir?lang=fra&p2=33&id=3580164

Notes: 1) The Canada Foundation for Innovation (CFI) is the primary source of federal funding for research infrastructure, with a mechanism to leverage support from provincial governments;
2) The Tri-Council refers to the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council of Canada and the Social Sciences and Humanities Research Council of Canada, which represent the most important sources of direct research funds at the federal level;
3) Infrastructure Operating Funds (IOF) are the share of the funding CFI devotes to Indirect Costs, that is 30% of CFI R&D funding; IOF includes salaries of personnel directly involved in the operation and maintenance of the CFI-funded infrastructure, training for the main operator(s) of the research infrastructure, extended warranties and/or service contracts not included in the infrastructure award, extensions to warranty coverage and software licences, maintenance and repairs, replacement parts, replacement of a CFI-funded infrastructure item needing repair, direct services, supplies and consumables needed to operate the research infrastructure.
4) According to Statistic Canada, departments and agencies that contributed 2% or more to the total fiscal year expenditures are named. The 'Other' category comprises the rest of the departments and agencies in the survey.
5) Definition of R&D: creative work undertaken to increase the stock of knowledge (OECD, 2002). Payments for research and development (R&D) made to higher education and private non-profit organizations. Includes R&D contracts, R&D grants and contributions, Research fellowships. Excludes Indirect or overhead costs and expenditures within the federal government, such as salaries of scientific personnel and the materials and equipment required to support their activities, are known as intramural expenditures (in-house). Excludes related scientific activities (RSA) focused on the generation, dissemination and application of scientific and technical knowledge, examples include the gathering, processing and analyzing of data, feasibility and policy studies, information services and museum services.
6) Definition of CFI Infrastructure Funding: equipment, laboratories, databases, specimens, scientific collections, computer hardware and software, communications linkages and buildings necessary to conduct leading-edge research.

Table 9 German Government Expenditures on R&D, in higher education and private non-profit institutions, by source of funds Annual 2008-2013 (euro, millions)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total | Average Annual Growth Rate | |
|---|---|---|---|---|---|---|---|---|---|
| Total R&D | 5 382 | 5 737 | 6 288 | 6 462 | 6 405 | 7 457 | 37 730 | 6% |  |
| Research Infrastructure | 374 | 597 | 553 | 589 | 547 | 609 | 3 269 | 8% | |
| % on Total R&D Devoted to Research Infrastructure | 7% | 10% | 9% | 9% | 9% | 8% | 9% | | |

Source: R&D from BMBF (Ministry for Education and Research) and DFG (German Research Council) Jahresberichte 2012 and 2013 (annual reports)

Notes:
1) The figures on direct research grants include all research grants provided at the federal level (direct research grants from BMBF and DFG.) This includes research grants to the universities, the four large research organizations: Max Planck, Fraunhofer, Leibnitz and Helmoltz as well as industry. The amount also includes expenditures to the private sector, but a very marginal amount according to the BMBF.
2) Research infrastructure: includes programs that cover research infrastructure funding through the DFG (German Research Council.) Note that research infrastructure grants to non-profit organizations are not included.
3) Definition of Research and development (R&D): creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications (cf. Frascati Manual 2002, section 63). Expenditure incurred in the context of this work is expenditure on research and development. A distinction is made between intramural and extramural R&D expenditures.
4) Definition of Infrastructure support: include Major Research Instrumentation by Art 91 of the Basic Law Federal countries, Large facilities in the countries under Article 143c GG (compensation Federal funds), Major equipment in research buildings on the type GG 91 (that are to be used for research, teaching and training, or for medical care), Scientific literature supply & Information: IT systems for computing centres, university libraries, and administrative systems at universities and clinics.

Table 10 UK Government Expenditures on R&D, in higher education and private non-profit institutions, by source of funds, Annual (British Pounds, millions)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total | Average Annual Growth Rate | |
|---|---|---|---|---|---|---|---|---|---|
| Total R&D | 4 594 | 4 952 | 4 871 | 4 800 | 4 698 | 4 712 | 28 627,0 | 0,4% |  |
| Research Infrastructure | 341,5 | 729,6 | 872,6 | 514,0 | 449,0 | 416,0 | 3 322,7 | 3% |  |
| % on Total R&D Devoted to Research Infrastructure | 7% | 15% | 18% | 11% | 10% | 9% | 12% | | |

Sources: ONS, GERD Gross Domestic Expenditure on Research and Development Table. Retrieved from: http://www.ons.gov.uk/ons/rel/rdit1/gross-domestic-expenditure-on-research-and-development/2012/stb-gerd-2012.html & Department of Science Innovation and Skills, Science allocations 2011-12 to 2014-2015, and DTI, Science Budget and Allocation, 2005-2006 to 2007-2008, may 2005. Retrieved from: https://www.gov.uk/government/publications/allocation-of-science-and-research-funding-2011-12-to-2014-15.

Notes:
1) Research Infrastructure funding series show data on resources (Capital) allocated instead of resources spent;
2) Total R&D figures are the summation of i) R&D funded by government - performed by higher education ii) R&D funded by Government - performed by private non-profit iii) R&D Funded by Research Councils - performed by higher education iv) R&D Funded by Research Councils - performed by private non-profit v) Funded by Higher Education Funding Councils - performed by higher education;
3) 2013 Total R&D figure show data on resources allocated instead of resources spent; and 2013 R&D data performed by non-profit institutions is extrapolated from 2008-2012 series;
2) Research and & Development: includes systematic, investigative and experimental activities (SIE) that are performed for the purposes of acquiring new knowledge or creating new or improved materials, products, devices, processes or services and that are intended to advance science or technology through the resolution of scientific or technological uncertainty; or involve an appreciable element of novelty.
3) Research infrastructure funding includes "Capital".

Table 11 US Federal extramural expenditures on R&D by All and Major Performers, in Higher education and US non-profit institutions Annual (US dollars, millions)

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | Total | Average Annual Growth Rate | |
|---|---|---|---|---|---|---|---|---|---|
| **NSF R&D** | **3 911** | **5 808** | **4 522** | **4 715** | **4 745** | **4 973** | **28 673** | **4,1%** | |
| **NSF R&D Plant** | **286** | **731** | **974** | **312** | **349** | **358** | **3 010** | **3,8%** | |
| **% of Total NSF R&D Devoted to R&D Plant** | **7%** | **11%** | **18%** | **6%** | **7%** | **7%** | **9,2%** | | |
| HHS R&D | 21 357 | 25 870 | 26 666 | 22 552 | 22 716 | 22 685 | 141 846 | 1,0% | |
| HHS R&D Plant | 26,1 | 55,1 | 936,0 | 26,1 | 20,6 | 20,6 | 1 084 | -3,9% | |
| % of HHS R&D Devoted to R&D Plant | 0% | 0% | 3% | 0% | 0% | 0% | 1% | | |
| DOD R&D | 3 988 | 3 950 | 4 341 | 5 353 | 4 637 | 4 246 | 26 515 | 1,0% | |
| DOD R&D Plant | 1,0 | 0,1 | 0,1 | 1,6 | 0,0 | 0,0 | 2,8 | 0,0% | |
| % of DOD R&D Devoted to R&D Plant | 0,03% | 0,00% | 0,00% | 0,03% | 0,00% | 0,00% | 0,01% | | |
| DOE R&D | 3 573 | 4 953 | 5 163 | 4 434 | 4 160 | 4 511 | 26 794 | 4,0% | |
| DOE R&D Plant | 462,3 | 1 459 | 737 | 576 | 562 | 550 | 4 346 | 2,9% | |
| % of DOE R&D Devoted to R&D Plant | 11% | 23% | 12% | 11% | 12% | 11% | 14% | | |
| NASA R&D | 1 380 | 1 766 | 1 766 | 1 627 | 1 657 | 1 744 | 9 940 | 4,0% | |
| NASA R&D Plant | 0,0 | 0,0 | 5,7 | 25,7 | 27,6 | 31,6 | 90,7 | 77,8% | |
| % of Nasa R&D Devoted to R&D Plant | 0,00% | 0,00% | 0,32% | 1,56% | 1,64% | 1,78% | 0,90% | | |
| USDA R&D | 736 | 739 | 771 | 790 | 905 | 762 | 4 701 | 0,6% | |
| USDA R&D PLANT | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0% | |
| % of USDA R&D Devoted to R&D Plant | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% | | |
| Others R&D | 1 118 | 1 281 | 1 363 | 1 208 | 1 184 | 1 399 | 7 553 | 3,8% | |
| Other R&D Plant | 65,9 | 90,5 | 82,4 | 234,9 | 217,0 | 250,3 | 941,1 | 24,9% | |
| % of Others R&D Devoted to R&D Plant | 6% | 7% | 6% | 16% | 15% | 15% | 11% | | |
| All R&D | 36 063 | 44 562 | 44 592 | 40 678 | 40 003 | 40 320 | 246 218 | 1,9% | |
| All R&D Plant | 822 | 2 336 | 2 735 | 1 161 | 1 176 | 1 210 | 9 441 | 6,7% | |
| All Total R&D | 36 885 | 46 898 | 47 327 | 41 840 | 41 179 | 41 530 | 255 659 | 2,0% | |
| % of Total R&D Devoted to R&D Plant | 2,2% | 5,0% | 5,8% | 2,8% | 2,9% | 2,9% | 3,5% | | |

Source: National Science Foundation/Division of Science Resources Statistics, Survey of Federal Funds for Research and Development, Federal Obligations for R&D and R&D Plant, by agency and performer (2002-2013). Retrieved from: http://www.nsf.gov/statistics/nsf14316/start.cfm

Notes:

1) R&D and R&D Plant Data cover the costs of extramural programs by federally administered to universities and colleges, non-profit institutions and federally funded research and development centers.

2) Others: AID-Agency for International Development; ARC-Appalachian Regional Commission; DHS-Department of Homeland Security; DOC-Department of Commerce; DOI-Department of the Interior; DOL-Department of Labor; DOT-Department of Transportation; ED-Department of Education; EPA-Environmental Protection Agency; GSA-General Services Administration; HUD-Department of Housing and Urban Development; NRC-Nuclear Regulatory Commission; OEO-Office of Economic Opportunity; OJP-Office of Justice Programs; S&E-science and engineering; SSA-Social Security Administration.

3) HHS includes National Institutes of Health (NIH) and DOE, mainly the Office of Science and Technology Directorate.

4) Definitions of Research and development (R&D): creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. Include: Administrative expenses for R&D. Exclude: Physical assets for R&D such as R&D equipment and facilities. Exclude routine product testing, quality control, mapping, collection of general-purpose statistics, experimental production, routine monitoring and evaluation of an operational program, and the training of scientific and technical personnel.

5) Definitions of R&D Plant (R&D facilities and fixed equipment, such as reactors, wind tunnels, and particle accelerators) include acquisitions of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities at Federal or non-Federal installations. Excluded from this category are expendable or movable equipment (e.g., spectrometers, microscopes) and office furniture and equipment, costs of predesign studies (e.g., those undertaken before commitment to a specific research facility. Also excluded are costs associated with the administration of intramural and extramural programs by federal personnel and actual intramural performance and F&A costs (Federal Government for facilities and administrative, "overhead" or "indirect costs".)

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