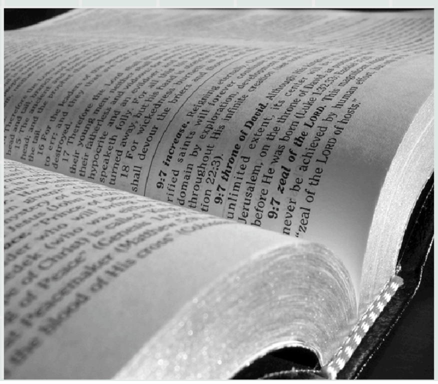
The State of Science & Technology in Canada



The Committee on
The State of Science & Technology in Canada

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

THE COUNCIL OF CANADIAN ACADEMIES
180 Elgin Street, Ottawa, ON Canada K2P 2K3

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This report was prepared for the Government of Canada in response to a request from the Minister of Industry. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors — the Committee on the State of Science & Technology in Canada — and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

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Council of Canadian Academies
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Science Advice in the Public Interest

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This project was undertaken in response to a request from the Government of Canada, through the Minister of Industry, outlining questions regarding the state of science and technology (S&T) in Canada. The study charge led to the appointment of the Committee on the State of Science & Technology in Canada. During the course of its deliberations, the committee sought assistance from many people and organizations who provided valuable advice and information for consideration. Special thanks are due to Derek Jansen, Vice-President of EKOS Research Associates Inc., and his colleagues who skilfully administered an online survey, the results of which constitute a core base of information for this report. Special thanks are also due to Éric Archambault and Grégoire Côté, respectively President and Project Director of Science-Metrix, who provided the bibliometric and technometric data analysis employed in the study; to Javier Gracia-Garza of the Office of the National Science Advisor for his assistance in consolidating information from within the federal government; and to Craig Wilson of Foreign Affairs and International Trade Canada who coordinated the provision of information from Canada's S&T network abroad.

This report was reviewed in draft form by the individuals listed below who were selected by the Board of the Council of Canadian Academies for their diverse perspectives, areas of expertise, and broad representation of the scientific and technological communities. The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered fully by the committee, and many of their suggestions have been incorporated in the report. The reviewers were not asked to endorse the final report, as it is exclusively the responsibility of the committee. We thank the following individuals for their reviews:

Mel Cappe, President, Institute for Research on Public Policy

Adam Chowaniec, Chairman of the Board of Directors, Tundra Semiconductor Corporation

Michael Clegg, Donald Bren Professor of Ecology & Evolutionary Biology, University of California, Irvine and Foreign Secretary, US National Academy of Sciences

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Elizabeth Dowdeswell, Chair
Committee on the State of Science & Technology in Canada

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ACRONYMS

The following is a list of acronyms that appear in the report.

ARC	Average of Relative Citations
ARIF	Average Relative Impact Factor
BERD	Business Enterprise Expenditure on R&D
CANARIE	Canadian Network for the Advancement of Research in Industry and Education
CFI	Canada Foundation for Innovation
CIAR	Canadian Institute for Advanced Research
CIDA	Canadian International Development Agency
CIHR	Canadian Institutes of Health Research
CLS	Canadian Light Source
GDP	Gross Domestic Product
GERD	Gross Domestic Expenditure on R&D
HERD	Higher Education Expenditure on R&D
IDRC	International Development Research Centre
ICSU	International Council for Science
ICT	Information and communications technology
IRAP	Industrial Research Assistance Program, NRC
ITAC	Information Technology Association of Canada
NCE	Networks of Centres of Excellence
NEPTUNE	North-east Pacific Time-series Undersea Network Experiments
NIH	US National Institutes of Health
NRC	National Research Council of Canada
NSE	Natural Sciences and Engineering
NSERC	Natural Sciences and Engineering Research Council of Canada
NSF	US National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OST	Observatoire des sciences et des technologies
PISA	Program for International Student Assessment
R&D	Research and Development
S&T	Science and Technology
SI	Specialization Index
SR&ED	Scientific Research and Experimental Development (Tax Credit)
SSHRC	Social Sciences and Humanities Research Council
SNO	Sudbury Neutrino Observatory
TPC	Technology Partnerships Canada
TRIUMF	Tri-University Meson Facility
USPTO	US Patent and Trademark Office

SUMMARY AND MAIN FINDINGS

1. The Charge – This report responds to a request in June 2006 from the Government of Canada, via the Minister of Industry, for advice as to Canada's strengths and capacity in science and technology (S&T), specifically to help better understand:

- The scientific disciplines in which Canada excels in a global context
- The technology applications where Canada excels in a global context
- The S&T infrastructure that currently provides Canada with unique advantages
- The scientific disciplines and technological applications that have the potential to emerge as areas of prominent strength for Canada and generate significant economic or social benefits.

2. What is Science & Technology? – In this report, science and technology are regarded as a *joint* entity rather than as two separate endeavours, hence the symbol, *S&T*. The scope of S&T encompasses disciplines in the natural sciences (the study of nature); the social sciences, humanities and health sciences (the study of human beings); and engineering (the creation and study of artifacts and systems). Our conception of S&T includes the myriad connections from science to technology and vice versa.

3. S&T and Innovation – Strength in science and technology is considered to be essential for a modern country's *ongoing* capacity to innovate and compete in the knowledge-based global economy. The connection between S&T and innovation begins with invention – an invention being the practical demonstration of a new idea that may derive from research results, from needs expressed in the market, or from the experience and imagination of individual inventors. The successful commercialization of inventions, or their significant application in society, produces 'innovations'. There is no linear progression from research through invention to innovations. Instead, the process involves false starts, blind alleys and feedback loops, and it includes obstacles that have little to do with the quality of the S&T involved. Above all, it requires talented, highly skilled people with a vision who are also entrepreneurial, energetic and persistent.

4. What is S&T Strength? – There is no simple, one-dimensional measure of Canada's S&T strength. The concept is inherently multidimensional and encompasses (a) the quality of science and technology in Canada; (b) the magnitude or intensity of the Canadian effort in various domains of S&T; (c) the trend of the foregoing factors (are we gaining or losing ground?); and (d) the extent to which our S&T capabilities can be applied effectively to achieve social and economic objectives. Qualitative judgments that integrate multiple dimensions and factors are unavoidable.

5. The Global Perspective – Strength in a global context matters for Canada because it determines our ability to compete for increasingly mobile resources of people and investment capital, and to participate in global knowledge-sharing networks that operate at the leading edge both of science and of technology development. We have therefore analyzed Canada's S&T strengths, relative to our size, against norms that are typical of other economically advanced countries of the OECD group, including the United States. We also note the growing importance of emerging economic giants, such as China and India, that are becoming forces to be reckoned with in increasingly sophisticated areas of S&T.

6. What the Report Seeks to Answer and What It Does Not – Our study focuses on describing the strength of the principal building blocks of Canada's S&T system. We also identify certain areas where we appear to be comparatively weak or declining in S&T capacity. It was beyond our mandate to analyze the difficult but crucial question of how S&T strengths become translated into the outcomes that ultimately contribute to Canada's economic performance and quality of life. Neither do we recommend on S&T policy or on priorities for the allocation of support.

7. Science & Technology Strength Through Four Lenses – There is no single best practice for assessing a nation's S&T strengths. We have therefore chosen four different approaches, or "lenses," to evaluate the questions posed:

- **Opinion Survey:** A large-scale, online survey of the opinion of Canadian S&T experts. These informed opinions represent, collectively, a broad and integrated picture.
- **Metrics:** An analysis of bibliometric data (the quantity and quality of published research in scientific journals) and technometric data (patents granted). This gives a narrower, but more precise, internationally comparable perspective.
- **View from Abroad:** A summary of reports and comments obtained from foreign sources that complements the self-assessment of the opinion survey.
- **Literature:** A review of relevant publications, including internationally comparable indicators of important aspects of S&T strength at the national level.

Our findings are based primarily on the first two of these lenses, and most extensively on the survey, which is the principal source of new insight in this study.

8. Survey of Informed Opinion – The target respondents for the online survey were senior people considered to be well informed on S&T in Canada, including those with both broad and highly specialized backgrounds. Access to the survey was distributed by the Council through a network of contacts in universities, governments, the private sector and in the Council's member Academies. We estimate that the link to the survey website was distributed to roughly 5,000 individuals from whom 1,529 completions were received over a three-week period between July 17 and August 8, 2006.

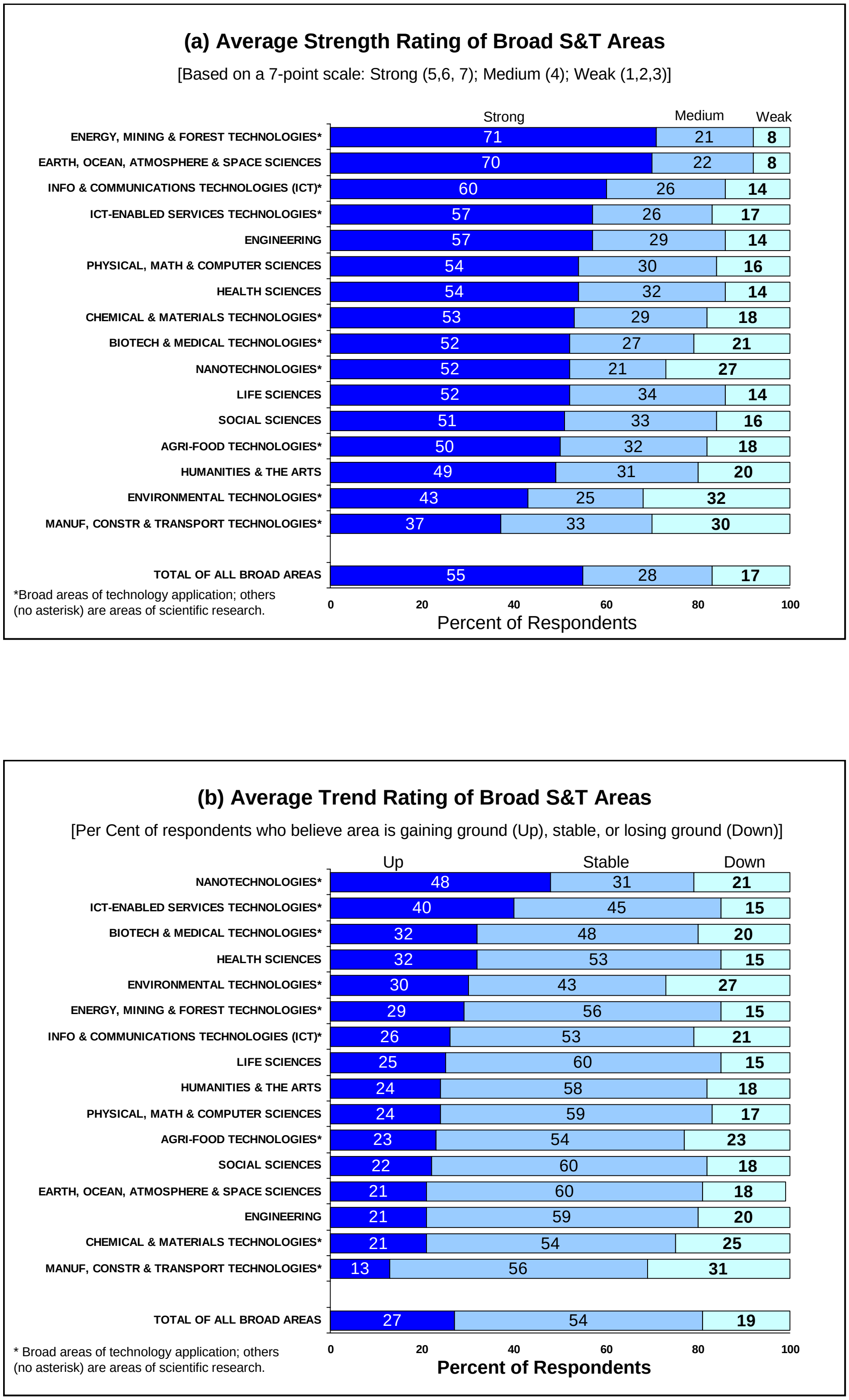
The reported results are not the views or the interpretation of the committee or of the Council of Canadian Academies. They are the views of a significant fraction of Canada's senior S&T community. The overall picture of S&T strengths portrayed by the survey results is remarkably consistent whether based on the responses of the university community; of those associated with business; or with government. The survey numbers speak for themselves and should be regarded as an amalgam of fact, informed judgment and aspiration.

9. Aggregate Strength in Broad Areas of S&T – In **Figure 1**, we summarize the views of survey respondents as to Canada's strength, and its trend, in 16 broad areas of S&T. Strength, **Figure 1(a)**, was rated on a seven-point scale (7 high) and trend, **Figure 1(b)**, reflects respondents' opinion on whether Canada has been gaining ground (against other advanced countries), losing ground, or has been relatively stable. The perception of strength is greatest for technologies and sciences related to natural resources, and second for information and communications technologies (ICT). Comparative weakness is seen in manufacturing, construction and transportation technologies and in environmental technologies. The perception of upward movement is strongest for nanotechnologies (i.e., technologies related to physical, chemical and biological phenomena at nanometer [10^{-9}m] scale), in new ICT-enabled services (e-commerce, e-health, etc.) and in health sciences and biotechnologies.

10. A Granular Assessment of S&T Strengths – The 16 broad areas in **Figure 1** conceal a great deal of variation among their component sub-areas of research and technology application. Survey respondents rated Canada's strength, and trend, in respect of 197 sub-areas distributed among the broad areas (and from which the averages in **Figure 1** were derived.) Individuals were asked to rate only those sub-areas for which they felt they could provide an informed opinion. The median number of responses for the 197 sub-areas was 220. The pattern of ratings remained essentially unchanged as the total number of survey responses increased from 1,000 to 1,500. This suggests that the results would not have changed significantly even had the survey remained open longer.

Figure 1

Average Strength and Trend Ratings of Broad S&T Areas



11. Four Clusters of Canada's S&T Strength – **Figure 2** is a core result of the survey and tabulates results for the 50 sub-areas of research and technology application that received the highest *strength ratings* — defined as the weighted average, or mean value, of respondents' ratings on the seven-point scale. (Results for all 197 sub-areas are tabulated in **Appendix 4**.) The sub-areas in the table are listed in descending order of rated strength, though small differences should *not* be regarded as being of significance. Each line of the table also includes the percentage of respondents who believe the particular sub-area is strong (ratings 5, 6, 7) or weak (ratings 1, 2, 3), as well as the percentage who believe it is gaining ground globally (up) and losing ground (down). The final column identifies four *clusters* that emerge from the survey ranking as macro-areas of particular Canadian strength. These are:

- Natural Resources – Canada has substantial strength in the sciences and technology applications related to natural resources, and in particular to mining and energy.
- ICT – Canada has a long-standing strength in the sciences and technologies related to telecommunications, computers and robotics, and more recently in the application of information and communications technologies in "new media" and related content.
- Health & Related Life Sciences and Technologies – Canada demonstrates strength in a number of the major components of the health sciences — e.g., cancer research and control; neuroscience; circulatory and respiratory health; infectious diseases and immunity — as well as in emerging multidisciplinary fields — e.g., Aboriginal health; aging; gender and health. These health sciences are supported by notable strength in genomics and proteomics, applied not only to human health but also to plant and animal biotechnology.
- Environmental S&T – Canada is strong in certain environmentally related sciences and technologies including climate science, oceanography, hydrology, environmental engineering, fuel cell and hydrogen technologies, and urban geography.

The shaded sub-areas in **Figure 2** are those for which the net upward momentum — i.e., the difference between the percentage of respondents who believe the area is gaining ground (up) and those who see it losing ground (down) — is especially high. These 21 sub-areas are the "double winners" that are in the top 50 according to *both* strength rating and net upward trend.

Figure 2

Top 50 Sub-Areas in Order of Strength (Weighted Average of Seven-point Ratings)

* Sub-areas marked with an asterisk are areas of technology application. The others are areas of research. Shaded sub-areas are those in the top 50 ranked by net upward trend – i.e., Up minus Down. The first column (Numb. Resps.) is the number of survey participants who rated each sub-area.

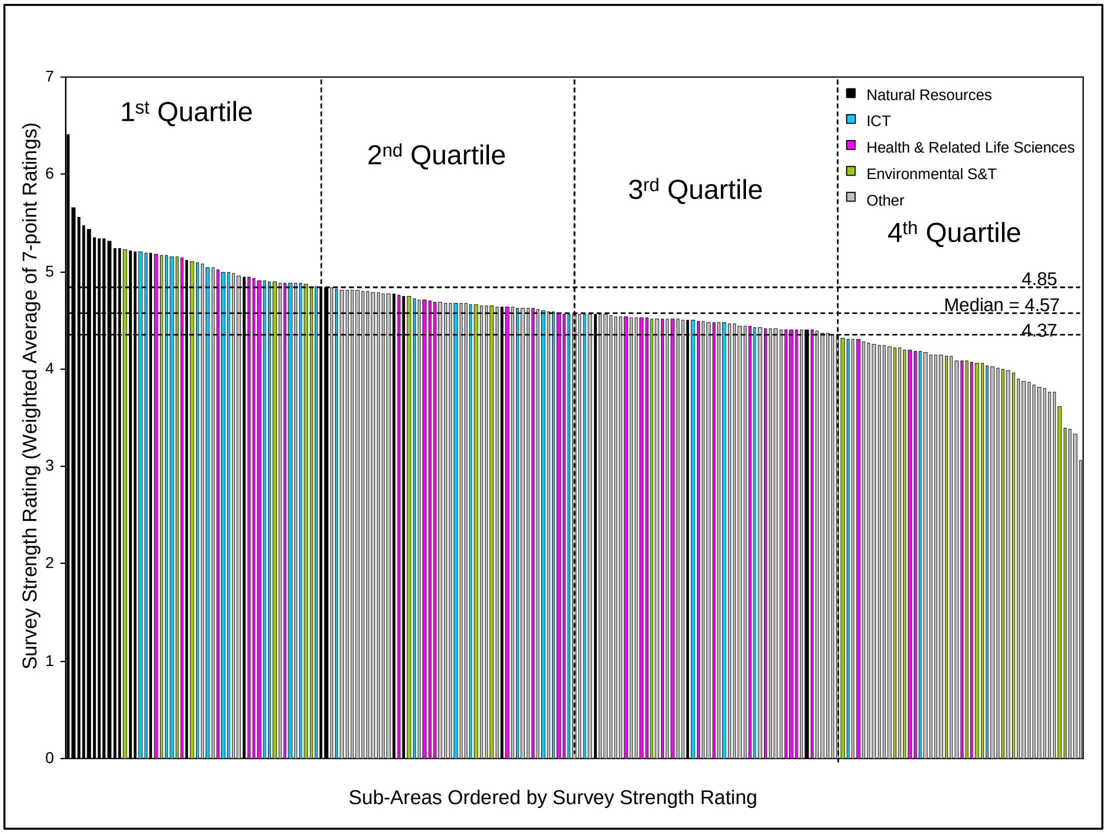
	Sub-Areas	Numb. Resps.	Mean	Percentage of Respondents				Cluster
				Strong	Weak	Up	Down	
1	Oilsands and Related*	316	6.41	97	1	77	2	Natural Res
2	Conventional Oil & Gas Exploration/Extraction*	305	5.66	84	1	43	3	Natural Res
3	Hydroelectric Power*	291	5.56	79	2	22	9	Natural Res
4	Resource Production in Cold Climates*	254	5.48	86	5	36	9	Natural Res
5	Geology	234	5.44	81	4	21	18	Natural Res
6	Mining Exploration*	249	5.35	77	3	24	8	Natural Res
7	Mineral Extraction & Primary Processing*	237	5.34	77	3	23	10	Natural Res
8	Aluminium Production*	120	5.34	76	3	34	12	Natural Res
9	Physical Geography, Remote Sensing	247	5.32	80	4	30	14	Nat Res/Envir
10	Petroleum / Polymer Eng	244	5.24	78	7	46	9	Natural Res
11	Genetics (Medical)	381	5.24	75	6	42	10	Health & Rel
12	Geochem & Geochronology	170	5.23	74	5	21	16	Nat Res/Envir
13	Mining & Mineral Processing	218	5.22	78	4	30	12	Natural Res
14	Offshore Oil and Gas*	287	5.21	74	6	35	8	Natural Res
15	Comms & Network Eng	233	5.20	76	7	27	19	ICT
16	New Media, Multimedia, Animation, Gaming*	169	5.19	77	10	59	8	ICT
17	Geophysics & Seismology	198	5.19	71	8	20	14	Natural Res
18	Genetics, Genomics & Proteomics	474	5.18	74	9	51	12	Health & Rel
19	Hydrology	208	5.17	75	4	25	14	Environ
20	Telecom Equipment*	313	5.17	75	9	25	32	ICT
21	Broadband Networks*	302	5.16	71	8	31	16	ICT
22	Oceanography	241	5.15	73	7	25	27	Environ
23	Cancer Research	441	5.14	73	6	44	9	Health & Rel
24	Pipelines*	260	5.12	68	4	22	4	Natural Res
25	Climate Science	265	5.11	72	7	26	19	Environ
26	Wireless Networks*	330	5.09	72	11	38	16	ICT
27	Cold Climate Construction*	217	5.08	75	11	28	11	
28	Optics, Laser Physics	188	5.05	68	11	38	13	ICT
29	Astronomy, Astrophysics, Cosmology	207	5.05	67	12	25	13	

	Sub-Areas	Numb. Resps.	Mean	Percentage of Respondents				Cluster
				Strong	Weak	Up	Down	
30	Neurobiology / Neurosciences	331	5.02	67	11	39	14	Health & Rel
31	Computer Software Development & Theory	258	5.00	68	9	27	16	ICT
32	Telecom Services*	277	5.00	68	10	25	18	ICT
33	Aerospace Products and Parts*	184	4.98	66	11	22	20	
34	Electricity Distribution*	246	4.96	64	11	19	18	
35	Forestry Engineering	208	4.95	67	11	23	18	Natural Res
36	Genomic and Proteomic Technologies*	408	4.94	67	12	46	15	Health & Rel
37	Circulatory & Respiratory	337	4.93	63	6	27	10	Health & Rel
38	Infection & Immunity	384	4.91	65	10	43	13	Health & Rel
39	Artificial Intell, Robotics	262	4.91	64	15	31	18	ICT
40	Electronic & Photonic Eng	240	4.90	64	11	27	17	ICT
41	Meteorology	208	4.90	58	5	12	12	Environ
42	Visual & Creative Arts	126	4.89	67	16	49	12	
43	Neuroscience, Mental Health, Addiction	340	4.89	64	12	36	14	Health & Rel
44	Quantum Informatics	167	4.89	60	17	51	12	ICT
45	Electrical Engineering	231	4.89	58	9	17	20	
46	Satellite Systems, Services*	270	4.88	62	14	23	20	ICT
47	Fuel Cells & Hydrogen*	241	4.87	65	18	32	24	Environ
48	Geography; Urban & Environmental Planning	165	4.85	67	13	31	21	Environ
49	Computer Databases, Information Systems	234	4.85	63	12	27	13	ICT
50	Pulp & Paper*	129	4.85	61	12	10	36	Natural Res

12. The Distribution of Strength – **Figure 3** depicts all 197 sub-areas in order of strength rating. While there are obviously some clear and important areas of Canadian strength and of relative weakness identified by the survey, the majority of sub-areas of S&T in Canada lie in a broad middle ground. (The weighted average on the seven-point scale declines by only 0.5 — from 4.85 to 4.35 — for the 100 sub-areas ranked between 50th and 150th.) It is not meaningful to distinguish sharply between the rankings of sub-areas in this broad middle ground. These include many fields where Canada is not world-leading, but that are nevertheless necessary to absorb, and adapt to Canadian needs, science and technology that is developed elsewhere. By definition, not everyone can be at the top, though all can aspire to be. The result of such aspiration is to maintain the pressure to continuously upgrade performance and thereby to ensure that Canadian S&T capabilities, overall, are globally competitive.

Figure 3

Full Sample of Sub-Areas Ordered by Survey Strength Rating



13. Interpretation of the Detailed Sub-Area Results – We have been content to let the survey results speak for themselves. Neither the time available nor our own expertise permits the depth of interpretation that the detailed sub-area results require. For the most part, this task must be left to the various expert communities and other users of the report. We nevertheless draw attention to certain noteworthy features of the results, simply as examples of some of the issues and questions they raise.

14. Natural Resources – Oilsands and Related Production Technologies was, by a wide margin, given the highest ranking (as to both strength and trend) of any item in the survey. Canada is seen to be virtually in a class by itself in this technology. There are, nevertheless, still challenges to be overcome in developing more cost-efficient and environmentally friendly extraction and upgrading methods — in short, there is a continuing need for extensive S&T.

Some areas of weakness in the natural resources cluster emerged from survey responses, notably in forest-related technologies — e.g., sawmills, conservation methods and even timber-harvesting technologies, and pulp and paper (where more respondents see Canada losing ground than gaining.) These weaknesses are noteworthy in view of the great economic importance of the forest sector.

15. Information and Communications Technologies – The survey confirmed Canada's international high standing with respect to ICT infrastructure (e.g., wireless and broadband networks). On the other hand, the telecommunication equipment sector in Canada is believed by a third of respondents to have been losing ground, while only a quarter saw the sector gaining. This perhaps reflects the pullback following the dotcom implosion.

The ICT field demonstrating the most promise in the view of respondents — i.e., with the highest net upward trend rating — is New Media, Multimedia, Animation and Gaming, where Canada is internationally recognized as a leader, with a number of successful companies as well as a reputation for superb skills training.

16. Health & Related Life Sciences – Many of the traditional foundation disciplines – e.g., Microbiology, Physiology — were judged by survey participants not to be particularly strong in Canada. The same pattern is observed in other areas of the survey and reflects a clear trend of aspiration toward transdisciplinary work. There is a paradigm shift under way in the way science is done around the world. Multidisciplinarity is becoming the norm, as illustrated, for example, by the subjects around which the Canadian Institutes of Health Research (CIHR) are organized. Networked collaboration, both across Canada and globally, is becoming common in most fields of research. All of this means that researchers today identify less and less with traditional subject areas such as physics, chemistry, biology, sociology, civil engineering. Aspiration and activity are shifting to areas such as biotechnology and nanoscale science wherein the traditional foundation disciplines become submerged as component competencies that are required to address these new areas. For example, the classic discipline of physiology is re-appearing in the new garb of systems biology and Canada's traditional strengths in chemistry and physics are being enlisted in nano- and bio- science.

There is a rather striking contrast between Canada's considerable research strength in the health and related sciences and our much more limited strength in areas of medical technology. (Exceptions are genomics/proteomics and, to a lesser extent, medical imaging.) In particular, we note the perceived weakness of pharmaceutical development — a mean strength of only 4.18, or 165th out of the 197 sub-areas. The survey conclusion in this case reflects the views of 433 respondents and thus appears to be quite robust.

17. Environmental S&T – The Environment cluster presents a challenge, as it does not have deep strength at present in respect of technology application — e.g., clean hydrocarbons, biofuels, energy cogeneration and wind power were all rated well down the list. Moreover, respondents are sharply divided on whether Canada is gaining or losing ground in many of these areas. Several fields of environmental science, on the other hand, are perceived to be very strong, a conclusion also borne out by our bibliometric analysis. There is considerable correlation in Canada between environmental S&T capabilities and the natural resources sector. In view of the increasing importance of sustainable resource use, and of clean energy in particular, Canada's global role in environmental S&T relates primarily to the environment–resources nexus.

18. Other Areas of Strength . . . and Some Weaknesses – Respondents identified a number of important fields of strength that are not categorized within the four main clusters. (The clusters, taken together, encompass 55 percent of the 197 sub-areas.) For example, Canada has exceptional strength in Astronomy, Astrophysics and Cosmology (strength rating of 5.05) that has increased over time in a self-reinforcing way — excellence begets further excellence. Survey respondents perceived significant strength in some emerging fields such as nanoscale materials and biotechnologies, quantum informatics and humanities computing. These latter transdisciplinary fields are specialities for which future prospects are seen to be more significant than currently established strength.

Some components of the aerospace and automotive sectors were also rated as quite strong in the survey (**Figure 4**). The aerospace industry has important concentrations of excellence across the country, but the perceived S&T strengths, and especially the trend, appear to fall short of the economic importance of the industry. The Canadian automotive industry was judged reasonably strong only in respect of motor vehicles and parts. This sector is not R&D-intensive in Canada. As a result, it does not appear to have — relative to the scale of the industry here — a strong indigenous base of skills for automotive innovation.

Figure 4

Automotive, Aerospace & Related Technologies

		Percentage of Respondents			
Sub-Areas	**Mean**	**Strong**	**Weak**	**Up**	**Down**
Aerospace Products and Parts*	4.98	66	11	22	20
Aerospace Engineering	4.77	61	23	19	32
Materials Engineering	4.67	54	10	27	13
Motor Vehicles & Parts*	4.65	59	16	23	24
Advanced Industrial Materials*	4.64	59	16	41	18
Automotive Engineering	4.15	41	32	12	30

* Sub-areas of technology application; others (without asterisk) are sub-areas of scientific research.

One important cluster of technologies — those related to transportation — was identified by survey respondents as unusually weak and perhaps getting weaker (**Figure 5**). Given the importance of efficient transportation, particularly in a geography as vast as Canada's, the committee notes that the apparent technological weakness of this infrastructure could have significant implications.

Figure 5

Transportation Technologies

		Percentage of Respondents			
	Mean	**Strong**	**Weak**	**Up**	**Down**
Air Transport Technologies	4.41	50	22	15	27
Rail Transport Technologies	3.99	41	40	17	33
Road Transport Technologies	3.90	30	36	10	23
Multi-modal Transport Technologies	3.76	25	35	9	26
Marine Transport Technologies	3.38	18	57	4	46

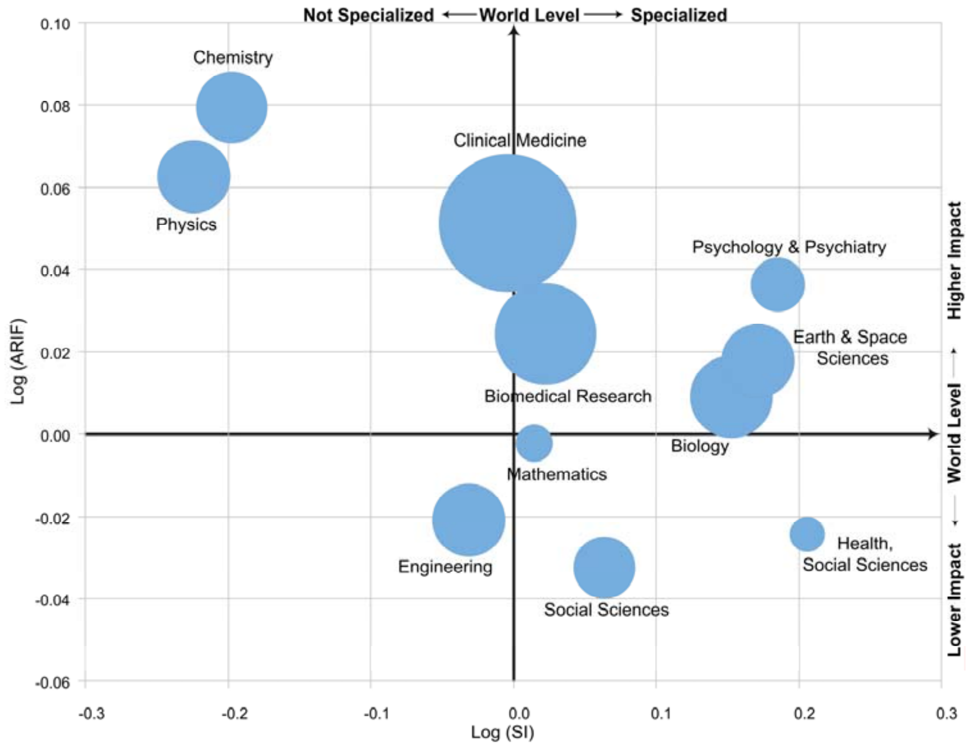
19. A Second Lens: Bibliometric Perspectives on Research Strengths – Canada currently ranks eighth in the world in total volume of scholarly publications. We have analyzed 125 fields of research (78 of which roughly matched sub-areas in the opinion survey) to determine areas of particular Canadian research specialization and publication quality, relative to the world average. The *quality* indicator — called the Average Relative Impact Factor, or ARIF — is derived from international ratings (based on citation numbers) of the journals in which Canadian researchers publish. The *intensity* of Canadian publication in various fields, relative to the world average, is measured by a Specialization Index, or SI. If the ARIF or SI is greater than 1.0 for a given field in Canada, it indicates that Canadian research in that field is of higher quality, or is pursued more intensively, than the world average. (Ratings less than 1.0 are below the world average.)

20. Bibliometric Analysis: The Big Picture – **Figure 6** depicts Canada's position relative to world science with respect to research intensity (SI on the x-axis) and research output quality (ARIF on the y-axis). The size of the circles on the chart is proportional to the number of Canadian papers published in the various fields over the eight years from 1997 through 2004. The top right quadrant contains the domains in which Canada is relatively specialized and in which it publishes in journals that are more highly cited than the world average. This is a quadrant of unambiguous relative strength for Canadian published research. The broad fields where Canada has the best overall performance are psychology and psychiatry, earth and space sciences, biomedical research and biology.

The top left quadrant identifies domains where Canada does not publish as *intensively* as the world average but where quality is high. Chemistry is clearly a field of excellence and is followed by physics. The lower quadrant on the right hand side contains those fields where Canada specializes but where it tends to publish in journals that are not cited as often as the world average. This quadrant contains many of the social sciences. We note that a significant amount of social science research deals with location- and culture-specific questions, which would explain, in part, why research in smaller countries like Canada is disproportionately published in locally specialized journals that are relatively less cited than the world average. Finally, the lower left quadrant of the figure shows that, at the aggregate level, Canada's greatest weakness is in engineering research. Of course there are important exceptions within sub-areas of engineering.

Figure 6

Position of Canada in Scientific Research Publications, 1997–2004



21. A More Detailed Perspective – In **Figure 7,** we list separately the top 30 sub-areas (out of 125 that we have analyzed) in terms of publication quality (ARIF) and publication intensity (SI). Some clear patterns emerge: a number of the top 30 areas fall into the clusters as identified from the survey results. In terms of publication quality, the top 30 includes eleven sub-areas of health and related life sciences and three in environmental science. In terms of publication intensity, there are nine sub-areas related to natural resources and the environment, and seven in health and related life sciences. A significant cluster of five psychology sub-areas appears in the list of greatest specialization, and there are 11 sub-areas of chemistry and physics in the list of highest quality as measured by ARIF.

The highlighted sub-areas in the figure are areas in which Canada publishes more intensely than the world average and also has publication quality above the world average — these are doubly strong. For example, clinical research, psychology, oceanography, forestry engineering, hydrology, geology, marine biology, environmental sciences and ecology are all areas in which Canada excels in terms of both publication quality and intensity.

Figure 7

Top 30 Sub-areas in Descending Order of ARIF and of SI (Shaded lines are fields for which both ARIF and SI are above the world average. The sub-areas indicated by asterisk are those for which there was no clear equivalent among the 197 sub-areas in the online survey.)

Top 30 ordered by ARIF

		ARIF	SI
1	Inorganic Chemistry	**1.43**	0.55
2	Clinical Research	**1.41**	1.10
3	Gastroenterology*	**1.41**	0.72
4	Psychology, Educational*	**1.40**	0.81
5	General Physics*	**1.29**	0.65
6	Pathology*	**1.26**	0.82
7	Obstetrics & Gynecology*	**1.25**	0.76
8	General Chemistry*	**1.25**	0.75
9	Nuclear Engineering	**1.25**	0.56
10	Psychology, General*	**1.23**	1.33
11	General Engineering*	**1.23**	1.10
12	Analytical Chemistry	**1.23**	0.66
13	Pharmacy*	**1.23**	0.37
14	Condensed Matter Physics	**1.22**	0.49
15	Social Sciences, Biomedical*	**1.21**	1.95
16	General Biomedical Research*	**1.21**	0.90
17	Cancer Research	**1.21**	0.88
18	Marine Biology & Hydrobiology*	**1.20**	1.87
19	Oceanography	**1.20**	1.37
20	Applied Chemistry*	**1.19**	0.84
21	Polymer Chemistry	**1.19**	0.69
22	Organic Chemistry	**1.18**	0.62
23	Dermatology*	**1.18**	0.46
24	Psychology, Mathematical*	**1.16**	2.06
25	Human Dev't & Youth Health	**1.16**	1.23
26	Circulatory & Respiratory Health	**1.16**	1.09
27	Nuclear Phys & Elem Particles	**1.15**	0.87
28	Nanoscale Physical Science	**1.15**	0.49
29	Astron, Astro Phys, Cosmol	**1.14**	0.99
30	Ecology & Evolution Biology	**1.13**	1.47

Top 30 ordered by SI

	SI	ARIF
Forestry Engineering	**3.06**	1.03
Industrial Relations & Labour*	**2.49**	0.75
Mining & Mineral Proc Eng	**2.48**	0.97
Hydrology	**2.36**	1.00
Psychology, Mathematical*	**2.06**	1.16
Kinesiology	**2.05**	1.02
Civil Engineering	**2.05**	0.83
Experimental Psychology	**1.99**	0.94
Geology	**1.98**	1.05
Operations Research*	**1.98**	1.03
Social Sciences, Biomedical*	**1.95**	1.21
Marine Biology & Hydrobiology*	**1.87**	1.20
Social Psychology	**1.86**	1.06
Earth & planetary Science*	**1.82**	0.89
Psychiatry*	**1.78**	1.05
Environmental Science*	**1.74**	1.08
Psychology, Biological*	**1.71**	0.95
Animal Biology	**1.70**	1.07
Soil Science	**1.70**	1.05
Physiology	**1.65**	0.98
Ergonomics*	**1.63**	1.05
Transport Studies*	**1.62**	1.03
Health Services & Policy	**1.61**	0.76
Women's Studies*	**1.56**	1.00
Linguistics	**1.56**	0.83
Entomology*	**1.53**	0.98
Population & Public Health	**1.53**	0.92
Psychology, Clinical*	**1.52**	1.09
Rehabilitation*	**1.48**	1.00
Ecology & Evolution Biology	**1.47**	1.13

22. Canada's Research Strength is Confirmed – When the bibliometric data are viewed in their entirety, Canada's broad strength in published research is apparent. We note that:

- For 38 percent of the 125 areas analyzed, *both* publication quality (ARIF) and intensity (SI) were above the world average. In only 10 percent of the 125 disciplines were quality and intensity both below the world average.
- Almost 70 percent of the 125 disciplines had publication quality ratings above the world average.
- In only 11 of the 125 disciplines was publication quality rated at less than 90 percent of the world average.

23. Technometrics – Analysis of Patent Data – The analysis of patents granted, using the database of the US Patent and Trademark Office (USPTO), provides insight into the intensity and significance of inventive activity in Canada, relative to the world average. (We note, however, that many inventions are never successfully commercialized, and thus patents granted do not necessarily qualify as "innovation", and, conversely, that not all innovations are patented.)

Owing to the constraints both of time and of the antiquated classification system in the USPTO database, our technometric analysis has been rather cursory. Highlights are as follows:

- Canada is particularly strong in optics and photonics (complementing research and technology strengths noted earlier) and in energy production technologies. Although patent activity has subsided in telecommunication technologies following the "dotcom" collapse in 2000, this field — together with optics and photonics — provides a strong base for future industrial growth.
- Canada produces considerable intellectual property in the pharmaceutical sector and in biotechnology, but this is not cited as often as the world average for other patents in these fields, suggesting that their technological importance, in the aggregate, is lower than the world average.
- Canada's patenting activity is relatively weak in many fields where Canada produces good science. For example, despite excellence in chemistry research, Canada's patenting metrics are below the world average in chemical products, organic chemicals and petroleum-related technologies.
- We have also computed figures for patent growth in Canada. These data show that in the past five years, Canada has been gaining share of USPTO patents granted in the ICT, health and biotechnology sectors.

24. Metrics and the Survey Compared – We were able to create bibliometric categories that reasonably overlap almost 90 percent of the research sub-areas included in the online survey. The two bibliometric dimensions of strength — i.e., publication quality (ARIF) and intensity (SI) — can not really be combined into a single strength indicator that can be directly compared with the survey's single seven-point scale. Instead we compared the survey results with both ARIF and SI separately. We found some areas of clear divergence between the bibliometric and survey measures. For example, the bibliometric analysis reveals the exceptionally high quality of Canadian published research in many domains of chemistry and physics, areas less highly rated in the survey. Conversely, in some of the newer transdisciplinary fields — e.g., communications, media and cultural sciences — the survey results suggest greater Canadian strength than bibliometric data show.

Notwithstanding examples like these, the areas of divergence do not appear to fit any systematic pattern and certainly would not invalidate the identification of four clusters of Canadian S&T strength derived from the survey responses.

On the contrary, the bibliometric analysis shows that Canada publishes intensively, and often of high quality, in areas related to natural resources and the environment. Canada is somewhat less intensively represented in health and related life sciences but the quality tends to be high overall. The ICT cluster does not show prominently in the bibliometric analysis, in part because of the limitations of sub-field classification but primarily because of the more technological orientation of ICT. Canada's strength in the latter was demonstrated in the technometric data. Overall, the results indicate that the survey and bibliometric lenses are both reinforcing and complementary.

25. A View from Abroad – A foreign perspective on Canada's S&T strengths is an important complement to the survey and bibliometric analysis. We were unable, in the time available, to canvas systematically a substantial and informed body of foreign views on Canada's S&T strengths. There is, at present, no formal database that lists all Canada's international agreements in respect of S&T, let alone the multitude of informal and semi-formal collaborations between scientists in Canada and colleagues around the world. Based on information provided by Canada's S&T Counsellors and Trade Commissioners, we have reviewed a number of S&T Memoranda of Understanding and formal agreements with several countries. The agreements concur reasonably well with the four clusters of strength that have been identified. Many of these agreements, for example, are related to health and life sciences, to natural resources and to ICT.

26. Canada's S&T Infrastructure – Research facilities and laboratories across the country constitute the tangible infrastructure needed to undertake leading-edge research and to train the next generation of Canadian scientists and technologists. Complementing this is *soft* infrastructure that includes a wide array of government programs and policies, as well as other intangibles such as the regulatory procedures that both use, and have an impact on, S&T. We identified three major categories of infrastructure that underpin Canada's S&T capacity:

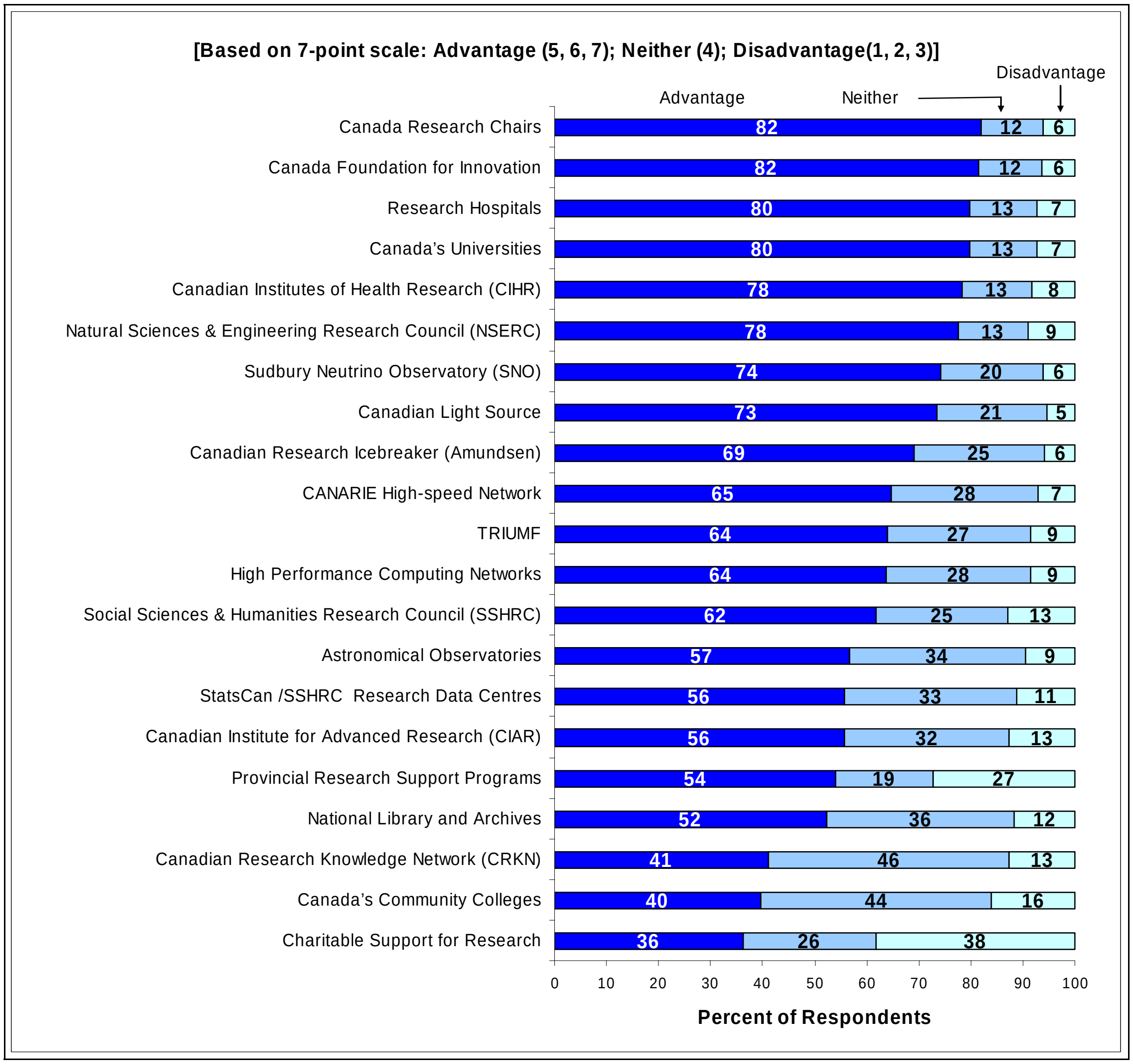
- Infrastructure that facilitates the production of knowledge — e.g., universities and research granting agencies;
- Infrastructure that promotes the commercialization and translation of research results — e.g., industrial research support programs and tax incentives; and
- Infrastructure that supports other public policy objectives that draw upon, or significantly affect, S&T activity — e.g., related to health, public safety, national data collection and analysis, and various regulatory systems.

The online survey canvassed the opinion of the S&T expert community as to the degree of advantage Canada derives (relative to other advanced countries) from 48 specific components of infrastructure belonging to the three major categories.

27. Knowledge Production and Support – Among 21 specific infrastructure components surveyed in this category, respondents of all affiliations and in all regions gave very high marks to the main national institutions that support research and advanced training — i.e., Canada Research Chairs, the Canada Foundation for Innovation, research hospitals, universities, and the granting agencies (particularly NSERC and CIHR). The ratings were among the highest recorded in the entire survey (**Figure 8**).

Figure 8

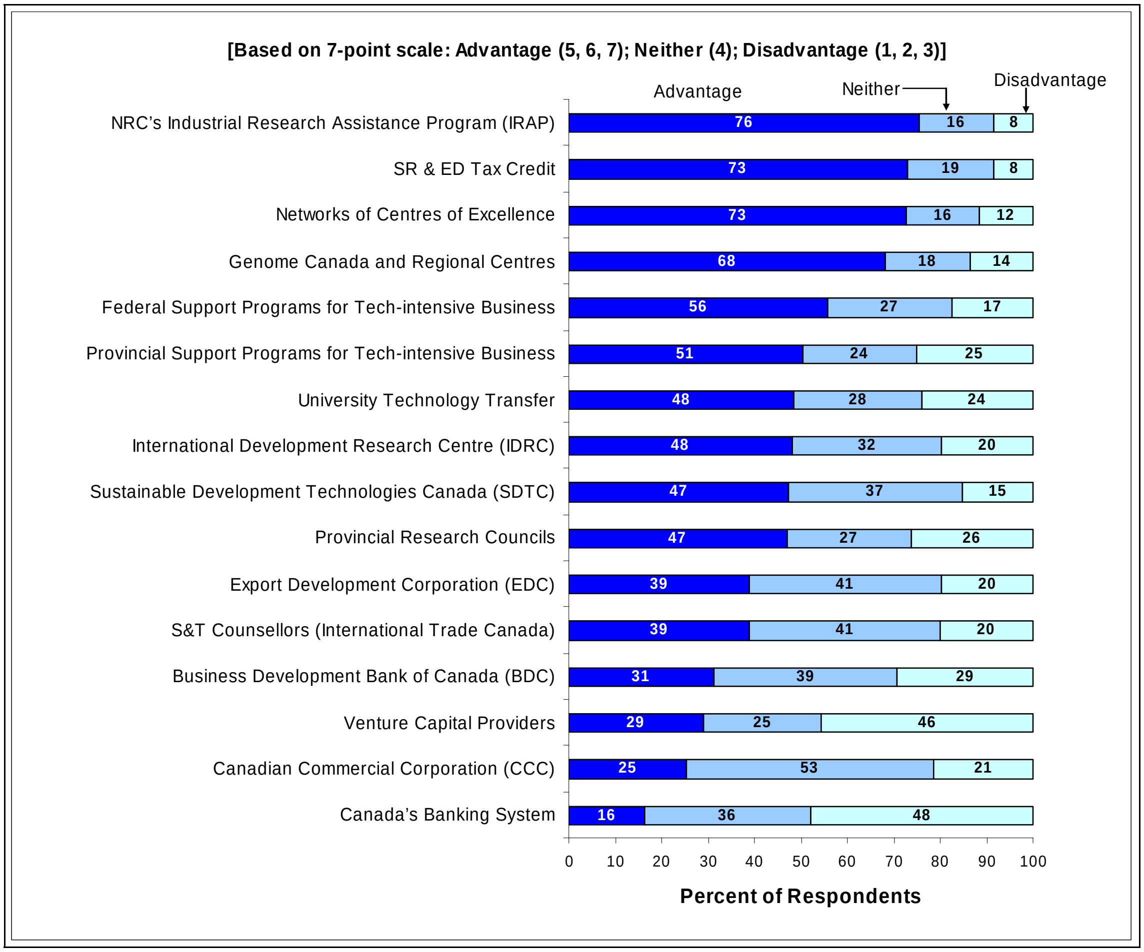
S&T Knowledge Production and Support



28. Support for Commercialization / Translation of S&T – Of the 16 specific components in this category (**Figure 9**), the highest ratings were accorded to four programs: the Industrial Research Assistance Program (IRAP), which promotes technology development in small and medium enterprises; the Scientific Research and Experimental Development tax credit (SR&ED); the Networks of Centres of Excellence program, which supports cross-Canada collaboration in significant areas of applied research; and Genome Canada, which supports research and applications in genomics and proteomics. These ratings were also among the highest recorded throughout the survey.

Figure 9

Support for Commercialization / Translation of S&T



Response rates for individual components of the infrastructure survey ranged from a low of 470 respondents to more than 1,400. This permits cross-tabulations by affiliation status — e.g., university, business, government — and by region across Canada. **Figure 10** does this for all 16 components of commercialization / translation support infrastructure. It is apparent, though hardly surprising, that respondents tend to rate infrastructure more highly when it serves their interest more directly — e.g., the exceptionally high rating of the SR&ED tax credit by those with business affiliation. Also notable is the unusually favourable rating given to provincial research councils by Quebec-based respondents.

Figure 10

Support for Commercialization/Translation of S&T—Affiliation and Regional Perspectives

	Percentage Rating Strong Advantage (Ratings 5, 6 or 7)										
Infrastructure	**Total**	**Univ**	**Bus**	**Gov**	**BC**	**AB**	**M/S**	**ON**	**QC**	**ATL**	**INTL**
IRAP	76	**71**	**82**	**82**	80	84	80	76	**66**	82	70
SR&ED	73	**66**	**84**	78	74	72	71	74	78	63	67
NCE	73	73	69	79	76	71	72	75	72	65	66
Genome Canada	68	65	65	74	75	67	67	66	71	60	76
Fed Supp for Tech Bus	56	**48**	**64**	59	61	52	59	52	61	53	63
Prov Supp for Tech Bus	51	48	57	52	48	48	38	51	60	40	52
Univ Tech Transfer	48	51	46	45	**61**	46	42	46	50	42	54
IDRC	48	47	42	46	48	36	50	52	46	48	48
Sust. Dev. Tech Cda.	47	46	47	45	44	46	43	46	56	52	32
Prov Resh. Councils	47	49	48	44	40	50	36	42	**65**	40	52
Export Dev Corp	39	**31**	**48**	43	38	40	41	38	43	36	23
S&T Counsellors	39	**28**	**46**	45	44	39	33	35	41	33	52
Bus Dev Bank	31	26	36	35	22	30	34	27	**43**	27	41
Venture Capital	29	26	30	28	22	33	33	28	31	25	39
Cdn Commercial Corp	25	18	**33**	27	17	27	24	26	32	22	14
Commercial Banks	16	14	16	16	10	11	21	15	18	18	37

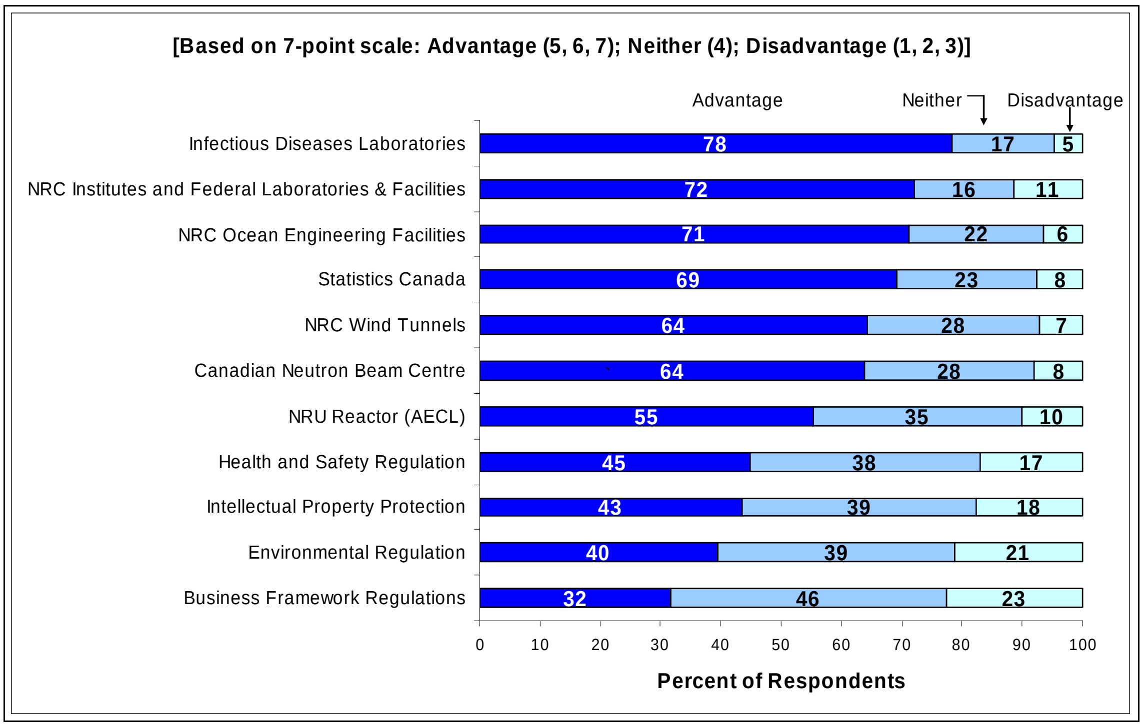
Note: Bolded figures indicate statistically significant variations from the overall rating — i.e., less than one percent probability that the difference was due simply to chance.

29. Commercial Financing of S&T – One finding that may be surprising is the relatively low rating given to Canada's financial support infrastructure for S&T (see bottom several rows in **Figure 10**). For example, fewer than 30 percent of survey respondents cited venture capital providers as a strongly advantageous element of Canada's infrastructure — among the lowest ratings of any element in the entire survey. Further study is required to fully understand the widespread negative perceptions held by the S&T community, not only of venture capital providers but also of commercial banks and of the government institutions engaged in the funding of commercial activity in Canada.

30. Government S&T Infrastructure – The committee notes that the S&T capacity of the government of Canada is a valuable national asset, since the government is often the only feasible provider of many important services — e.g., standards setting; public goods such as the meteorological service and the geological survey; national statistical services; science in support of regulatory functions; and maintenance of long series of observational data (e.g., to support climate science). **Figure 11** shows that survey respondents gave high ratings to three major federal institutions: the infectious diseases laboratories; NRC Institutes and other federal labs; and Statistics Canada. A number of specific facilities — e.g., NRC's ocean engineering facilities, wind tunnels, and the Canadian Neutron Beam Centre — were also well regarded.

Figure 11

Federal S&T Infrastructure and Regulatory System



31. The Regulatory System as Infrastructure – The regulatory system can be regarded as an element of soft infrastructure that has a significant impact on, and relationship to, S&T. Good science is needed to inform wise and effective regulation — e.g., in fisheries and other environmental areas, or in respect of health and safety. Intellectual property regulation (e.g., the patent and copyright systems) has important implications for the incentives to innovate in Canada, while business framework regulations (relating for example to business start-up, competition and bankruptcy) can either enhance or degrade the environment for entrepreneurial activity.

The four regulatory elements in the survey — health and safety, intellectual property, environment, and business framework — nevertheless received remarkably low support compared with the great majority of infrastructure rankings (**Figure 11)**. Fewer than half of respondents rated them as providing a relative advantage for Canada. Regulation is often perceived as an inhibitor. The challenge is to design regulations that achieve their objectives while minimizing unintended negative consequences — i.e., *smart* regulations. The survey results suggest that, from the perspective of a significant proportion of S&T stakeholders, Canada's regulatory frameworks are falling short. Detailed analysis confirms that these views are broadly held irrespective of affiliation or region.

32. Areas of Potential S&T Strength for Canada – Our findings with respect to the question "what are the scientific disciplines and technological applications that have the potential to emerge as areas of prominent strength for Canada and generate significant economic and social benefits?" are more speculative than those described elsewhere in the report. This is because, first, we have not had the opportunity to carry out a thorough foresight analysis; and second, because of the substantial uncertainties in our understanding of how, and over what time period, particular strengths in S&T lead to "significant economic or social benefits".

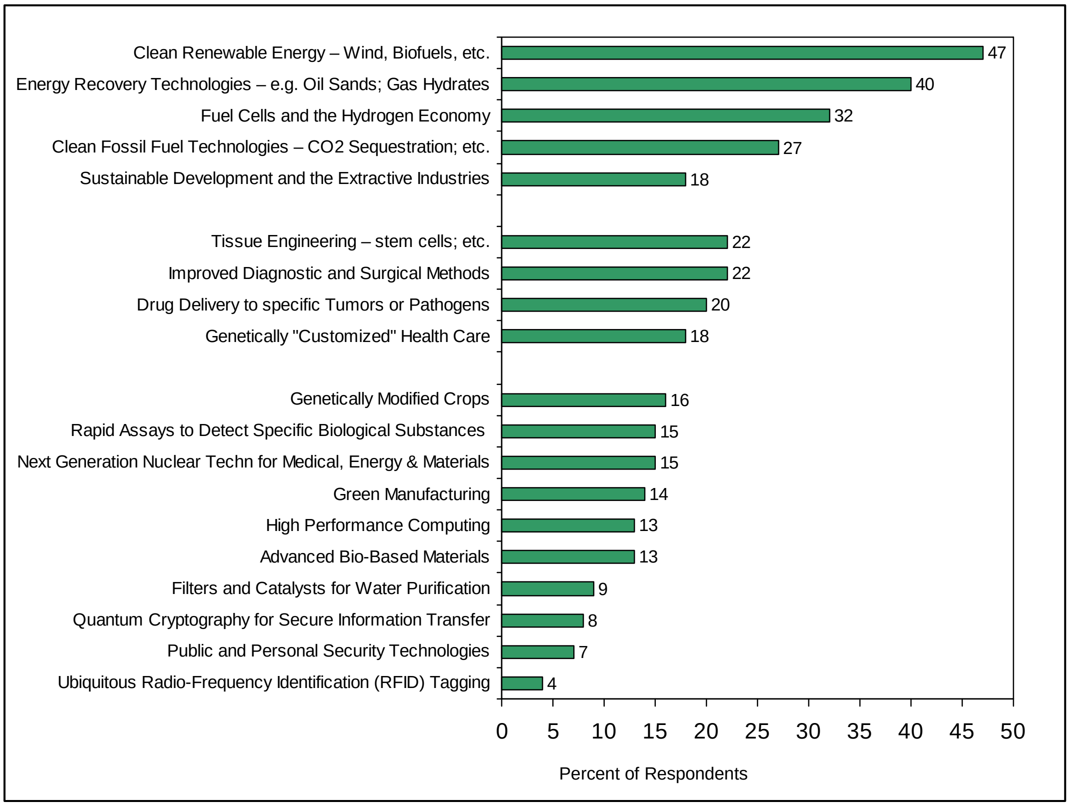
We have relied primarily on the online survey, which presented participants with a list of 19 areas of research or technological application that are thought likely to be of increasing significance over the next 10 to 15 years. (The selection of the menu of 19 areas was based on an extensive analysis by the RAND Corporation, augmented with items of more particular relevance to Canada.) Respondents were asked to choose up to *five* areas in which they believed "Canada is best-placed to be among the global leaders in development and/or application."

33. Clean Energy Technologies Lead the List – By a wide margin, survey respondents identified energy technologies as the area where Canada is best positioned to develop prominent strength in the future (**Figure 12**). The four top-ranked emerging areas all fell into the energy category, and three of them related to sustainable energy. In second place was a set of healthcare technologies — including tissue engineering (e.g., use of stem cells), targeted drug delivery, and genetically customized healthcare — that were viewed as having great potential for Canada.

34. A Caveat – The committee notes that the top ranking given to clean energy as an emerging area of potential Canadian leadership is inconsistent with respondents' assessment that Canada does not *currently* have much strength in the field of "green energy". This calls into question whether the survey responses reported above reflect a hard-headed assessment of where Canada is *best positioned* to be a global leader, or whether the responses reveal a powerful aspiration as to where Canada *ought* to be a leader. In any event, there is a significant gap between aspiration and current reality. If Canada is to become an international leader in clean energy, there is much work to be done.

Figure 12

Survey Results on Emerging Opportunities — Percent of Respondents Including the Listed Areas in Their Top Five



35. Diverse Perspectives on Future Opportunities – The more than 1,500 survey responses as to the most promising emerging opportunities provide a rich statistical base for cross-tabulation (**Figure 13**). This reveals some significant regional variations around the survey averages. For example, BC respondents were significantly more likely than the average to select "fuel cells and the hydrogen economy" in the top five; Albertans were far more likely to select "energy recovery technologies" and "clean fossil fuel technologies", while Quebecers were significantly less likely than the average to name these. Respondents from Manitoba and Saskatchewan were much more likely than the average to see opportunity in "genetically modified crops". In all these cases, one can see the strong influence of existing regional specialization on the perception of future opportunity.

Figure 13

Various Perspectives of Survey Respondents on Emerging Opportunities

	Percentage of Respondents Including Item in Top Five												
Item	**Total**	**Univ**	**Bus**	**Gov**	**<35**	**>55**	**BC**	**AB**	**M/S**	**ON**	**QC**	**ATL**	**INT**
Clean Renewable Energy — Wind, Biofuels, etc.	47	**44**	**58**	49	55	**42**	52	50	57	**41**	53	49	45
Energy Recovery Technologies — e.g. Oilsands; Gas Hydrates	40	**36**	**51**	**51**	29	**47**	34	**62**	47	42	**30**	41	36
Fuel Cells and the Hydrogen Economy	32	**27**	**39**	**40**	35	31	**45**	26	25	32	30	32	30
Clean Fossil Fuel Technologies — CO2 Sequestration; etc.	27	25	32	31	25	28	29	**55**	28	25	**18**	27	28
Tissue Engineering — stem cells; etc.	22	25	21	22	22	22	18	18	16	24	**29**	**12**	20
Improved Diagnostic and Surgical Methods	22	21	23	22	16	24	17	27	14	**26**	24	**10**	16
Drug Delivery to Specific Tumours or Pathogens	20	22	21	16	22	20	27	18	14	18	**29**	15	13
Sustainable Development and the Extractive Industries	18	15	21	22	16	17	21	18	27	16	15	20	19
Genetically "Customized" Health Care	18	19	**14**	21	17	20	23	16	12	18	22	11	23
Genetically Modified Crops	16	14	14	**24**	15	19	13	**24**	**39**	16	**9**	17	17
Rapid Assays to Detect Specific Biological Substances	15	17	17	16	10	13	13	13	24	14	18	12	13
Next Generation Nuclear Technologies for Medical, Energy and Materials	15	14	17	19	13	**20**	11	14	23	**19**	11	11	9
Green Manufacturing	14	14	15	14	**23**	12	20	11	11	12	15	16	25
High Performance Computing	13	13	11	16	14	14	15	11	7	13	15	14	14
Advanced Bio-Based Materials	13	13	16	16	14	13	10	9	**25**	14	14	14	14
Filters and Catalysts for Water Purification	9	8	12	12	8	10	7	11	10	11	6	11	6
Quantum Cryptography for Secure Information Transfer	8	7	4	9	10	9	6	11	4	8	7	3	12
Public and Personal Security Technologies	7	6	8	**13**	6	8	5	6	1	8	8	10	7
Ubiquitous Radio-Frequency Identification (RFID) Tagging	4	3	**7**	5	2	3	2	4	4	3	5	5	3

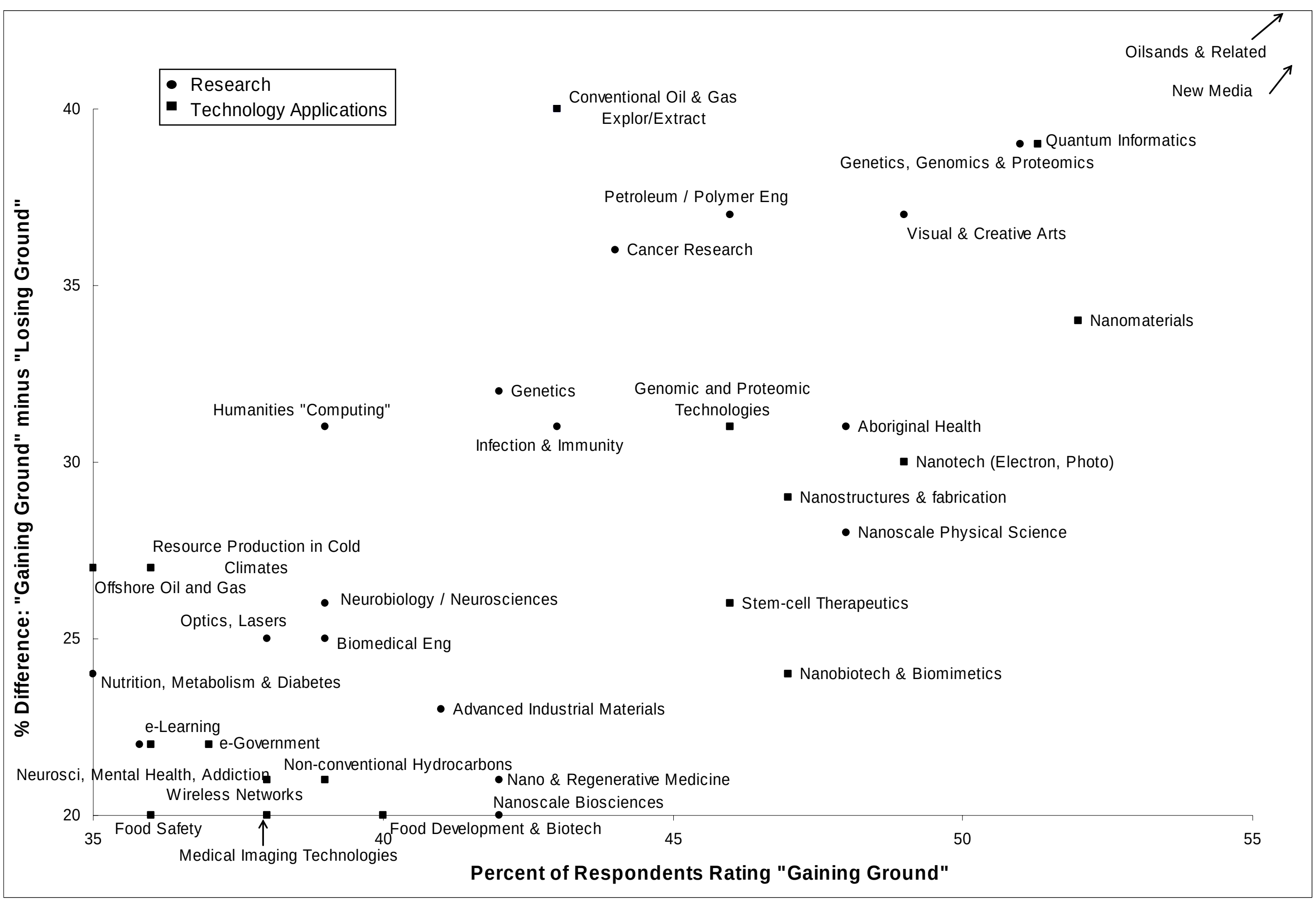
Note: Bolded figures are statistically significant deviations from the total – i.e., less than one percent probability that the difference was due simply to chance.

36. Where Upward Momentum Appears to be Strongest – A final perspective on areas of future promise for Canada can be gleaned from the trend ratings assigned by survey respondents to the 197 sub-areas of research and technology application discussed earlier. **Figure 14** maps the areas for which respondents were most united in their view that Canada has been gaining ground. (The sub-areas plotted are those for which two conditions were met: (i) at least 35 percent of respondents believe the area is gaining ground in Canada; and (ii) the *net* trend – i.e., percent who see an uptrend minus the percent who see a downtrend – is at least 20 percent.)

It is notable that almost all the disciplines and technologies in the figure are associated with ICT and its applications, the bio-based and health sciences, various applications of nanotechnology, and natural resources. There are no representatives of the newer breed of environmental sciences and technologies needed to fulfill the aspirations so forcefully expressed by survey respondents when they selected their top five future opportunities for Canada.

Figure 14

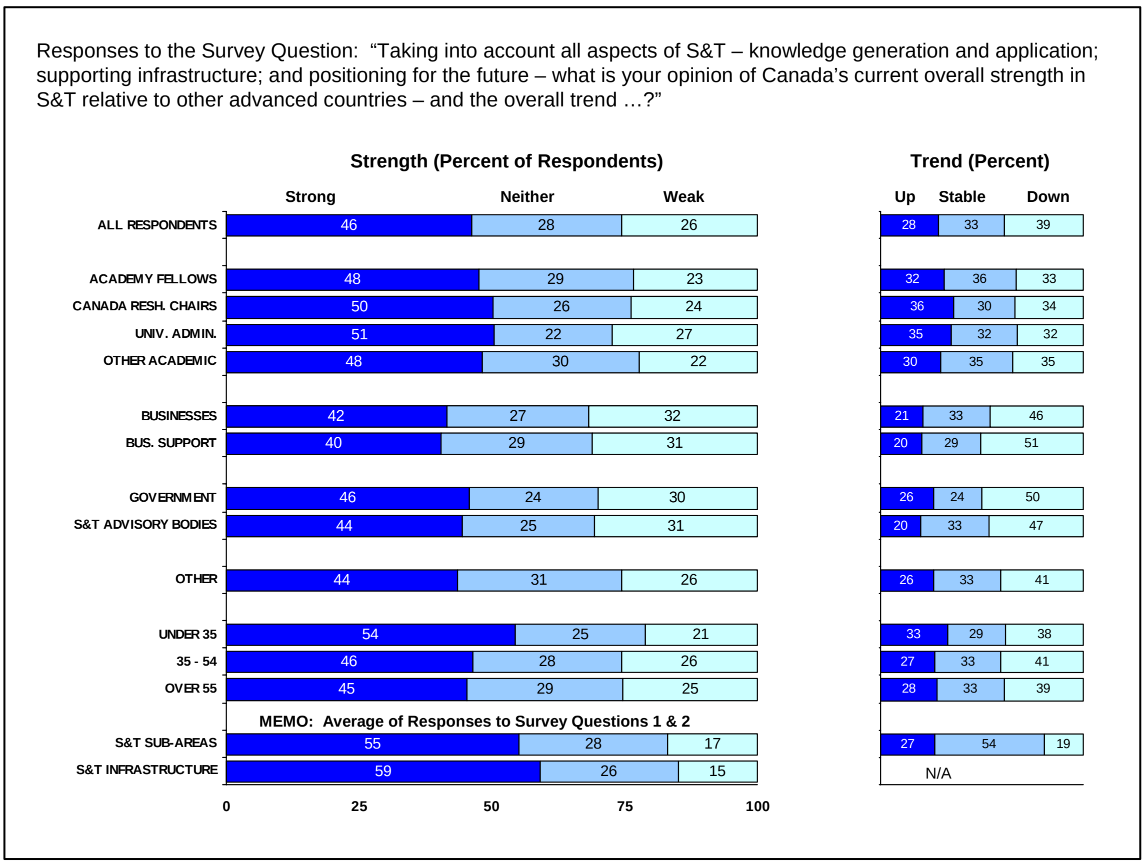
Areas Judged to Have the Highest Growth Prospects



37. Canada's S&T Strength, Overall – Participants in the online survey were asked to rate Canada's strength in S&T, and its trend, overall. The results, reflecting 1,490 responses, are depicted in **Figure 15**, disaggregated by age and affiliation. The integrated view of Canada's strength in science and technology is somewhat more pessimistic than survey respondents' opinion of S&T strengths in *specific* areas of research, technology application, and infrastructure. Fewer than half of respondents ranked Canada strong overall in S&T (ratings 5, 6, 7) and roughly a quarter believe we are weak relative to the average of other economically advanced countries. The perception of overall trend is rather pessimistic – almost 40% believe Canada is losing ground, while only 28% see us gaining. The net trend, again, is considerably more pessimistic than is the case for the (average) outlook in the specific areas of research and technology application (see bottom of **Figure 15**).

Figure 15

Perspective on Canada's S&T Strength Overall



38. Looking Forward: Implications of Findings – The survey results, in addition to providing a detailed map of where Canada's S&T strengths are perceived to lie, pointed to some potentially significant challenges including: the perceived shortcoming of the financial institution infrastructure to support S&T; the state of Canada's capabilities related to transportation technologies; perceived weaknesses in important components of the forest products industry, as well as in the pharmaceutical sector; and the guarded view of survey respondents concerning the S&T benefits, or otherwise, of Canada's regulatory systems. We express no view on any of these questions but simply raise them here as an agenda for others to consider.

The committee made very few attempts to interpret what lies behind the survey results. They contain a wealth of information that can be further analysed and interpreted by the various stakeholder communities. We believe that one of the most useful aspects of our report is the foundation it provides to develop a much deeper, and more broadly shared, understanding of Canada's S&T system. To this end, the set of Strength vs. Trend charts for the 197 sub-disciplines in **Figure 5.15** of the full report might stimulate a number of dialogs within and between expert communities as to why the survey respondents, collectively, placed the various disciplines and technologies where they did.

39. Looking Forward: Still to be Addressed – This report leaves two large issues unresolved – one implicit, the other explicit. The explicit question, raised by the survey, is the gap between an aspiration to develop a leading capability in clean energy technologies, and the current reality. This is a significant challenge that has clearly been identified.

The second, and much broader issue, is the difficulty of knowledge transfer from researchers in universities to innovators in industry. A central conclusion from the evidence in this report is that Canada has built significant strength in many fields of research and there is optimism that we are gaining ground in several of the newer areas. Based on survey commentaries, and in the view of the committee, we do less well in converting strength in basic science into sustained commercial success. This is a long-standing deficiency in Canada's innovation system which requires resolution for the full benefit of Canada's considerable S&T strengths to be realized. An in-depth study of Canadian weaknesses and strengths, their causes and possible remedies, could build on the current study by first focusing on the areas of S&T where Canada is currently strong. Where are the hurdles in translating Canadian strengths in S&T into innovation and wealth creation that will enhance the quality of life of Canadians? How can those barriers be overcome?

40. Looking Forward – We leave the final word to our survey respondents.

Thoughts on S&T Strategy – Voices of the Survey

- We have transformed the country since 1997 from a mediocre performer (broadly speaking) on the R&D stage internationally to a country that is perceived to be on the rise in terms of basic-research investment and output. But, we've only built some momentum. We MUST continue to invest nationally to harvest the fruits of that momentum. *Fellow, RSC Academy of Sciences*

- We spend a lot of money on discovery research, and we are globally competitive there. Where we are very weak is in the translation either to commercial applications or public good. *Fellow, RSC Academy of Sciences*

- Canada has a significant advantage in some areas of basic science and needs to ensure that this is preserved as it attempts to develop strength in applications. *Program Member, Canadian Institute for Advanced Research*

- It is important to support humanities and social science research in conjunction with 'pure' S&T to make sure we are pursuing socially valuable programs and that we know how to integrate the products that emerge in a complex, diverse, society. *Fellow, RSC Academy of the Arts and Humanities*

- Canada desperately needs a science strategy based upon our strengths and the commercial opportunities that will arise. *Fellow, RSC Academy of Sciences*

- I would hope that a possible outcome of this survey and others that may follow is the development of a research strategy or philosophy. Where do we see Canadian S&T in 5 or 10 years? How can we improve the current situation? How can we foster collaborations between government labs, universities and industry? There has to be an open dialogue that addresses these issues. *Canada Research Chair*

1. The Charge

This report summarizes two months of research — beginning in mid-June, 2006 — on Canada's strengths in science and technology (S&T). The study addresses a request by the federal Minister of Industry to the Council of Canadian Academies as follows (see **Appendix 1** for the full text):

> Industry Canada would welcome the advice of the Council in gaining a better understanding of Canada's S&T strengths and capacity. In particular, it would be helpful to better understand:
>
> - The scientific disciplines in which Canada excels in a global context
> - The technology applications where Canada excels in a global context
> - The S&T infrastructure that currently provides Canada with unique advantages
> - The scientific disciplines and technological applications that have the potential to emerge as areas of prominent strength for Canada and generate significant economic or social benefits

In addressing these questions, the report is organized as follows.

Chapter 2 explains our view of the concept of S&T strength and excellence in a global context. **Chapter 3** describes briefly the methodologies used in the research leading to this report. **Chapter 4** sets the context for the report's detailed analysis. It presents a high-level overview of key elements of Canada's S&T system using a set of national indicators for which internationally comparable data are readily available.

Chapters 5, 6 and **7** are the core of the report and respond directly to the questions posed by Industry Canada. **Chapter 5** explores the first two questions combined: What are our strengths in S&T? The chapter is based on an extensive online survey specifically carried out for this study; on bibliometric (journal publications) and technometric (patents granted) analysis; on some perspectives from abroad; and on published literature.

Chapter 6 responds to the third question: Which elements of S&T infrastructure provide Canada with unique advantages? This includes both *hard* infrastructure (e.g., laboratories and major installations) and *soft* infrastructure (e.g., support systems for knowledge production and technology transfer).

Chapter 7 addresses the fourth question: What are the emerging academic disciplines and technological sectors with potential to be areas of strength for Canada?

Finally, **Chapter 8** provides some concluding observations on overarching themes and identifies matters for further investigation.

2. Defining the Question

Why Does Strength in S&T Matter for Canada?

A country's strengths in science and technology play a key role in furthering innovation, productivity growth, international competitiveness, environmental sustainability and quality of life. More specifically:

- S&T strengths lead to the production of highly trained people at the frontier of knowledge who become the agents by which scientific expertise and technological application are deployed in the economy and society.
- S&T strengths help to attract, and retain in Canada, highly skilled people and are also magnets for investment in Canada, both foreign and domestic.
- S&T strengths can stimulate "clusters" of specialized capabilities that often become self-reinforcing hubs of job growth and wealth generation.
- S&T strengths can lead to first-mover advantages for new goods and services that can be exploited by *Canadian* entrepreneurs to capture market share and generate growth.

S&T capability also contributes to broader goals. For example, it can be a source of national pride and a demonstration of what Canada can accomplish. S&T strength enhances Canada's image in the world. It also enables Canada to contribute its share, as an advanced and wealthy country, to expansion of the common global pool of knowledge. This supports human development worldwide as well as the universal quest for greater understanding.

What is Science and Technology?

The definition of science and technology used in this report is the conventional one that treats science and technology more as a *joint* entity than as two separate endeavours, hence the symbol "S&T". It encompasses the traditional disciplines in the natural sciences — the study of nature; the social sciences, humanities and health sciences — the study of human beings; and engineering — the creation and study of artifacts and systems. Our conception of S&T includes, but does not specify, the myriad connections from science to technology and vice versa. It encompasses a very broad concept of technology — the predictable and reproducible application of knowledge in everyday life, in the form of goods, services, organizations, methods and tools.

A popular but incorrect perception is that science represents the upstream activity of basic research and that technology represents the downstream application of this knowledge. The actual relationship is far more complex. Many areas of basic research are and have always been technologically intensive. From Kepler's observatory to today's genome sequencing devices, instrument making and engineering have been as integral to basic research as theorems and formulae. Moreover, we can identify many areas of applied research in which the conceptual element can be just as strong as it is in pure science.

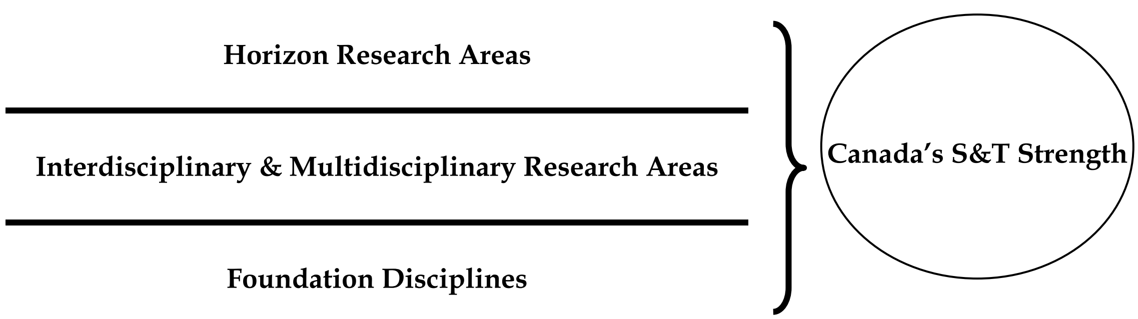
In the context of this study, we are most concerned with areas of research in which technology application and scientific research interact. Thus, we are concerned with a broad range of fields that have both scientific origins and immediate practical application — fields such as medicine, information and communications technologies, manufacturing, resource extraction and processing, transportation and construction.

This study also includes research fields in the humanities and the arts. These disciplines are sources of skills and knowledge that are essential to Canada's economic future as well as its cultural development. We note that roughly 70 percent of Canada's employment and economic output is attributable to services. Technology-intensive services such as media, software, gaming, advertising, market research and so forth often draw heavily upon arts and humanities graduates — many of whom now have technical as well as interpretive skills.

It is helpful to think of S&T capacity in three parts: (i) competence in the *foundation disciplines* of science and the core technologies; (ii) the ability to develop and participate in new *combinations of disciplines* and to create related new technologies; and (iii) the ability to reach *beyond the horizon* and conduct research in potentially important fields where the disciplines are yet undefined and the technology unimagined (**Figure 2.1**).

Figure 2.1

Different Types of S&T Disciplines Contributing to S&T Strength



The foundation disciplines — e.g., mathematics, physics, chemistry, biology, geology, basic engineering, economics, history, among others — provide basic concepts and highly organized frameworks for education and training in scientific investigation and technological development.

Many multidisciplinary research areas were developed through inputs from several streams, often guided by an applied or problem-oriented dimension. Thus, for example, the parameters of medical research have evolved over the years to encompass many knowledge streams — from the primarily biological and chemical to the psychological, sociological, mechanical and computational.

Horizon research areas are not generally related to the existing disciplinary configuration but instead reflect the lack of previous experience with a particular research problem or subject.

It is important for assessment purposes to recognize that some areas of investigation will be much more mature and stable than others, and therefore less likely to yield major discoveries frequently. But this does not diminish the importance of core fields to the process of scientific investigation and technological application as a whole. For example, all physicians must have a thorough grounding in anatomy — even though there have been few groundbreaking discoveries in this field for perhaps a century.

Our task in this study is therefore not only to assess strengths in terms of the fastest moving or fastest growing fields (although this is important to know) but also to assess how strong Canada's systems are for producing, linking and, where possible, applying the knowledge that is produced at all three levels of investigation.

What is S&T Strength?

There is no simple, one-dimensional measure of Canada's S&T strength. The concept is inherently multidimensional and encompasses (a) the quality of science and technology in Canada; (b) the magnitude or intensity of the Canadian effort in various domains of S&T; (c) the trend of the foregoing factors (are we gaining or losing ground?); and (d) the extent to which our S&T capabilities can be applied effectively to achieve social and economic objectives. Qualitative judgments that integrate multiple dimensions and factors are unavoidable. (We present, in **Appendix 2**, one graphic description of the myriad elements of a country's S&T system to illustrate the profound complexity of the entity whose strengths we seek to assess.)

The Global Perspective

Strength in a global context matters for Canada because it determines our ability to compete for increasingly mobile resources of people and investment capital, and to participate in global knowledge-sharing networks that operate at the leading edge of both science and technology development.

But Canada need not, and can not, be equally strong in all aspects of S&T. We will specialize according to our particular needs and aptitudes. Inevitably, most scientific knowledge and technology will be developed elsewhere or cooperatively. That is why Canada needs to maintain the capacity to absorb, adapt and diffuse leading-edge technologies, scientific ideas and best practices throughout our economy and society.

In this report, we seek to analyze Canada's S&T strengths relative to our size and against norms that are typical of other economically advanced countries of the OECD group, including, of course, the United States. This choice is justified by established relationships of trade and scientific cooperation and, in practical terms, by the availability of reasonably comparable data. The committee also notes the growing importance of emerging economic giants such as China and India that are becoming forces to be reckoned with in increasingly sophisticated areas of S&T (**Box 2.1**).

Box 2.1

Growing Economic and S&T Strength Beyond the OECD

An important trend since the mid-1990s has been the emergence of Asian economies outside of Japan as increasingly strong players in the global S&T system. South Korea and Taiwan were already well established in particular markets, and Singapore, Malaysia, Thailand and others have boosted their market strength and shown potential for further increases in competitiveness. As the National Research Council of Canada noted, "By 2020, given present trends, China will have an economy that rivals that of the United States in size. India will achieve this mark sometime in the 2040s and Russia may again emerge as a major player" (2005 (b), p. 7).

China has already become an important participant in high-technology markets, has attracted the world's major corporations, and was the top destination of foreign direct investment in 2004. China's international patenting and publishing activities, although still modest, are increasing rapidly. In fact, China's volume of scholarly publication now exceeds Canada's. Meanwhile, India is focusing particularly on knowledge-intensive service sectors and biotechnology. In short, it is rapidly becoming the case that Canada's relative international strength in S&T must be judged in the context of a wider group than the traditional OECD countries.

What the Report Seeks to Answer and What it Does Not

Our study focuses on describing the strength of the principal building blocks of Canada's S&T system. We do this by identifying, within the limits of available data and methodology, those areas of S&T where Canada is currently strong in comparison with other economically advanced countries. We indicate, as well, areas where we are believed to be getting stronger. We also identify where Canada appears to be comparatively weak or declining relatively in S&T capacity. Finally, we report informed opinion on emerging areas of potential strength, though these are necessarily more speculative.

It was beyond our mandate to analyze the difficult but crucial question of how S&T strengths become translated into the *outcomes* that ultimately contribute to Canada's economic performance and Canadians' quality of life. Nor do we recommend on S&T policy or on priorities for the allocation of support.

The aims of the report are therefore limited, but we hope it will provide important foundational information to assist the Government in the development of S&T strategy.

3. APPROACH AND METHODS

S&T Strength Through Four Lenses

Aspects of Canadian S&T have been explored in many studies, and there has been much investigation of challenges and opportunities in specific areas. While a great deal of Canada's S&T territory has therefore already been explored, this report provides a new and reasonably comprehensive map of our S&T standing in the world, with a focus on the question: "Where does Canada stand tallest?"

Measuring the S&T strengths of an entire country is a complex undertaking — there is no one best practice. Different countries use different indicators and approaches to define their own strengths, which can make international comparisons difficult. Moreover, each method of assessment has its limitations and biases. Most methods are *atomistic* in the sense that they capture only a specific subset of the multiple dimensions of strength in a country's S&T system (**Appendix 2**). For this reason, and because our concept of S&T strength is broad, it is important to supplement the traditional atomistic perspective with other methods that are more holistic and capable of capturing the multiple aspects of S&T strength.

Both viewpoints — atomistic and holistic — have their advantages and disadvantages. This point is succinctly made by C.S. Holling (1998) in pointing out that the danger of an atomistic approach (at least in the field of ecology) is to provide the "exactly right answer for the wrong question" while the danger of the holistic approach is to provide the "exactly right question but a useless answer." Therefore, we should put Canadian S&T strengths under both the microscope *and* the "macroscope" (De Rosnay, 1979).

The committee has chosen the following four different approaches, or *lenses*, to evaluate the questions put to us:

- **Opinion Survey:** A large-scale, online survey of the opinion of Canadian S&T experts. These informed opinions, collectively, represent a broad and integrated picture that has the character of a holistic assessment.
- **Metrics:** An analysis of bibliometric data (published research in scientific journals) and technometric data (patents granted). This approach is the most atomistic of the four lenses.
- **View from Abroad:** A summary of reports and comments obtained from Science Counsellors and Trade Commissioners stationed in Canadian Embassies around the world, with a particular emphasis on S&T agreements between Canada and other countries. A view from abroad complements the self-assessment of the opinion survey.
- **Literature:** A review of relevant publications, including internationally comparable indicators of important aspects of S&T strength at the national level.

We did not apply every lens to each question because all four were not always relevant. For example, when assessing Canada's advantages in infrastructure, bibliometric and technometric data were not directly applicable. A short description of each lens follows.

Survey — Do Crowds Have Wisdom?

In *The Wisdom of Crowds*, James Surowiecki (2004) tells the story of British scientist Francis Galton who, in 1906, observed to his surprise that a crowd of approximately 800 country fair-goers was able to "guess" the weight of an ox. The average of 800 individual guesses — precise to within one tenth of one percent — was much more accurate than the individual guesses of *expert* farmers and butchers in the crowd. This observable strength in numbers is one of the foundations of statistics. In the online survey conducted for this report, we combine two strong approaches — the wisdom of experts with the wisdom of crowds — by surveying a crowd of experts.

The survey questionnaire (**Appendix 3**) was developed on the basis of several existing taxonomies of fields of science and technology and selective consultations with experts. It was programmed and hosted by EKOS Research, an opinion research firm (www.ekos.com). Invitations to participate in the survey were sent to members of 27 different affiliation groups (see **Chapter 5**). The survey was open from July 17 to August 8, 2006. Respondents were asked to:

1. Select one or several of 16 broad areas of research or technology application that they knew well and, within these, to rate specific sub-areas in terms of Canada's relative strength on a seven-point scale, as well as the current trend (gaining ground, stable or losing ground).
2. Rate specified elements of S&T infrastructure in terms of the relative advantage (or disadvantage) they represent for Canada.
3. Select from an array of emerging technologies those for which the respondent believes Canada is best positioned to develop prominent strength.
4. Rate the strength and trend of Canadian S&T overall.
5. Express any further thoughts on Canada's S&T strength in their own words.

For each of the first three questions, respondents could expand the specified menu of choices if they believed they were insufficient. The results of the 1,529 completed survey questionnaires are presented in **Chapters 5, 6** and **7**.

Metrics — Measuring Outputs

Bibliometrics and technometrics are well-established methods in the evaluation of S&T strengths. These objective indicators provide useful and internationally comparable benchmarks, but they are not sufficient to describe the entire S&T system. They are complementary to the other lenses and particularly to the survey results on the strength of sub-areas of research. All bibliometric and technometric results in this report were computed by Science-Metrix (www.science-metrix.com) and use data from the Observatoire des sciences et des technologies (www.ost.qc.ca). The results of the analysis are presented in **Chapter 5**.

International — The View from Abroad

Through contacts in the Department of Foreign Affairs and International Trade Canada, invitations were sent to Science Counsellors and Trade Commissioners stationed in Canadian Embassies around the world. We obtained reports and other data from this network of contacts. The information was used to complement the data obtained from the metrics and the survey.

A limitation of this method is that Canada's S&T strengths, unlike those of the United States or the countries that make up the European Union, are not often studied from abroad. The committee therefore paid special attention to S&T agreements, memoranda of understanding and established collaborations with other countries on the presumption that the disciplines and sectors identified in these collaborations target real strengths in the Canadian S&T system. This information is presented primarily in **Chapter 5**.

Existing Literature

There is almost no published literature focused specifically on strengths of the Canadian S&T system *overall*, and particularly not at a reasonably fine level of detail. The few existing publications — e.g., the influential publication by the United Kingdom's Chief Scientific Adviser, David King (2004) — are pitched at a very broad level of generalization. Nevertheless, the literature lens provided a useful and complementary perspective to augment the other three.

To our knowledge, this four-lens approach has not previously been used to assess S&T strength. In addition to breadth and mitigation of bias, the approach also identifies the S&T areas where information provided by different methods converges or diverges. Specifically, the perspectives provided by multiple lenses permit us to identify three different cases:

- Clear strengths — areas where there is substantial convergence or agreement among the relevant lenses;
- The grey zone — where the combined evidence does not permit unequivocal conclusions to be drawn; and
- Need for further research — where there is clear and unresolved disagreement among the different methods.

This approach also contributes to the development of general methods for identifying S&T strengths. For example, if our opinion survey can be shown — by comparison with other lenses — to be reasonably reliable, it can be used in other circumstances as a relatively quick and inexpensive way to measure S&T strengths periodically and to track changes over time.

4. SETTING THE CONTEXT

Strength in science and technology is considered to be essential for a modern country's *on-going* capacity to innovate and compete in the knowledge-based global economy — to develop new goods and services that succeed in world markets, and along the way to master and apply new organizational concepts and production methods.

It is important to be clear on the connection between S&T and innovation. It begins with invention — an invention being the practical demonstration of a new idea that may derive from research results, from needs expressed in the market, or from the experience and imagination of individual inventors. The successful commercialization of inventions, or their significant application in society, produces innovations.

It is common to talk about a national "innovation system", which is the sum of all institutions, linkages, relationships and arrangements involved in generating inventions and commercializing them. There is no linear progression from research through invention to product development and then sales. Indeed, the innovation process involves false starts, blind alleys and feedback loops, and it includes obstacles that have little to do with the quality of the S&T involved. Above all, it requires talented, highly skilled people with a vision who are also entrepreneurial, energetic and persistent.

For these reasons, assessing and measuring national innovation performance is extremely difficult. We lack a detailed model of innovation that encompasses all its behavioural and organizational aspects. Nor do we have reliable and genuinely comparable data on most of these elements, even for the OECD countries. Quantitative analysis of national innovation systems is therefore limited mostly to that which can be shown from basic input and output indicators.

We can measure *inputs* such as R&D expenditures, capital investment and highly qualified personnel. While all of these inputs can be required for innovation to occur, their presence is no guarantee that innovation will occur. Likewise, we can measure *outputs* such as scientific publications, patents and numbers of start-up firms. At best, these are proxies for some of the elements of innovation activity. For example, the vast majority of patents granted are never exploited commercially, and many innovations are not patented.

In most respects, innovation is actually an *outcome* of input and output factors like the above and of many more social and economic factors besides. Under the right combination of factors, knowledge does become incorporated into new goods, services and practices that may succeed in the market and contribute to economic growth. A national (or regional) innovation system can be said to be successful to the extent that it facilitates, rather than inhibits, these knowledge flows.

In this chapter, we present a broad sketch of those major features of Canada's innovation system that can be portrayed with currently available input and output indicators. Even though these indicators do not give the full picture, they are in most cases all we have.

Placed in proper context, they can nevertheless be useful tools for indicating trends and pointing to important strengths and weaknesses in Canada's innovation system.

Input Indicators

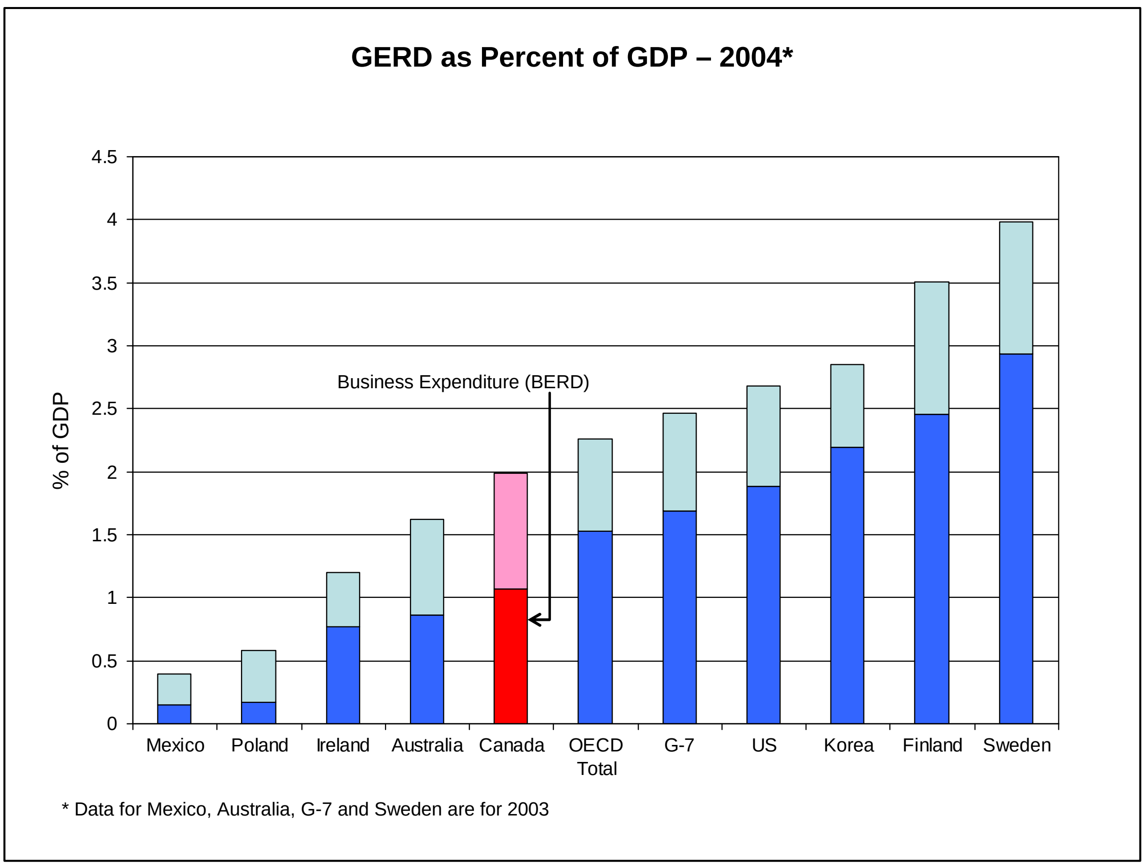
Expenditure on R&D is the most widely reported indicator of S&T effort at the national level. In the understated words of the OECD:

> Expenditure on R&D can be considered as an investment in knowledge that can translate into new technologies and more efficient ways of using existing resources. Insofar as it is successful in these respects, it is therefore plausible that higher R&D expenditure would result in higher growth rates (OECD, 2003, p. 60).

The latest figures show that Canada's gross domestic expenditure on R&D (GERD), expressed as a percent of GDP, is at the low end of our peer group of advanced OECD countries (**Figure 4.1**). At about two percent of GDP, Canada's GERD ratio is half that of the leader, Sweden.

Figure 4.1

Gross Domestic Expenditure on R&D Relative to Gross Domestic Product



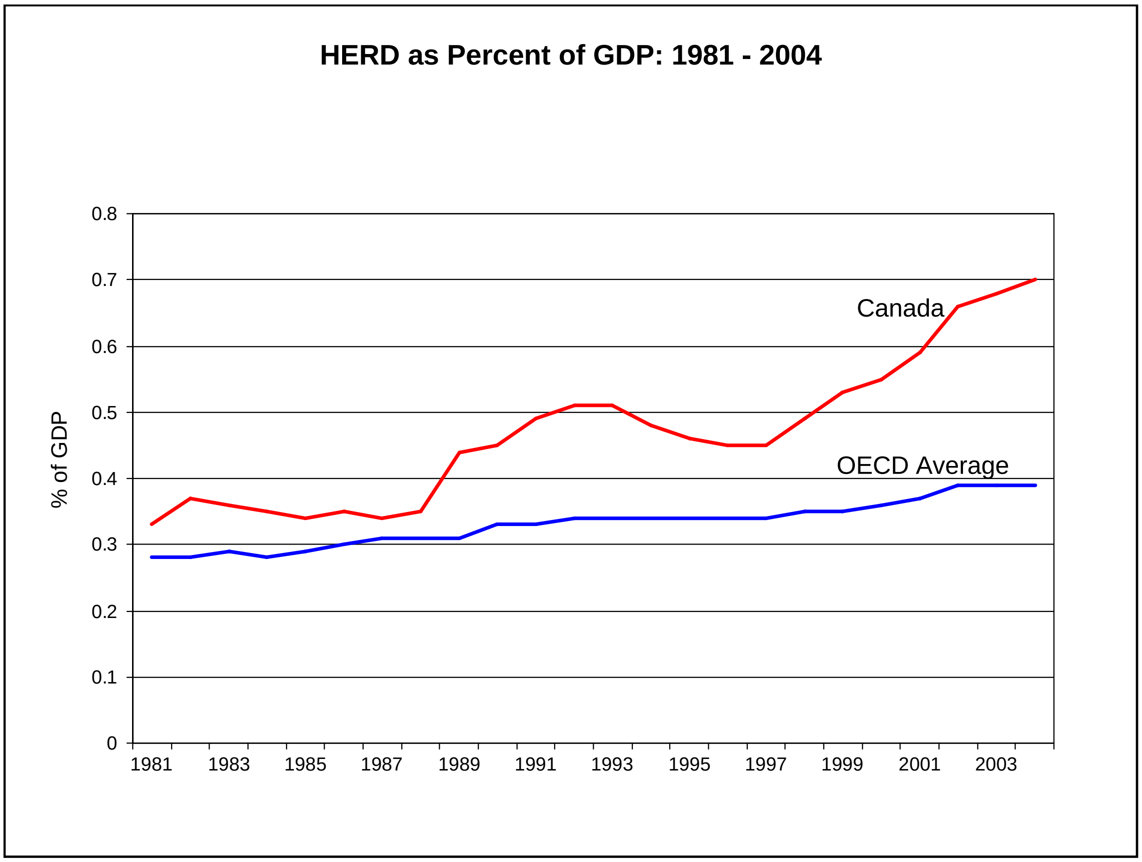
Source: OECD Main Science and Technology Indicators, 2006-1

Canada's spending on R&D has risen significantly over the past 15 years — from $10.3 billion in 1990 to $26.3 billion in 2005 — an average annual growth rate of nearly 6.5 percent. Between 1997 and 2003, Canada recorded the fastest growth of R&D spending in the G-7. But many other countries have been boosting R&D as well, leaving Canada's position in the global league tables comparatively static.

This is despite the fact that Canada has experienced sharply increased R&D spending in the higher education sector as the federal government, businesses and universities themselves made significant new investments in university-based research. Canada's higher education expenditure on R&D (HERD), as a percent of GDP, now stands second in the OECD just behind Sweden and accounts for more than 35 percent of the total R&D performed in Canada (**Figure 4.2**).

Figure 4.2

Higher Education Expenditure on R&D Relative to Gross Domestic Product

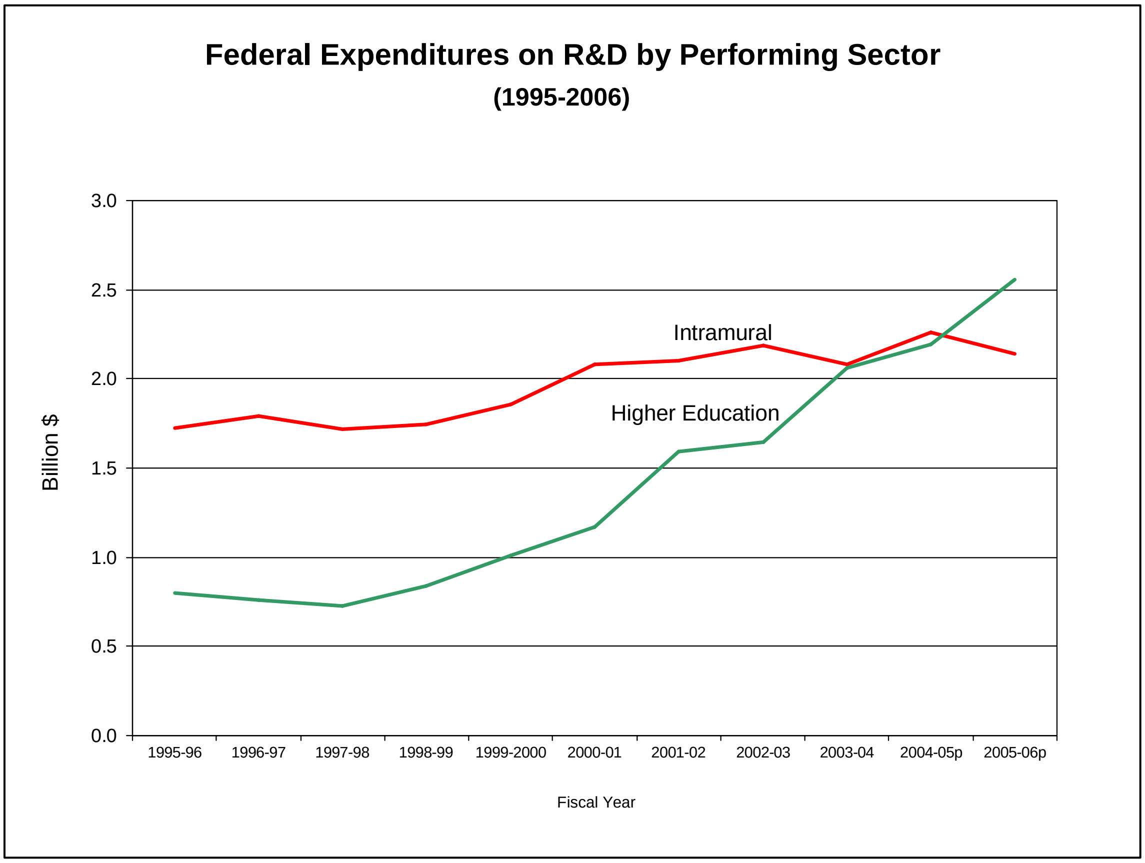


Source: OECD Main Science and Technology Indicators, 2006-1

The federal government's emphasis on university research is evident from the trend of budgetary outlays that show expenditures in support of university R&D of more than $2.5 billion in 2005-06. For the first time, this exceeds federal spending on its own in-house R&D, which has remained largely unchanged for the past six years (**Figure 4.3**).

Figure 4.3

Federal Direct Expenditures on R&D by Performing Sector



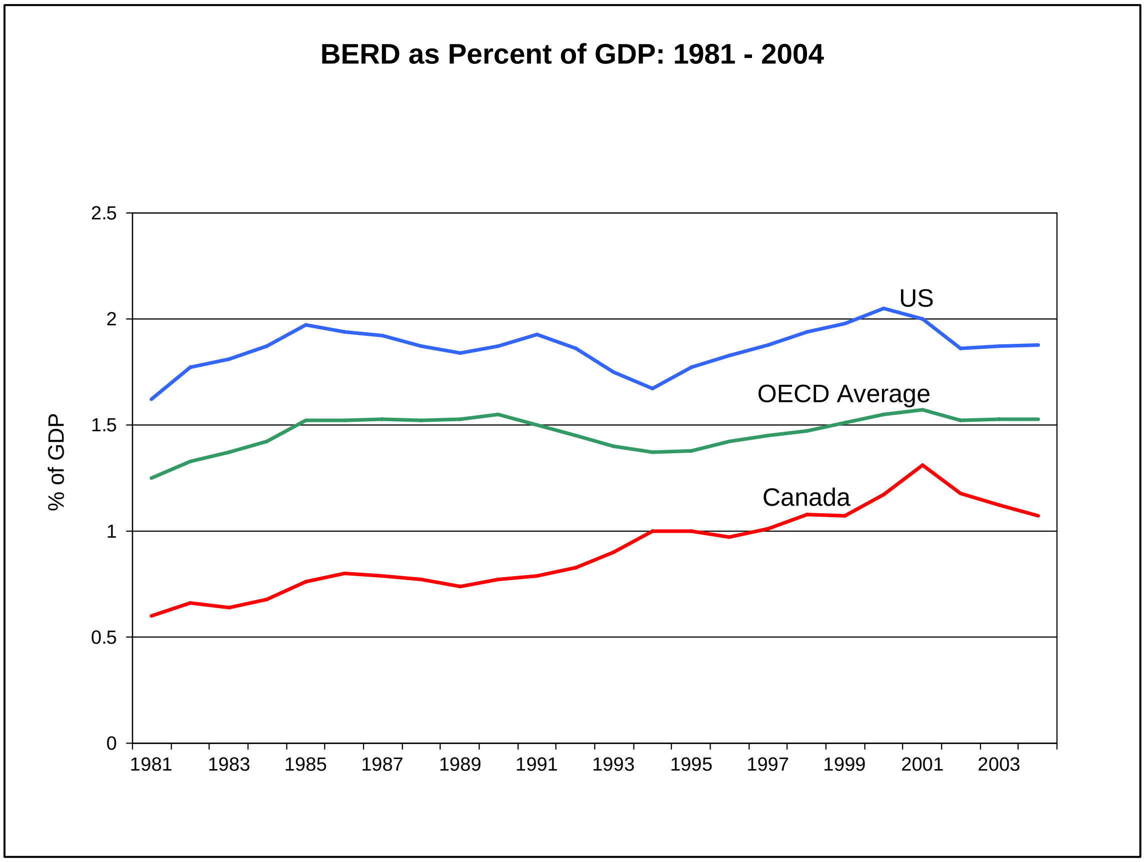
Source: Statistics Canada Cat No. F88-204-XIE 2004/2005

Business expenditure on R&D (BERD) is believed to be more closely linked to commercial innovation outcomes than R&D spending overall. Canada's BERD ratio increased much faster than the OECD average for two decades until 2001. The collapse of the "dotcom bubble" depressed R&D investment, notably in the telecom sector where Canada has particular strength. And since 2001, Canada's ratio of BERD to GDP has been declining and is now only about half the US ratio (**Figure 4.4**).

The question is "why does Canada persistently lag well behind the OECD average in business R&D investment?" Part of the reason lies in this country's industrial structure. Canada's economy is relatively specialized in industries (e.g., related to resource extraction and processing) that do comparatively little measured R&D regardless of the country in which they are located.

Figure 4.4

Business Enterprise Expenditure on Research and Development Relative to Gross Domestic Product



Source: OECD Main Science and Technology Indicators, 2006-1

Structure is only part of the answer, however. There are also some important sectors in Canada for which R&D intensity (i.e., R&D spending as a percent of revenue) is much lower than international norms. The Canadian auto industry, for example, does little measured R&D, relying instead on foreign R&D embodied in state-of-the-art factory equipment. And for reasons that appear to be less well understood, Canada's (commercial) service sector has a significantly lower R&D intensity than its US counterpart, though not less than the G-7 average. Since services and the auto sector together account for more than two-thirds of business value-added in Canada, our relatively low R&D intensity in these areas explains a significant part of the Canada–US gap in business R&D spending. Partially offsetting this are several Canadian high-tech sectors — notably telecom equipment, office and computing machinery, and pharmaceuticals — for which R&D intensity on average *exceeds* both the US and G-7 levels (Industry Canada, 2006[a], p. 11–14).

The most significant complements of R&D spending are advanced skills and investment in technologically sophisticated capital equipment.

Considering first Canada's international standing with respect to skills, the data tabulated in **Figure 4.5** demonstrate the exceptionally strong general educational attainment of our workforce. In 2003, 44 percent of the population aged 25–64 had post-secondary education — the highest proportion in the OECD. (Canada's proportion of university graduates is slightly less than that of the US, but this is more than offset by our higher proportion of community college graduates.)

A different picture emerges if we focus on specialization in science and engineering. In Canada, these fields comprise only about one-fifth of new degrees, compared with roughly 30 percent in most European countries, but still somewhat higher than the US proportion of just over 15 percent.[1] Canada exhibits a particularly low ratio of PhDs in science and engineering subjects — 0.3 percent of total graduates in 2002 — compared with 0.45 percent in the US and more than one per cent in Sweden and Switzerland. The final column in **Figure 4.5** — business researchers per 1,000 employed in the economy — is strongly correlated with business spending on R&D. Predictably, Canada lags well behind leaders such as Finland, the US, Japan and Sweden, though not behind the UK, France and Germany.

The message in these high-level data is that Canada is *comparatively* well-endowed with the skills needed in an advanced economy, even though there will always be particular gaps and shortages. On the other hand, the relatively low level of specialization in science and engineering appears to reflect the particular nature of Canada's economy. In this country, a comparatively low level of R&D-intensive economic activity — due partly to industrial structure and partly to firm behaviour in certain sectors — translates into relatively less *demand* in Canada than in many OECD countries for highly specialized S&T skills. We emphasize that this conclusion applies to the economy as a whole, and on average. There will be many specific instances where *supply* constraints are real and demand for advanced skills is unmet.

Looking forward, there is reason to be optimistic that Canada's schools are preparing the next generation with the basic skills of literacy and numeracy needed to function effectively. Canada's 15-year olds are among the world's best performers in international tests of mathematics, reading and knowledge of science (**Box 6.5** in Chapter 6).

[1] By selecting only science and engineering graduates, the OECD skills analysis ignores industry research effort that is unrelated to technology but highly related to innovation — i.e., market research, economic research, human factors research, psychological research, etc.

Figure 4.5

An International Perspective on Highly Trained People

	Persons with post-secondary education as % of 25–64 year olds (2003)[1]		**Share of science and engineering (S&E) degrees as % of new degrees (2003)[2]**		**PhDs in S&E as a share of graduates (2002)[3]**		**Business researchers per 1,000 employment[4]**	
	Percent	Rank	Percent	Rank	Percent	Rank	Percent	Rank
Canada	**44.0**	**1**	**20.4**	**10**	**0.30**	**9**	**4.4**	**5**
United States	38.4	2	15.7	11	0.45	8	7.5	2
Japan	37.4	3	25.9	7	0.27	10	7.0	3
Sweden	33.4	4	**31.0**	**1**	**1.37**	**1**	6.4	4
Finland	33.3	5	29.0	3	0.70	6	**10.0**	**1**
Australia	31.3	6	21.6	9	0.52	7	2.0	10
United Kingdom	28.0	7	28.2	6	0.81	3	3.2	9
Switzerland	27.0	8	28.5	5	1.06	2	4.0	6
Germany	24.0	9	30.9	2	0.73	5	4.0	7
France	23.4	10	28.7	4	0.80	4	3.8	8
Italy	10.1	11	22.9	8	0.20	11	1.2	11

Notes: 1: Italy 2002; 2: Canada 2000; 3: Canada 2000, Finland, France and Italy 2001; 4: UK 1998, US 1999, Switzerland 2000, Sweden 2001, Canada, Australia, France and Italy 2002; others 2003.

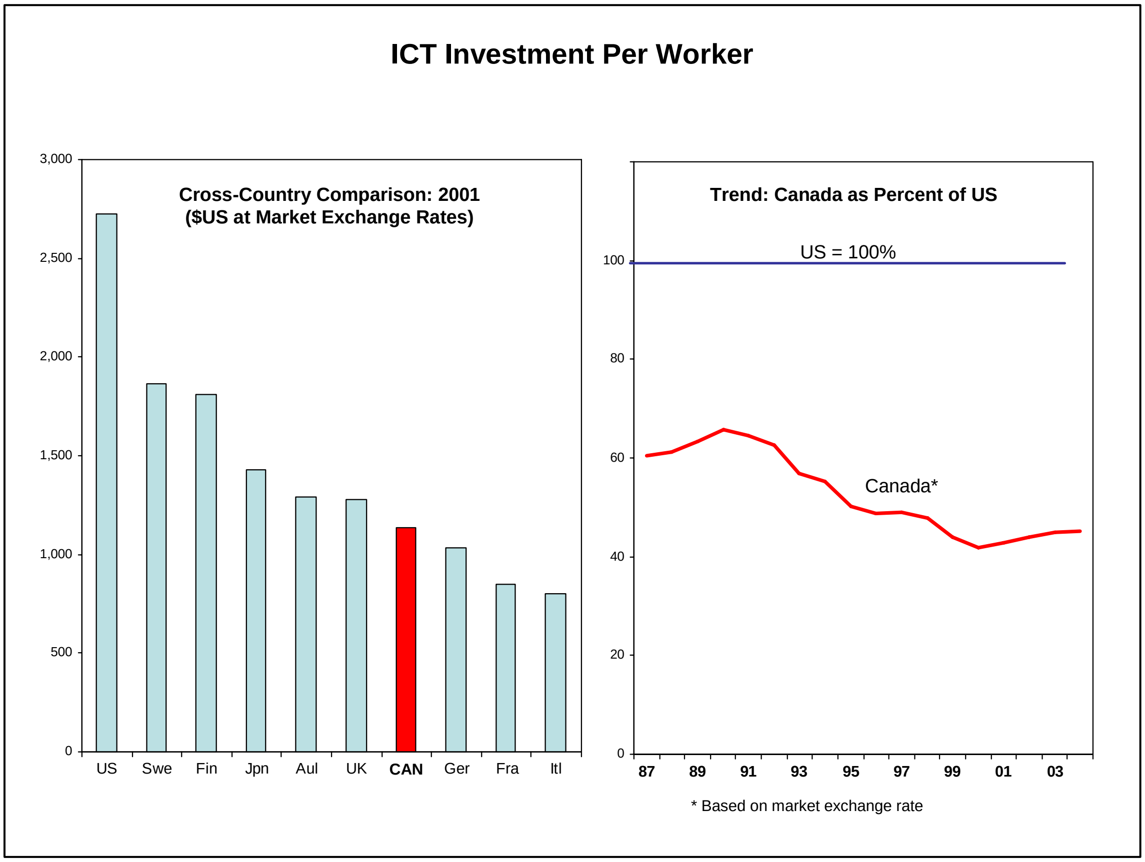
Source: Education at a Glance: OECD Indicators, 2005 edition; OECD Science, Technology and Industry Scoreboard 2005

Capital investment, particularly in advanced machinery and equipment (M&E), is a fundamental element of a country's S&T strength. This is because a significant proportion of technological progress becomes useful for people only when it is embodied in capital equipment — e.g., ranging from computers and medical imaging devices to aircraft and power plants.

Canadian businesses invest less overall in M&E (as a percent of GDP) than most of their OECD counterparts, but at a level comparable with the US. Of particular relevance is investment per worker in information and communications technology (ICT). Canada's comparatively low level — ranking well behind the US, Australia, Finland and Sweden according to 2002 data — is noteworthy since ICT is the premier enabling technology of our era (Sharpe and Guilbaud, 2005) (**Figure 4.6**).

Figure 4.6

Investment in Information and Communications Technology per Worker Compared with Selected OECD Countries and Trend (1987–2003)



Source: Centre for the Study of Living Standards based on data from Statistics Canada and the US Bureau of Labour Statistics.

Output Indicators

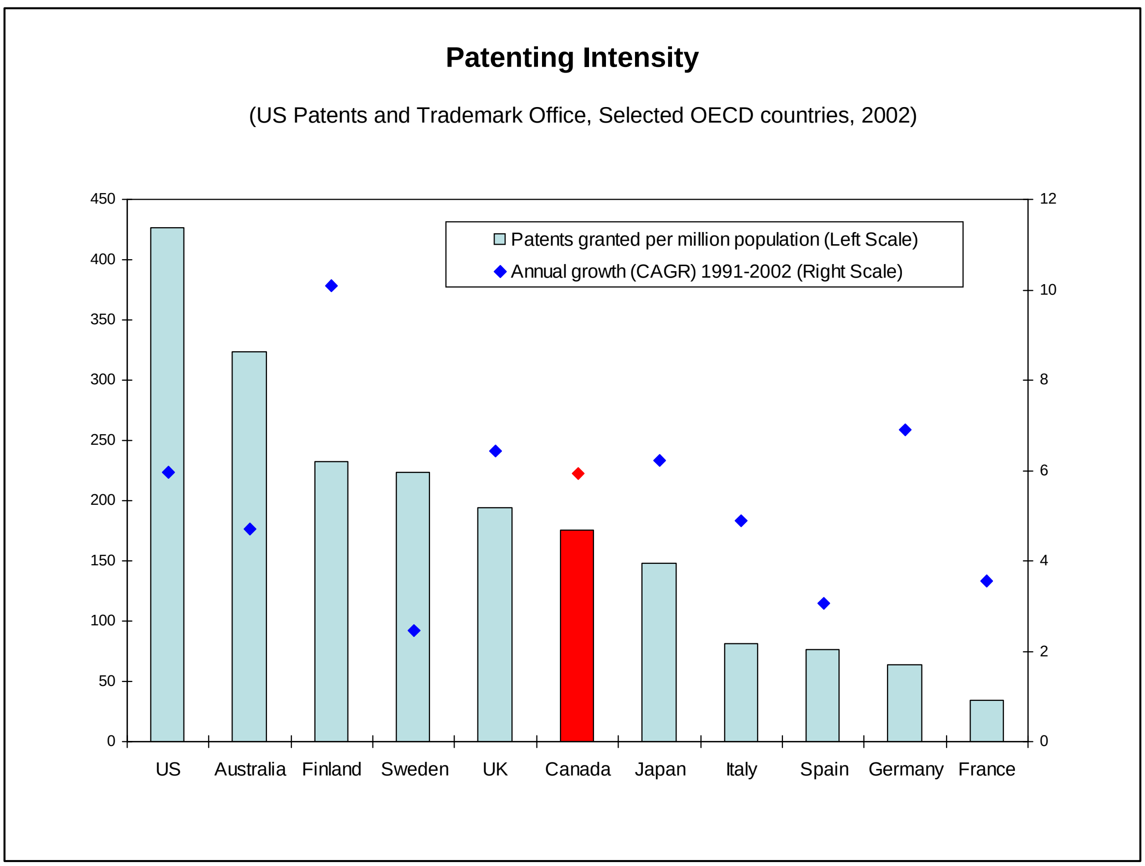
The S&T-related outputs of national innovation systems are measured much less comprehensively than the inputs. Studies typically report outputs such as (a) the volume and quality of scientific publications as a rough measure of research productivity; (b) the rate of patent generation as one proxy for commercial innovation; and (c) the rate of formation of tech-based start-up companies as a rough gauge of entrepreneurial vitality and research commercialization potential.

Detailed bibliometric and technometric data are presented in **Chapter 5**. Suffice it to say here that between 1997 and 2001, Canada ranked sixth in the world in terms of publications in science and engineering, accounting for 4.6 percent of the global total — the US produced 35 percent (Archambault and Gingras, 2004). Within the G-7, we ranked second to the UK in total publications per capita, and fourth in publications per university researcher (behind the UK, US and Italy.) Between 2001 and 2004, the volume of Canada's publications has increased more slowly than the world average — 4.7 percent versus 6.4 percent globally — as the output of large emerging economies has increased. Canada now ranks eighth overall in total publication volume, having given up two places to Italy and China since 2001 (Archambault and Gingras, 2004).

A standard, though imperfect, indicator of industrial innovation output is *patenting intensity* — i.e., the number of patents per capita to better normalize for inter-country comparison (**Figure 4.7**). Canada ranks well below the OECD average, and even in resource-based industries, Canada's patenting intensity lags behind that of the US (Industry Canada, 2006[a]). Further detail can found in **Chapter 5**.

Figure 4.7

Patents Granted Relative to Population Size for Selected OECD Countries



Source: OECD, Patent Database, December 2005

International comparisons of firm-level dynamics — e.g., rate of new business formation, proportion of firms claiming to innovate, and fraction of sales due to new/improved products — are limited. Based on the cross-national data available, it appears that Canada generates an unusually high number of start-ups — about 15 percent of the number of existing businesses annually — compared with 10 percent in the US and typically less in Europe. There is a correspondingly high business 'death rate' in this country, reflecting the fact that the *net* growth of new businesses is very modest both here and elsewhere (OECD, 2004 and Statistics Canada, 2003).

Innovation "density" — i.e., the fraction of firms that report developing new/improved products and processes — is measured by periodic surveys in Canada and Europe. These surveys suggest that Canadian firms have a comparatively high propensity to innovate but do not appear, on average, to generate a higher percentage of sales from new products than European counterparts (Industry Canada, 2006[a]).

The message in these output data is that, by international standards, Canada is strong in the production of scientific knowledge (journal publications), relatively weak in commercially tangible innovation (patents) and quite dynamic in the early stages of commercialization of inventions arising out of research.

As we move from S&T inputs, to outputs, to ultimate outcomes, the thread of cause and effect becomes progressively more tenuous and difficult to trace. This is because many interrelated factors, in addition to S&T, combine to produce important macro-outcomes such as productivity growth or high-tech export competitiveness. There are also long and uncertain time lags between key inputs — e.g., spending on basic research or training a PhD in bioinformatics — and the appearance of some desired outcome such as a sustainable Canadian-based business or treatment of a previously intractable disease.

By international standards, Canada's overall economic outcomes continue to be very good, though it is difficult to say how much is due to an extended and exceptionally favourable macroeconomic environment and, more recently, to a boom in commodity prices. The sustainability of these conditions is not assured.

Looking forward — as Canada's population matures and new competitors emerge in virtually every field — it can be said that innovation and the productivity growth that innovation generates are the only assured and sustainable ways to keep Canada's prosperity and quality of life abreast of its peers.

> Canada is currently enjoying the benefits of a commodity boom. However, this will not last forever. And when the commodity price cycle dips, when demographics begins to dramatically reduce the ratio of working people to retirees, and when the impacts of China's and India's massive investments in innovation are felt in the international trading system, Canada will face declining prosperity - unless it immediately begins turning its focus and resources to S&T.
> *Representative of a Provincial Government**
>
> *Here and elsewhere in the report we include quotations from comments made by participants in the online survey undertaken for this study.

5. CANADA'S STRENGTHS IN RESEARCH AND TECHNOLOGY APPLICATION

In this chapter, we use the multi-lens approach to assess Canada's strengths in research and in the application of technology. The existing literature on this topic is sparse. Although a number of studies address particular aspects — and these are drawn upon throughout the report — we have found no source that deals with the question in a detailed and comprehensive way.[2] Consequently, the analysis in this chapter is based on three of the four lenses — survey, metrics and the view from abroad, and primarily on the first two.

The principal innovation in the work underlying this report was the creation of a web-based survey of informed opinion on S&T in Canada. The questionnaire will be found in **Appendix 3**. The survey was administered by EKOS Research, a major opinion research firm. Access to the survey was distributed by the Council of Canadian Academies through a network of contacts in universities, governments, the private sector and in the Council's member Academies. The target respondents were senior people considered to be well-informed on S&T in Canada, including those with both broad and highly specialized backgrounds (**Figure 5.1**). We estimate that the link to the survey website was distributed to roughly 5,000 individuals from whom 1,529 completions were received over a three-week period between July 17 and August 8, 2006. The results of the survey are presented in this chapter and the next two.

The most valuable attributes of the survey are that (a) it reflects a holistic view — not just a single element of strength but the integrated strength of a discipline or field of technology overall; and (b) it represents the views of S&T stakeholders themselves — not the views or the interpretations of the committee or of the Council. The committee believes, therefore, that the survey findings are an important and credible contribution to the overall picture. It is through this lens that we are presenting a fresh perspective on Canada's S&T strengths.

The survey findings are also compelling because of the sample size. We are able to report the views of a significant fraction of Canada's senior S&T community, well distributed throughout the country (**Figure 5.1**). The respondents are people with extensive experience and knowledge, and it is reasonable to assume that their perceptions take into account multiple factors and dimensions of strength — the kind of complex interrelationships that are not captured by more precisely defined quantitative indicators. But all individuals, experts included, have biases and blind spots. It was therefore necessary to sample a substantial and diverse body of opinion so that we could use statistical aggregation to capture the *wisdom of the crowd* (**Box 5.1**).

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[2] Three main sources have been identified as relevant to benchmark Canada's S&T strengths in a global context. Highlights of Sir David King's paper, *The Scientific Impact of Nations* (2004), are summarized in **Box 5.2** in the section of this chapter dealing with bibliometrics. The report by the Conference Board, *The World and Canada – Trends Reshaping Our Future*, contains a wealth of useful performance indicators but does not address, except incidentally, the specific question of Canada's S&T strengths. Finally, the work of the OECD contains a great deal of relevant information, which we draw upon elsewhere in the report, but this does not include a focused assessment of Canada's S&T strengths.

Figure 5.1(a)

Number of Survey Respondents by Affiliation

Affiliation	**Respondents Number**	**Percent**
Academies		
• Fellow of Academy of Arts and Humanities	54	3.5
• Fellow of Academy of Social Sciences	55	3.5
• Fellow of Academy of Science	256	16.0
• Fellow of the Canadian Academy of Engineering	61	4.0
• Fellow of the Canadian Academy of Health Sciences	84	5.5
Universities		
• University or College Administrator (President, VP Research)	95	6.2
• Canada Research Chair	311	20.3
• Networks of Centres of Excellence	160	10.5
• Canadian Institute for Advanced Research Program Member	49	3.2
• Other Faculty from a University or College	547	35.9
Business		
• Senior Employee of a Business Corporation		
- Small business (under 20 full-time employees)	61	4.0
- Medium business (20–99 employees)	22	1.4
- Medium–Large business (100–500 employees)	22	1.4
- Large business (over 500 employees)	65	4.3
• Senior Representative of an Industry Association	27	1.8
• Recipient of technology development funding[1]	137	9.0
• Officer of IRAP or Technology Partnerships Canada[1]	102	6.7
Government		
• Senior Executive in Federal Government	75	4.9
• Representative of a Provincial Government	27	1.8
• Other Federal Government (or Affiliate) Employee	96	6.3
• Current Member of a Federal or Provincial S&T Advisory Board	124	8.1
Other		
• Senior Representative of a "Think Tank"	18	1.2
• Member of the international development community	38	2.5
• Member of S&T-related Non-Governmental Organizations	76	5.0
• Shad Valley Alumnus	73	4.8
• Other	132	8.6
• No affiliation provided	35	2.3
Total	**1,529**[2]	**N/A**

[1] For purposes of tabulation by affiliation, we include in the "Business" category those government officials directly involved in providing assistance to private sector firms We also include those (some of whom are in universities) who received government funding for development of technology that potentially has commercial application.

[2]Note that the sum of respondent affiliations exceeds the number of respondents since many respondents have multiple affiliations.

Figure 5.1(b)

Distribution of Survey Respondents by Location

	Distribution	
Province or Location	**% Population**	**% Respondents**
British Columbia	13.2	12
Alberta	10.1	10
Saskatchewan	3.1	2
Manitoba	3.7	3
Ontario	38.9	44
Quebec	23.6	20
Nova Scotia	2.9	4
New Brunswick	2.3	2
Prince Edward Island	0.4	*
Newfoundland & Labrador	1.6	1
Yukon	0.1	*
Northwest Territories	0.1	*
Nunavut	0.1	*
Canada Total %	100	100
Canada Total (Number)	32.3 million	1,439
Outside Canada (Number)		69
No location provided (Number)		21
Total Number	**32.3 million**	**1,529**

* There were seven responses from PEI, four from the Yukon, none from the Northwest Territories and one from Nunavut.

Figure 5.1(c)

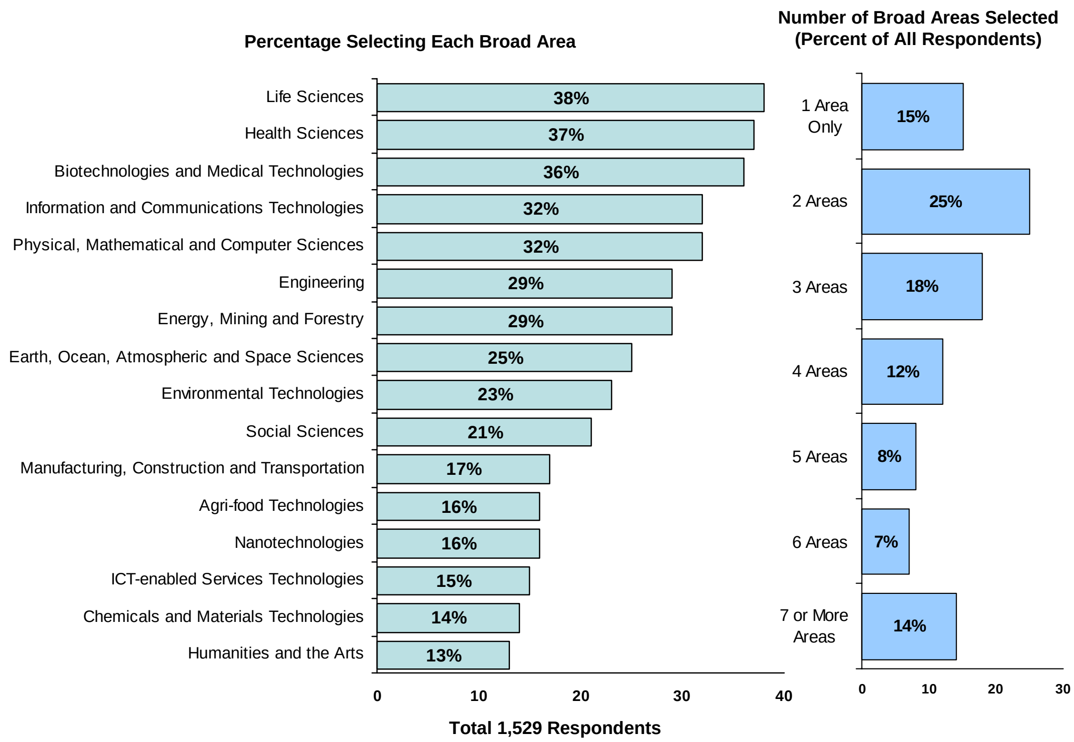
Distribution of Survey Respondents by Age

	Number	**Percent**
Under 35	146	9.6
35–44	226	14.8
45–54	467	30.5
55 or older	665	43.5
No age provided	25	1.6
Total	**1,529**	**100**

Box 5.1

Some Statistical Features of the Survey

We summarize several noteworthy features of the survey, beginning with the proportions of the 1,529 respondents choosing the various "gateways" to broad areas of research and technology (see **Appendix 3**).



- 40 percent of respondents provided ratings in only one or two of the 16 broad areas. Younger respondents tended to rate in more areas, as did those with government and business affiliation. Academics over 55 tended to be the most "specialized".
- The broad areas were broken down into 197 sub-areas. The number of responses in the sub-areas ranged from just under 100 to a maximum of 474 (Genetics, Genomics & Proteomics). The median number was 220.
- The strength ratings on the seven-point scale, when accumulated for all 197 sub-areas, were distributed as follows: 7 (6 percent), 6 (20 percent), 5 (28 percent), 4 (28 percent), 3 (12 percent), 2 (4 percent) and 1 (1percent). The weighted average strength rating was 4.64 — i.e., stronger than the mid-point of the seven-point scale.
- Interim results were presented by EKOS as the survey progressed — first with 672 responses, then with 1,081 and finally with 1,529. There was little change in the rating of sub-areas between 672 and 1,081 responses, and virtually none between 1,081 and the close of the survey. (The same was true for the other questions in the survey that are covered in the following chapters.) It is therefore very unlikely that further sampling would have changed the pattern of responses though it would permit more reliable cross-tabulations of responses in the various sub-areas.

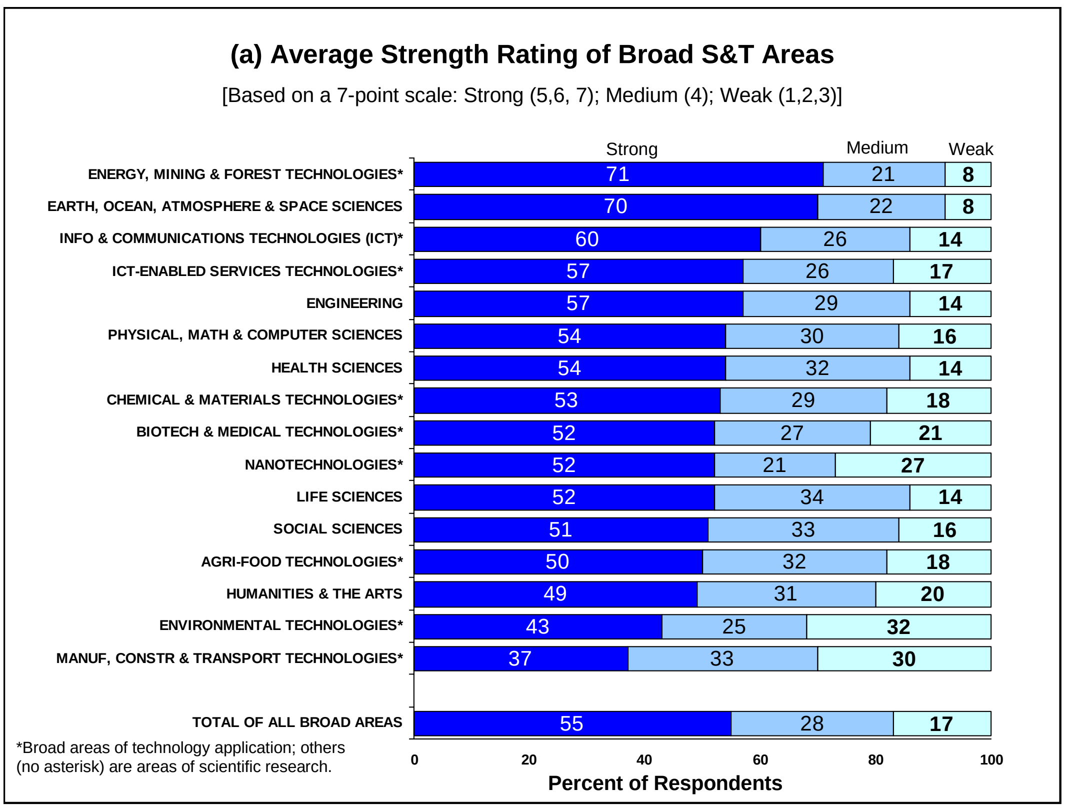
The Survey Perspective on Canada's S&T Strengths

Respondents were asked to rate Canada's standing in 16 major areas (seven dealing primarily with research domains and nine with areas of technology application), each of which was broken down into much more specific sub-areas, with 197 in all (**Appendix 3**).[3]

Figures 5.2(a) and **(b)** display the top-level results averaged over all sub-areas in each of the 16 major areas surveyed. Respondents were asked to give their informed opinion of Canada's strength in a particular sub-area — e.g., Geology, Condensed Matter Physics, Pulp and Paper Technologies — relative to other economically advanced countries on a seven-point scale (with 7 highest). In **Figure 5.2(a)** we describe a rating of 7, 6 or 5 as *strong* and a rating of 1, 2 or 3 as *weak*. We see that the sub-areas of Energy, Mining and Forestry had an average strong rating of 71 percent, whereas Manufacturing and Construction Technology was at the opposite end of the scale with a strong rating of only 37 percent. The other major research and technology areas are interleaved, more or less uniformly, between these two extremes.

Figure 5.2

Average Strength and Trend Ratings of Broad S&T Areas



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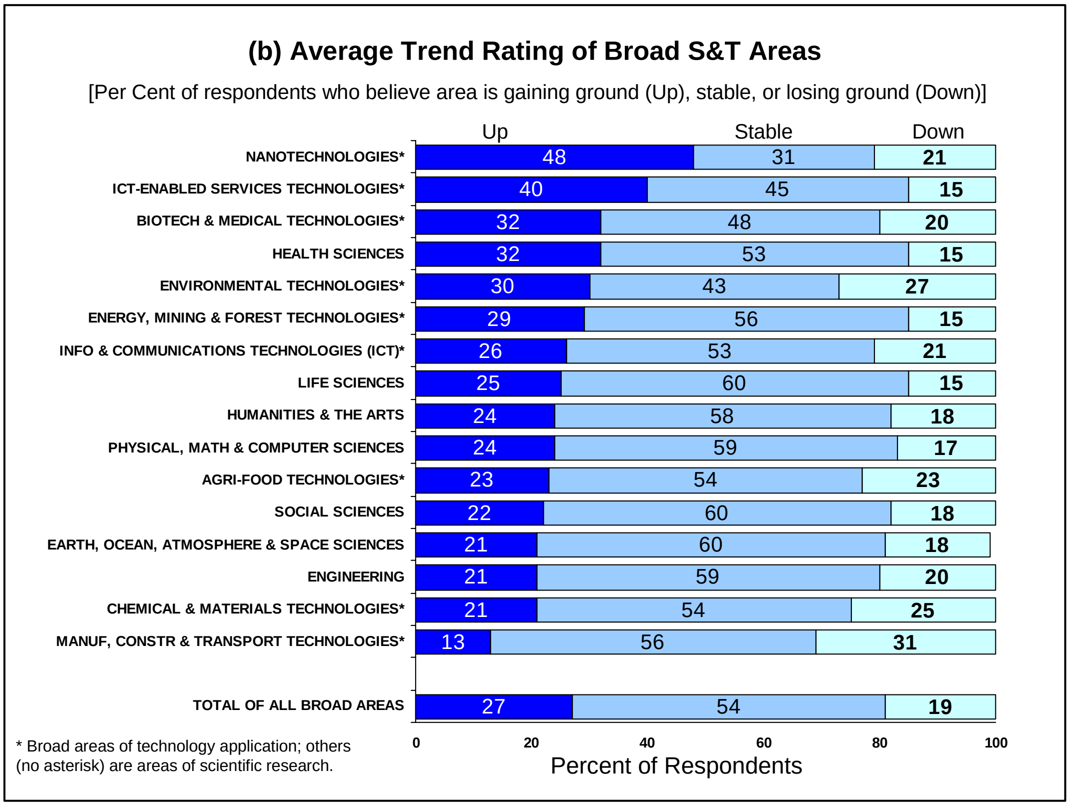
[3] Respondents were asked to provide ratings only in those areas for which they had an informed opinion. They were not asked to specify their own fields of expertise, only to indicate their affiliations (**Figure 5.1**).

Figure 5.2(b) is a rough proxy for the overall trend perceived in each broad area. The bars represent the average of the percentage of respondents who believed the sub-areas with each broad area are gaining ground globally, losing ground or stable. (The component sub-areas exhibit a wide range of trends, as will be outlined below.) At this level of aggregation, we see that growth perception is most bullish in the area of Nanotechnologies, with almost 50 percent of the respondents believing that Canada has been gaining ground globally, followed by ICT-enabled Services Technologies (40 percent). Of course, many respondents believe that we are losing ground, so it is the difference between the proportion who see an uptrend and those who see a downtrend that is the best indicator of perceived net momentum.



Results at the level of aggregation in **Figure 5.2** are of limited value because each broad area includes a multitude of sub-areas whose status may diverge sharply from the sector average. The survey results for all 197 sub-areas are tabulated in **Appendix 4** and summarized graphically in a sequence of "Strength vs. Trend" charts later in this chapter (**Figure 5.15**).

Figure 5.3 is a core result of the survey and presents the ratings of all respondents for the 50 sub-areas of research and technology application that received the highest "strength ratings" — defined as the weighted average, or mean value, of respondents' ratings on the seven-point scale. The sub-areas in the table are in descending order of strength, though small differences should *not* be regarded as being of significance. Each line of the table also includes the percentage who believe the particular sub-area is strong (ratings 5, 6 and 7) or weak (ratings 1, 2 and 3), as well as the percentage who believe it is gaining ground globally (up) and losing ground (down). The final column identifies four *clusters* that emerge from the survey ranking as macro-areas of particular Canadian strength. These are:

- Sciences and technologies related to *Natural Resources;*
- *Information and Communications Technologies* and areas of scientific research related directly to these technologies;
- *Health and Related Life Sciences and Technologies*; and
- *Environmental Sciences and Technologies.*

Figure 5.3

Top 50 Sub-Areas in Order of Strength (Weighted Average of Seven-point Ratings)

	Sub-Areas	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
1	Oilsands and Related*	316	6.41	97	1	77	2	Natural Resources
2	Conventional Oil & Gas Exploration/Extraction*	305	5.66	84	1	43	3	Natural Resources
3	Hydroelectric Power*	291	5.56	79	2	22	9	Natural Resources
4	Resource Production in Cold Climates*	254	5.48	86	5	36	9	Natural Resources
5	Geology	234	5.44	81	4	21	18	Natural Resources
6	Mining Exploration*	249	5.35	77	3	24	8	Natural Resources
7	Mineral Extraction & Primary Processing*	237	5.34	77	3	23	10	Natural Resources
8	Aluminium Production*	120	5.34	76	3	34	12	Natural Resources
9	Physical Geography, Remote Sensing	247	5.32	80	4	30	14	Nat Res/Envir
10	Petroleum / Polymer Eng	244	5.24	78	7	46	9	Natural Resources
11	Genetics (Medical)	381	5.24	75	6	42	10	Health & Related
12	Geochemistry & Geochronology	170	5.23	74	5	21	16	Nat Res/Envir
13	Mining & Mineral Processing	218	5.22	78	4	30	12	Natural Resources
14	Offshore Oil and Gas*	287	5.21	74	6	35	8	Natural Resources
15	Comms & Network Eng	233	5.20	76	7	27	19	ICT
16	New Media, Multimedia, Animation, Gaming*	169	5.19	77	10	59	8	ICT
17	Geophysics & Seismology	198	5.19	71	8	20	14	Natural Resources
18	Genetics, Genomics & Proteomics	474	5.18	74	9	51	12	Health & Related
19	Hydrology	208	5.17	75	4	25	14	Environment
20	Telecom Equipment*	313	5.17	75	9	25	32	ICT
21	Broadband Networks*	302	5.16	71	8	31	16	ICT
22	Oceanography	241	5.15	73	7	25	27	Environment
23	Cancer Research	441	5.14	73	6	44	9	Health & Related
24	Pipelines*	260	5.12	68	4	22	4	Natural Resources
25	Climate Science	265	5.11	72	7	26	19	Environment

	Sub-Areas	Numb. Resps.	Mean[1]	Percentage of Respondents Strong[2]	Weak[3]	Up[4]	Down[5]	Cluster
26	Wireless Networks*	330	5.09	72	11	38	16	ICT
27	Cold Climate Construction*	217	5.08	75	11	28	11	
28	Optics, Laser Physics	188	5.05	68	11	38	13	ICT
29	Astronomy, Astrophysics, Cosmology	207	5.05	67	12	25	13	
30	Neurobiology / Neurosciences	331	5.02	67	11	39	14	Health & Related
31	Computer Software Development & Theory	258	5.00	68	9	27	16	ICT
32	Telecom Services*	277	5.00	68	10	25	18	ICT
33	Aerospace Products and Parts*	184	4.98	66	11	22	20	
34	Electricity Distribution*	246	4.96	64	11	19	18	
35	Forestry Engineering	208	4.95	67	11	23	18	Natural Resources
36	Genomic and Proteomic Technologies*	408	4.94	67	12	46	15	Health & Related
37	Circulatory & Respiratory	337	4.93	63	6	27	10	Health & Related
38	Infection & Immunity	384	4.91	65	10	43	13	Health & Related
39	Artificial Intelligence, Robotics	262	4.91	64	15	31	18	ICT
40	Electronic & Photonic Eng	240	4.90	64	11	27	17	ICT
41	Meteorology	208	4.90	58	5	12	12	Environment
42	Visual & Creative Arts	126	4.89	67	16	49	12	
43	Neuroscience, Mental Health, Addiction	340	4.89	64	12	36	14	Health & Related
44	Quantum Informatics	167	4.89	60	17	51	12	ICT
45	Electrical Engineering	231	4.89	58	9	17	20	
46	Satellite, Systems, Services*	270	4.88	62	14	23	20	ICT
47	Fuel Cells & Hydrogen*	241	4.87	65	18	32	24	Environment
48	Geography; Urban & Environmental Planning	165	4.85	67	13	31	21	Environment
49	Computer Databases, Information Systems	234	4.85	63	12	27	13	ICT
50	Pulp & Paper*	129	4.85	61	12	10	36	Natural Resources

* Sub-areas of technology application; others (without asterisk) are sub-areas of scientific research.
[1] Mean = Weighted average of seven-point scale ratings
[2] Strong = Percentage of survey respondents rating the sub-area 5, 6, 7
[3] Weak = Percentage rating the sub-area 1, 2, 3
[4] Up = Percentage rating the sub-area as “Gaining Ground”
[5] Down = Percentage rating the sub-area as “Losing Ground”

Of the top 50 sub-areas rated by strength, all but six (**Figure 5.4**) fall into one of the four identified clusters. Among these, Cold Climate Construction and Electricity Distribution are closely related to Canada's natural resources and environmental technologies, while Visual and Creative Arts are increasingly associated with digital media and thus indirectly related to ICT.

Figure 5.4

"Other" Sub-Areas in the Top 50

		Percentage of Respondents			
Sub-Areas	**Mean**	**Strong**	**Weak**	**Up**	**Down**
Cold Climate Construction	5.08	75	11	28	11
Astronomy, Astrophysics, Cosmology	5.05	67	12	25	13
Aerospace Products and Parts	4.98	66	11	22	20
Electricity Distribution	4.96	64	11	19	18
Visual & Creative Arts	4.89	67	16	49	12
Electrical Engineering	4.89	58	9	17	20

It might be suspected that the top 50 sub-areas would reflect the particular perspectives and biases of various major sub-groups among respondents. We therefore analyzed all responses according to the (self-identified) affiliation of respondents, specifically (1) those affiliated with universities (as faculty or administration); (2) those affiliated with business (directly as employees or, for example, as field officers of NRC's Industrial Research Assistance Program); and (3) those affiliated with the federal or provincial governments.

Figure 5.5 shows that the cluster structure of the top 50 rankings is remarkably consistent across all three major affiliations. While the top-ranked sub-areas were of course not identical for each affiliation, the prominent representation of the four clusters — Natural Resources, ICT, Health & Related Life Sciences, and Environmental S&T — was preserved. For example, the top 50 for business-affiliated respondents included several sub-areas not in the overall top 50, and vice versa (**Figure 5.6**). Similar inclusion–exclusion lists can be put together for other affiliations, but they do not change the overall pattern of four-cluster strength.

Figure 5.5

Distribution of Top 50 Sub-areas by Cluster (Number of Sub-areas in Top 50)

		Affiliation of Respondents		
Cluster	**All**	**University**	**Business**	**Government**
Natural Resources	16	16	17	16
ICT	13	12	12	12
Health & Related	8	9	5	7
Environmental	7	6	7	6
Other	6	7	9	9
Total	**50**	**50**	**50**	**50**

Figure 5.6

Comparing the Top 50 – Business-Affiliated vs. All Respondents
Relative to the total sample Top 50, the business-affiliated Top 50:

Excluded	Strength Rating Business	Strength Rating All	Included	Strength Rating Business	Strength Rating All
• Astrophysics, Cosmology	4.59	5.05	• Food Safety Assurance Tech*	5.13	4.80
• Neurobiol/Neurosciences	4.78	5.02	• Software Development*	4.91	4.82
• Aerospace Products & Parts*	4.69	4.98	• Hydrocarbon Refining*	4.88	4.77
• Genomic & Proteomic Technology*	4.78	4.94	• Library & Archive Sciences	4.87	4.83
• Infection & Immunity	4.70	4.91	• ICT Systems Eng*	4.85	4.72
• Artificial Intell, Robotics	4.78	4.91	• Environ Eng	4.82	4.75
• Meteorology	4.71	4.90	• Biomedical Eng	4.82	4.69
• Quantum Informatics	4.36	4.89	• Timber harvesting Technologies*	4.81[1]	4.84
• Neurosciences, Mental Health, Addiction	4.75	4.89	• Building Construction*	4.81	4.80
• Satellite Systems, Services*	4.76	4.88	• Clean Water Tech*	4.80	4.66
• Pulp & Paper	4.78	4.85	• Nuclear Power*	4.80[1]	4.81
• Geography, Urban Planning	4.44	4.85	• Civil Engineering	4.79	4.77

*Sub-areas of technology application; others (no asterisk) are sub-areas of scientific research.

[1] The business-affiliates' strength rating dropped off more sharply than the all-respondent average. Thus an area could be in the business top 50, but not in the all-sample top 50, despite receiving a lower strength rating from business affiliates than from the total sample.

A further important perspective on overall strength is provided by **Figure 5.7**, which includes the 21 sub-areas that are in *both* the top 50 rated by strength *and* in the top 50 rated by net upward trend. These are *double winners* in the view of survey respondents — i.e., fields for which Canada already has considerable perceived strength and where prospects are believed to be improving significantly.

Figure 5.7

Sub-Areas of both High Strength and Strong Net Trend (in order of decreasing "up" minus "down" rating)

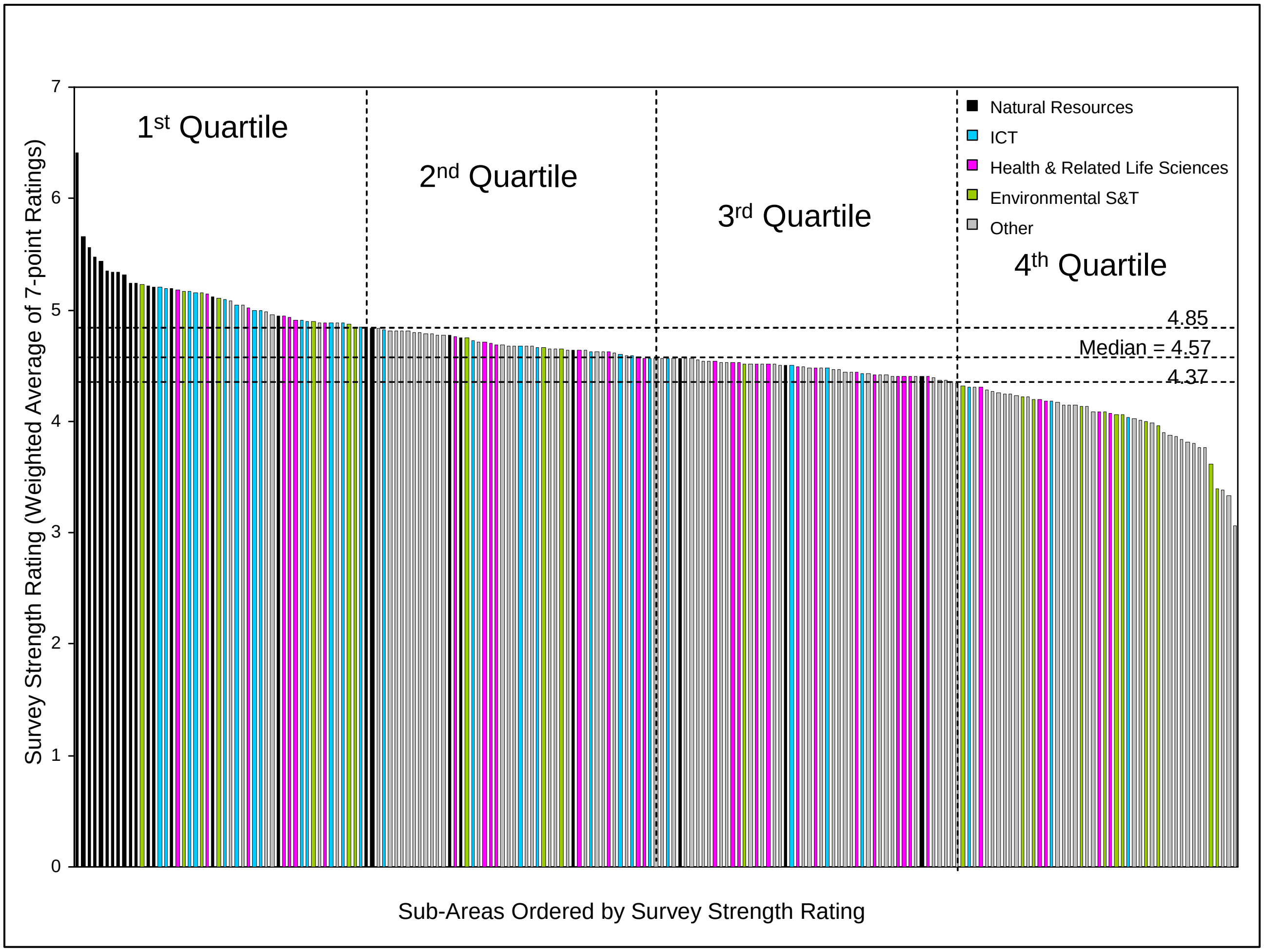
		Percentage of Respondents				
	Sub-Areas	**Up–Down**	**Up**	**Down**	**Mean**	**Cluster**
1	Oilsands and Related*	75	77	2	6.41	Natural Resources
2	New Media, Animation, Gaming*	51	59	8	5.19	ICT
3	Convent Oil & Gas Explor/Extract*	40	43	3	5.66	Natural Resources
4	Genetics, Genomics & Proteomics	39	51	12	5.18	Health & Related
5	Quantum Informatics	39	51	12	4.89	ICT
6	Petroleum / Polymer Engineering	37	46	9	5.24	Natural Resources
7	Visual & Creative Arts	37	49	12	4.89	
8	Cancer Research	36	44	8	5.14	Health & Related
9	Genetics (Medical)	32	42	10	5.24	Health & Related
10	Genomic and Proteomic Technols*	31	46	15	4.94	Health & Related
11	Infection & Immunity	30	43	13	4.91	Health & Related
12	Resource Prod in Cold Climates*	27	36	9	5.48	Natural Resources
13	Offshore Oil and Gas*	27	35	8	5.21	Natural Resources
14	Optics, Laser Physics	25	38	13	5.05	ICT
15	Neurobiology / Neurosciences	25	39	14	5.02	Health & Related
16	Aluminium Production*	22	34	12	5.34	Natural Resources
17	Wireless Networks*	22	38	16	5.09	ICT
18	Neurosci, Mental Health, Addiction	22	36	14	4.89	Health & Related
19	Mining & Mineral Processing	18	30	12	5.22	Natural Resources
20	Pipelines*	18	22	4	5.12	Natural Resources
21	Cold Climate Construction*	17	28	11	5.08	

* Sub-areas of technology application; others (without asterisk) are sub-areas of scientific research.

Although we have listed sub-areas in order of strength or net trend in the various tables, the committee emphasizes that the *precise* rank order is of no real significance in the sense that relatively small differences in rankings are not meaningful. This is so because of normal statistical variability and because of the qualitative nature of the judgments respondents were asked to make in the survey.

It is extremely important as well to bear in mind the overall distribution of the strength ratings of the 197 sub-areas. **Figure 5.8** shows that the distribution is relatively steep at both ends — i.e., the strength rating drops off rapidly in both the 1st and 4th quartiles but is relatively flat in the middle. To be more precise, fully half the set of sub-areas have strength ratings between 4.35 and 4.85 — a range of only 0.5 for the 100 sub-areas ranked between 50th and 150th — whereas the top 50 range from 6.41 to 4.85, and the last 50 from just over 4.35 to 3.06.

Figure: 5.8 All Sub-Areas Ordered by Strength Rating



Two important messages follow from these observations:

- It would be wrong for users of this report to focus on the rank-ordered set of all sub-areas (for example, in **Appendix 4**) as a "league table" and to conclude, for example, that sub-area A at rank 73 (in this case, Polymer Chemistry, with a strength rating of 4.69) is stronger than sub-area B at rank 87 (in this case, Biochemistry, with a strength rating of 4.64). The survey results can not support such a fine-grained conclusion.
- While there are some clear and important areas of Canadian strength and of relative weakness identified by the survey — and this can be seen plainly in **Figure 5.8** — the majority of sub-areas of S&T in Canada lie in a broad middle ground. These include many research fields and areas of technology application where Canada is not world-leading but that are nevertheless necessary to absorb, and adapt to Canadian needs, science and technology that is developed elsewhere. By definition, not everyone can be at the top, though all can aspire to be. The result of such aspiration is to maintain the pressure to continuously upgrade performance and thereby to ensure that Canadian S&T capabilities, overall, are globally competitive.

Composition of the Four Clusters of Strength

Natural Resources

The sub-areas comprising the Natural Resources cluster are summarized in **Figure 5.9**. It is no surprise that natural resources emerge as the strongest category overall. Natural resource-based activity contributes roughly 13 percent of Canada's GDP, provides direct employment to approximately a million people and accounts for nearly $150 billion in annual exports (NRCan, 2006). The exceptionally strong rating of many technologies in this cluster confirms that the application of technology in most components of Canada's natural resources sector is perceived to be world-class. And while certainly not all the technology is developed in Canada, the science supporting the resource sector is generally solid, elevating this area overall to among the world leaders.

Considering the detailed data in **Figure 5.9**, the committee acknowledges that, for the most part, it must be content to let the survey results speak for themselves. Neither time nor our own expertise permits the depth of interpretation that the detailed sub-area results require. Instead, we will simply point out in what follows items that we believe deserve closer attention and leave more comprehensive interpretation to the users of our report. In that spirit, we would make the following further observations.

> An area that is particularly important to Canada is the linkage between natural and social sciences on environmental and natural resource issues. Issues surrounding endangered species, land use, air and water quality, climate change and aboriginal people all require strong integration between natural and social sciences. As Canadian institutions around the environment and natural resources are somewhat unique - there is a need for Canadian research on these topics. *Canada Research Chair*

- Oilsands and Related Production was, by a wide margin, given the highest ranking (both as to strength and trend) of any item in the survey. And while Canada is virtually in a class by itself in this technology, there are still challenges to be overcome in developing more cost-efficient and environment-friendly extraction and upgrading methods. In short, there is a continuing need for extensive S&T.

- Several areas of relative weakness emerged from survey responses, notably in the forest-related technologies — e.g., sawmills, conservation methods, and even timber-harvesting technologies, and pulp and paper (where more of the respondents see Canada losing ground than gaining.) These weaknesses are noteworthy in view of the great economic importance of the forest sector.

Figure 5.9

The Natural Resources Cluster

		Percentage of Respondents			
	Mean	Strong	Weak	Up	Down
Sub-Areas — Scientific Research					
Geology	5.44	81	4	21	18
Physical Geography, Remote Sensing	5.32	80	4	30	14
Petroleum / Polymer Engineering	5.24	78	7	46	9
Geochem & Geochronology	5.23	74	5	21	16
Mining & Mineral Processing	5.22	78	4	30	12
Geophysics & Seismology	5.19	71	8	20	14
Forestry Engineering	4.95	67	11	23	18
Soil Science	4.81	58	8	8	15
Sub-Areas — Technology Application					
Oilsands and Related	6.41	97	1	77	2
Conventional Oil & Gas Explor/Extract	5.66	84	1	43	3
Hydroelectric Power	5.56	79	2	22	9
Resource Production in Cold Climates	5.48	86	5	36	9
Mining Exploration	5.35	77	3	24	8
Mineral Extraction Processing	5.34	77	3	23	10
Aluminium Production	5.34	76	3	34	12
Offshore Oil and Gas	5.21	74	6	35	8
Pipelines	5.12	68	4	22	4
Pulp & Paper	4.85	61	12	10	36
Timber Harvesting Technologies	4.84	64	15	14	22
Hydrocarbon Refining	4.77	53	9	18	11
Other Non-conventional Hydrocarbons	4.75	62	17	39	18
Forest Conservation Techs / Methods	4.64	58	19	24	34
Sawmills / Primary Processing	4.56	49	16	11	26
Fish Harvesting & Processing	4.50	52	20	14	31
Metal Products	4.41	43	18	15	27
"Clean" Hydrocarbons	4.13	44	36	33	34

Information & Communications Technologies

Early on, Canada's vast geography motivated a focus on communications innovation that led to pioneering developments in communications satellites and digital telecommunications technology. As the telecommunications industry developed worldwide, the creation of what was to become Nortel, as part of the Bell System in North America, gave Canada exceptional strength in telecommunications equipment manufacturing and research. This strength has been maintained as telecommunications fused with the computer industry, diffusing broad ICT skills and contributing to Canada's continued capacity in this field.

Survey respondents identified strong scientific disciplines supporting this technology tradition — e.g., optical and laser physics, and electronic and photonic engineering (**Figure 5.10**). Canada's continued strength has given rise to applications enabled by ICT, notably new media, and to a lesser degree, new e-services (health, government and learning) that are seen to be areas of considerable potential but still relatively underdeveloped in Canada. These can benefit greatly from this country's excellent broadband infrastructure.

Figure 5.10

The ICT Cluster

		Percentage of Respondents			
	Mean	Strong	Weak	Up	Down
Sub-Areas — Scientific Research					
Communications & Network Engineering	5.20	76	7	27	19
Optics, Laser Physics	5.05	68	11	38	13
Computer Software Dev't & Theory	5.00	68	9	27	16
Artificial Intelligence, Robotics	4.91	64	15	31	18
Electronic & Photonic Engineering	4.90	64	11	27	17
Quantum Informatics	4.89	60	17	51	12
Computer Databases, Info Systems	4.85	63	12	27	13
Computer Engineering	4.50	51	19	14	29
Computer Hardware	4.03	37	36	13	40
Sub-Areas — Technology Application					
New Media, Animation, Gaming	5.19	77	10	59	8
Telecom Equipment	5.17	75	9	25	32
Broadband Networks	5.16	71	8	31	16
Wireless Networks	5.09	72	11	38	16
Telecom Services (Design, Production)	5.00	68	10	25	18
Satellite-based Systems and Services	4.88	62	14	23	20
Software Development	4.82	58	12	26	17
ICT Systems Engineering	4.72	55	10	21	14
e-Learning	4.67	55	16	36	14
e-Government	4.66	57	18	37	15
Robotics, Automation & AI	4.63	57	19	29	22
Nanotechnology (Electronics, Photonics)	4.60	57	24	49	19
Data - Architecture, Processing, Security	4.59	49	15	25	12
Computer - Human Interfaces	4.57	53	18	24	14
ICT-enabled Commercial Services	4.56	51	15	33	11
e-Commerce	4.48	49	19	29	19
Microelectronics Components & Systems	4.43	47	21	20	32
e-Health	4.30	52	27	43	26
Computer & Related Equipment	4.18	37	29	14	31

The survey confirmed Canada's international high standing with respect to ICT infrastructure (e.g., wireless and broadband networks). However, the telecommunication equipment sector, while still a clear strength, is believed by a third of respondents to have been losing ground, perhaps reflecting the sharp pullback following the "dotcom" implosion.

The ICT field demonstrating the most promise in the view of respondents — i.e., having considerable existing strength and the highest net upward trend — is New Media, Multimedia, Animation and Gaming, where Canada is internationally recognized as a leader with a number of successful companies as well as a reputation for superb skills training.

Health & Related Life Sciences

The biomedical and life sciences and related technologies are regarded worldwide as areas of enormous scientific and technological opportunity and dynamism. Canada has recognized and adapted to this new opportunity through the creation of the Canadian Institutes of Health Research, Genome Canada and the inclusion of research hospitals explicitly in the mandate of the Canada Foundation for Innovation. Survey results indicate that there is considerable strength in Canada's health and related life sciences capabilities (**Figure 5.11**). Strong public support for health research has kept Canada among the world leaders.

The committee notes that behind every row of **Figure 5.11** (and the others that summarize the survey results) lies a complex and often subtle story. We hope that the data in this report will stimulate the various expert communities and other stakeholders to look behind the numbers and articulate the deeper messages they convey. For now, we would make three observations on the table.

- Clinical Research received a surprisingly low rating in the survey in view of bibliometric evidence (presented later) that suggests this field is one of Canada's strongest in terms of quality and quantity of research publications. The committee enquired as to possible reasons for the dissonance. One particularly knowledgeable observer offered the following explanation:

> Canada has an elite group of extraordinarily productive and influential clinical scientists but the number is relatively small and the population is aging. The career path of 'clinician–scientist' is perceived to be a very difficult struggle — difficulties securing salary dollars, uneven institutional support (often in conflict with patient care mandates), perceptions of systematic barriers (e.g., underdeveloped infrastructure to support clinical trials, multi-centre ethics review). All of this leads to pessimism about attracting the best of the best into a career as a clinician–scientist. Significant and very public investments in clinical research in other jurisdictions leave a perception of 'being left behind'. Both the UK and USA have made significant high profile investments in recent years. There is an enormous perception of 'lost' opportunity among Canadian clinical researchers — having invested in knowledge creation, there is a sense that the investment / talent / infrastructure required to take that knowledge to the next level — application to human health and disease — is weak. This perception is not Canada specific but is widely held internationally — hence the targeted investments elsewhere.

Figure 5.11

The Health & Related Life Sciences Cluster

	Mean	Percentage of Respondents			
		Strong	Weak	Up	Down
Sub-Areas — Scientific Research					
Genetics (Medical)	5.24	75	6	42	10
Genetics, Genomics & Proteomics	5.18	74	9	51	12
Cancer Research	5.14	73	6	44	9
Neurobiology / Neurosciences	5.02	67	11	39	14
Circulatory & Respiratory Health	4.93	63	6	27	10
Infection & Immunity	4.91	65	10	43	13
Neurosciences, Mental Health, Addiction	4.89	64	12	36	14
Cell Biology	4.71	55	11	22	14
Nutrition, Metabolism & Diabetes	4.70	57	13	35	10
Biomedical Engineering	4.69	62	15	39	14
Population & Public Health	4.62	56	16	33	16
Microbiology	4.58	49	13	19	13
Aging	4.57	53	14	32	13
Clinical Research	4.54	47	19	25	26
Human Development & Youth Health	4.53	47	14	25	14
Gender & Health	4.53	46	14	33	12
Systems Biology & Bioinformatics	4.51	54	21	40	23
Musculoskeletal Health & Arthritis	4.51	46	11	19	9
Aboriginal Health	4.49	54	22	48	17
Health Services & Policy	4.48	51	21	30	22
Kinesiology	4.44	40	13	16	9
Global Health	4.42	49	23	31	19
Nano and Regenerative Medicine	4.41	48	20	42	21
Physiology	4.40	41	16	10	19
Nursing Science	4.19	32	23	22	20
Dental Science	4.09	26	19	6	17
Sub-Areas — Technology Application					
Genomic and Proteomic Technologies	4.94	67	12	46	15
Medical Imaging Technologies	4.76	60	17	38	17
Stem-cell Therapeutics	4.64	56	20	46	20
Nanobiotechnology & Biomimetics	4.41	50	27	47	23
Bioinformatics	4.41	49	21	36	18
e-Health	4.30	52	27	43	26
Other Medical Devices	4.30	42	21	21	22
Pharmaceutical Development	4.18	42	34	19	35
Medical Nanotechnologies	4.07	44	32	44	29

• The traditional foundation disciplines — e.g., Microbiology, Physiology — are judged not to be particularly strong and in some cases are thought likely to be declining rather than gaining ground in Canada. The same pattern is observed in other areas of the survey and appears to reflect a strong trend of aspiration toward transdisciplinary work. It has been remarked, for example, that researchers in physiology have been transforming the discipline into systems biology, which ranks much higher up in the table. Another example may be dental science, which, despite a rich history, may now be fragmenting into other fields related to pain, or even cancer.

• One is struck by the contrast in Figure 5.11 between the considerable research strength compared with much more limited strength in areas of medical technology. (Notable exceptions are genomics / proteomics and, to a lesser extent, medical imaging.) In particular, we note the perceived relative weakness of pharmaceutical development and the opinion of more than a third of respondents that Canada is losing ground. The survey conclusion in this case reflects the views of 433 respondents and thus appears to be quite robust.

> The Canadian health system represents a strategic advantage for development of health-related industries and technologies. We have failed to take advantage of this opportunity because of federal-provincial jurisdiction issues and public concern about privatization. *Fellow of the Canadian Academy of Health Sciences*

Environmental Sciences & Technologies

The exploitation of natural resources and a desire to reduce the environmental impact of such exploitation have motivated the development in Canada of significant capability in environmental sciences and technologies (**Figure 5.12**). The Environment cluster nevertheless presents a challenge, as it does not have deep strength at present in respect of technology application. Several areas of environmental science, on the other hand, are perceived as very strong, a finding that is reinforced by the bibliometric analysis later in this chapter. In **Chapter 7**, we confirm that there is a strong aspiration to master a set of environmental technologies, particularly those related to clean energy.

Figure 5.12

The Environment Cluster

		Percentage of Respondents			
	Mean	**Strong**	**Weak**	**Up**	**Down**
Sub-Areas — Scientific Research					
Physical Geography, Remote Sensing	5.32	80	4	30	14
Geochemistry & Geochronology	5.23	74	5	21	16
Hydrology	5.17	75	4	25	14
Oceanography	5.15	73	7	25	27
Climate Science	5.11	72	7	26	19
Meteorology	4.90	58	5	12	12
Geog; Urban & Environmental Planning	4.85	67	13	31	21
Soil Science	4.81	58	8	8	15
Environmental Engineering	4.75	59	14	27	25
Ecology & Evolutionary Biology	4.65	50	14	22	15
Sub-Areas — Technology Application					
Fuel Cells & Hydrogen	4.87	65	18	32	24
Clean Water Technologies	4.66	56	16	36	20
Forest Conservation Techs / Methods	4.64	58	19	24	34
Environmental Monitoring & Systems	4.52	50	21	28	19
Industrial & Environmental Biotech	4.32	45	23	32	19
"Green Building" Technologies	4.22	46	32	35	24
Clean Air Technologies	4.20	40	27	26	28
"Clean" Hydrocarbons	4.13	44	36	33	34
Smart Energy & Conservation	4.08	38	33	29	30
Recycling & Recovery	4.06	39	35	25	29
Energy Cogeneration	4.06	36	32	29	28
Biofuels	4.00	39	37	36	25
Solid Waste Management	3.96	34	36	19	32
Wind Power Technologies	3.62	28	55	38	34
Solar Power Technologies	3.40	20	58	20	40

We make two observations on **Figure 5.12**:

- There is considerable and obvious correlation in Canada between environmental S&T capabilities and the natural resource sector. Indeed, several of the stronger sub-areas in **Figure 5.12** belong to both the natural resources and environmental clusters. In view of the increasing importance of sustainable resource use, and of clean energy in particular, Canada's global comparative advantage in environmental S&T relates primarily to the environment-resources nexus.

> Canada's extractive industries - energy, mining, and forestry - have made much progress towards being sustainable and environmentally friendly - but so have other developed countries. These industries need to be as efficient as possible to remain competitive. Thus they need to draw on a strong public and private R&D sector.
> *Fellow, RSC Academy of Sciences*

- It is nevertheless clear from the technology sub-panel in the table that survey respondents do not believe Canada is currently strong in many of the key environmental technologies — e.g., "clean" hydrocarbons; biofuels; energy cogeneration; and wind power. Moreover, respondents are sharply divided as to whether Canada is gaining or losing ground in many of these.

Other Sectors

Respondents identified a number of important fields of strength that are not categorized within the four main clusters. For example, Canada has exceptional strength in Astronomy, Astrophysics and Cosmology (strength rating of 5.05), which has increased over time in a self-reinforcing way — excellence begets further excellence.

Some components of the automotive and aerospace sectors were also rated as quite strong in the survey (**Figure 5.13**). The aerospace industry has important clusters of excellence across the country, but the perceived S&T strengths, and especially the trend, appear to fall short of the economic importance of the industry. The Canadian automotive industry represents over 12 percent of manufacturing GDP but was judged reasonably strong only in respect of motor vehicles and parts, a competence that is highly dependent on foreign-owned and sourced technology. This sector is not R&D-intensive in Canada. As a result, it does not appear to have — relative to the scale of the industry here — a strong indigenous base of skills for automotive innovation.

Figure 5.13

Automotive, Aerospace & Related Technologies

		Percentage of Respondents			
Sub-Areas	**Mean**	**Strong**	**Weak**	**Up**	**Down**
Aerospace Products and Parts*	4.98	66	11	22	20
Aerospace Engineering	4.77	61	23	19	32
Materials Engineering	4.67	54	10	27	13
Motor Vehicles & Parts*	4.65	59	16	23	24
Advanced Industrial Materials*	4.64	59	16	41	18
Automotive Engineering	4.15	41	32	12	30

* Sub-areas of technology application; others (no asterisk) are sub-areas of scientific research.

One important cluster of technologies — those related to transportation — was identified by survey respondents as unusually weak and likely getting weaker (**Figure 5.14**)[4]. Given the importance of efficient transportation, particularly in a geography as vast as Canada's, the committee notes that the apparent technological weakness of this infrastructure could have significant implications.

Figure 5.14

Transportation Technologies

		Percentage of Respondents			
	Mean	**Strong**	**Weak**	**Up**	**Down**
Air Transport Technologies	4.41	50	22	15	27
Rail Transport Technologies	3.99	41	40	17	33
Road Transport Technologies	3.90	30	36	10	23
Multi-modal Transport Technologies	3.76	25	35	9	26
Marine Transport Technologies	3.38	18	57	4	46

Survey Results in Summary

The survey assessment of Canada's S&T strengths (and weaknesses) provides a rich base of data that is much in need of further interpretation by various expert communities. To facilitate such discussion, we present in **Figure 5.15** a series of charts that position each of the 197 sub-areas covered by the survey along axes of strength and net trend. These Strength vs. Trend charts are organized around the broad areas of research and technology described at the beginning of this chapter. We hope that the various expert and stakeholder communities will examine the results in light of their detailed knowledge and thereby provide a much more comprehensive interpretation than has been possible in this report.

[4] The technometric analysis reported later in this chapter points to relatively strong patenting activity in the rail and marine transport fields. Patenting, on the other hand, is not necessarily an indicator of the overall quality and extent of the technology that is actually deployed in the economy.

Summary of Survey Results — Strength vs. Trend

Figure 5.15.1

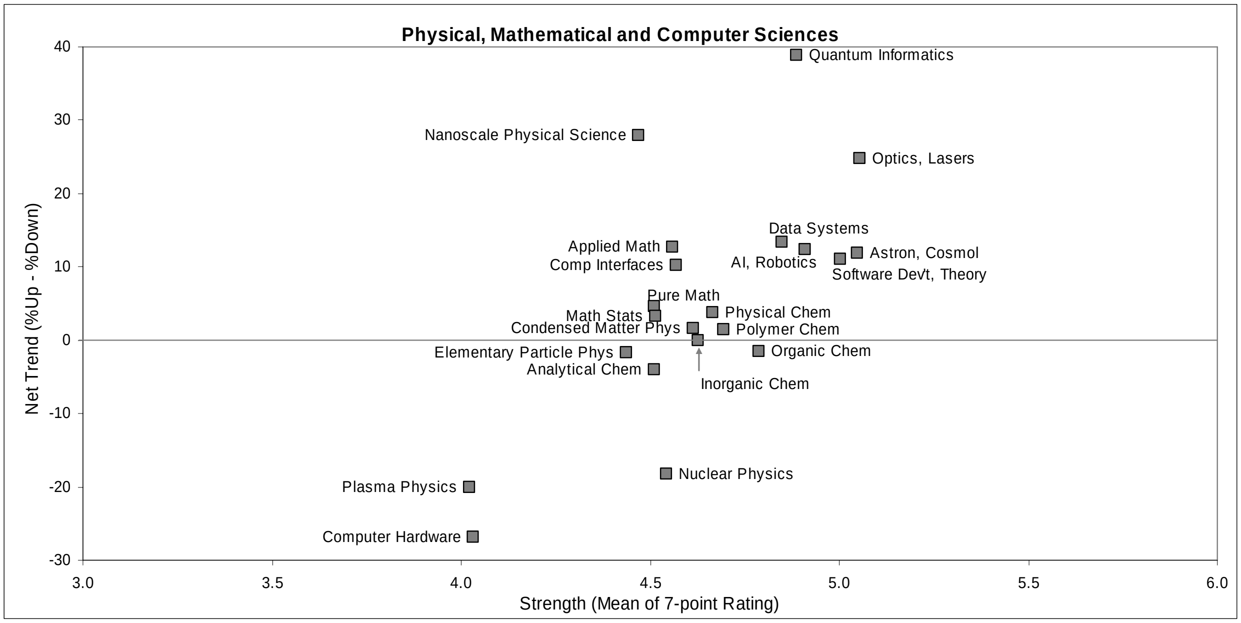


Figure 5.15.2

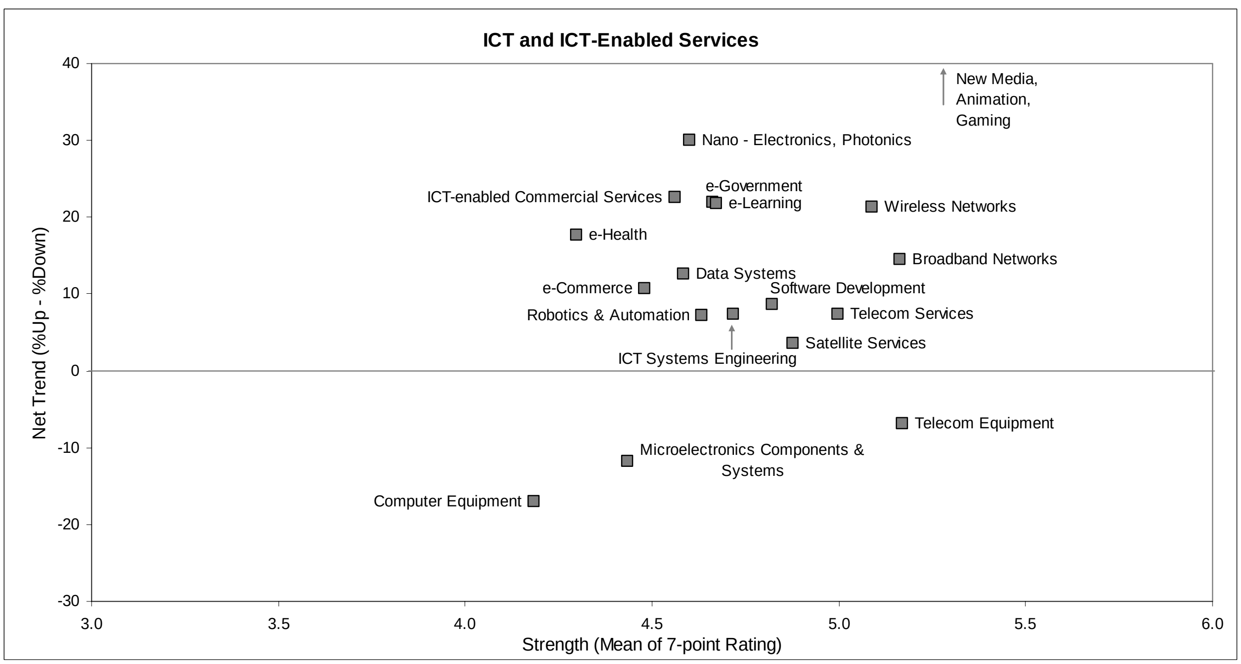


Figure 5.15.3

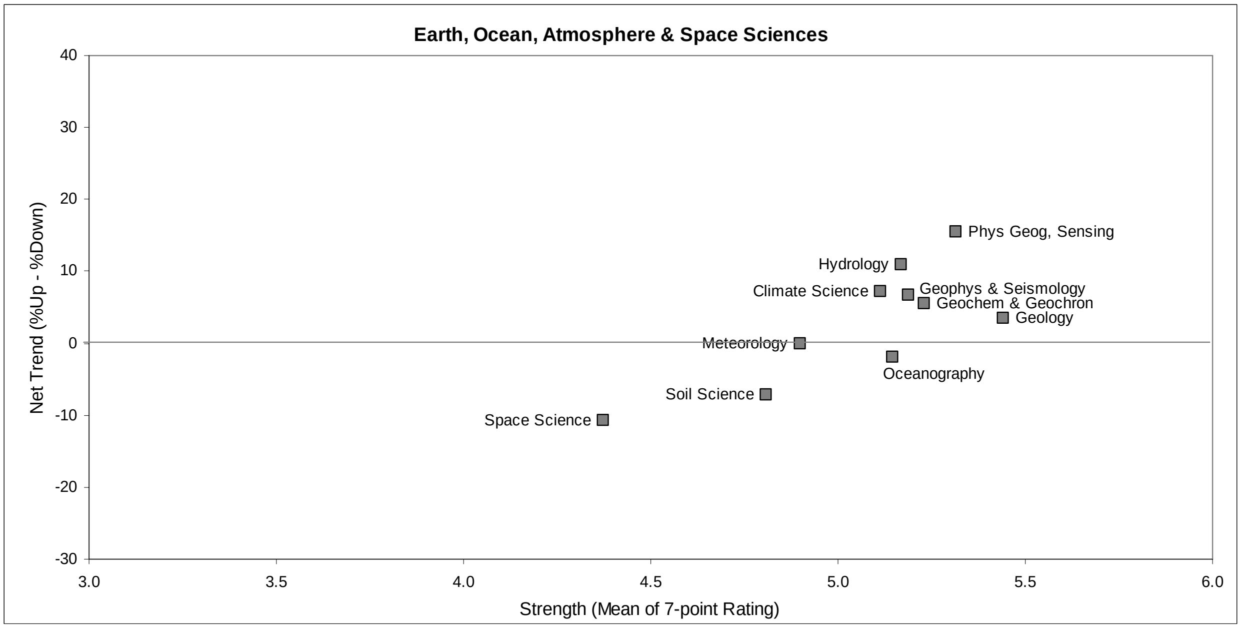


Figure 5.15.4

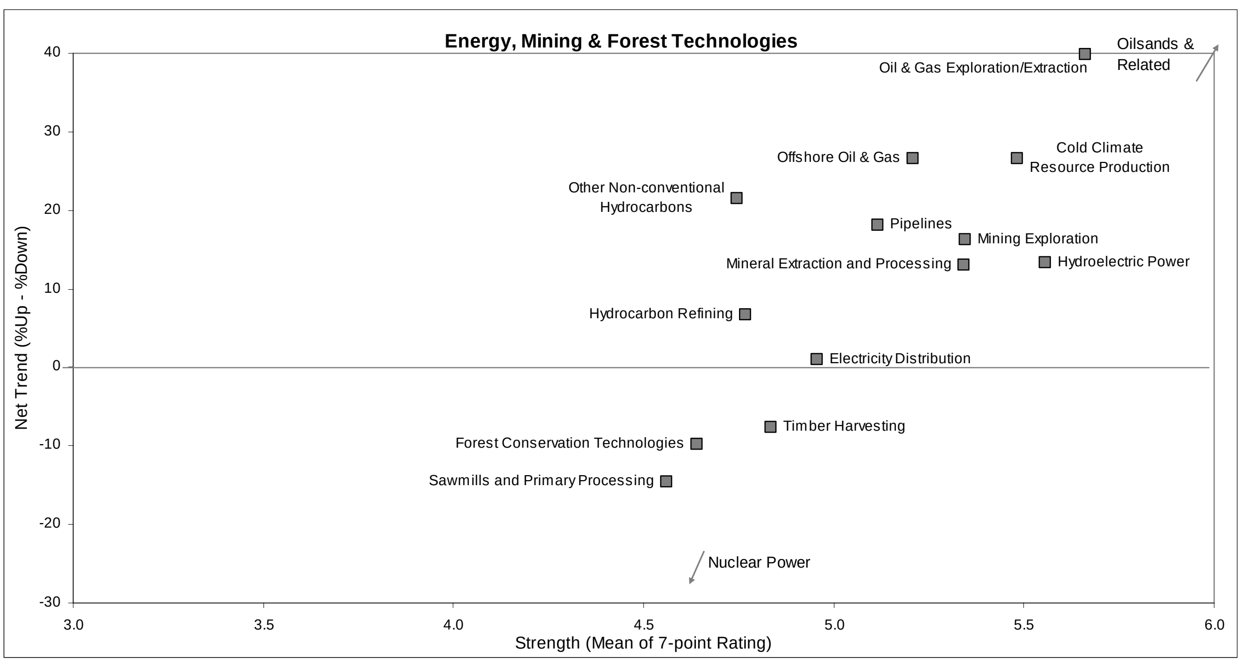


Figure 5.15.5

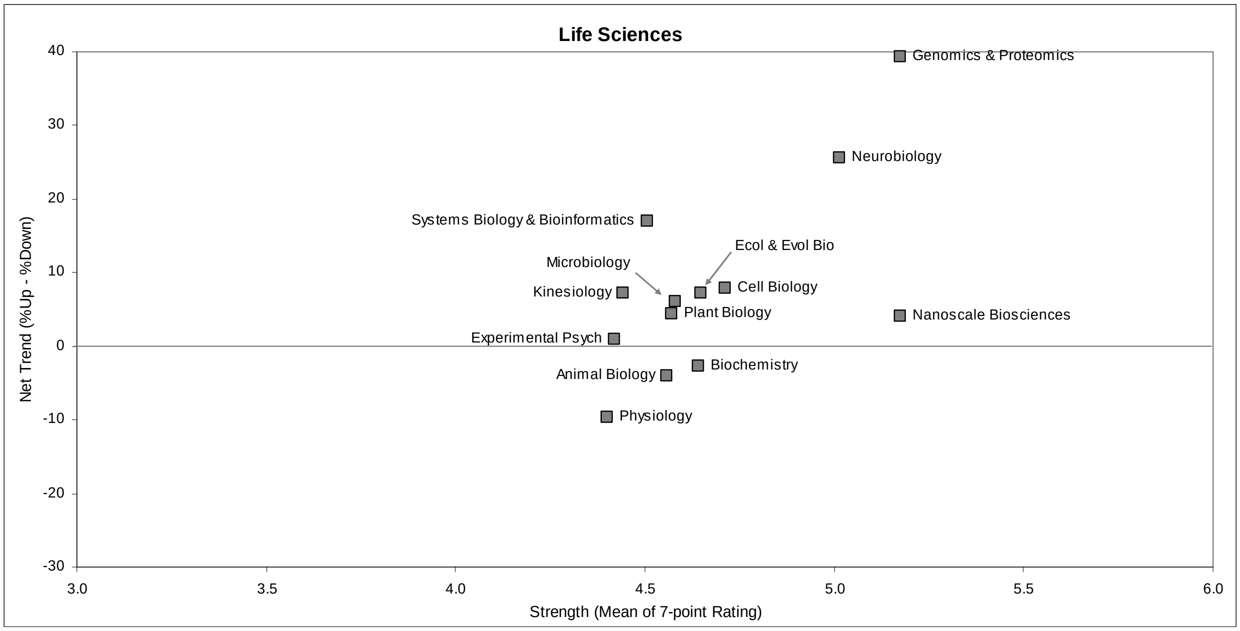


Figure 5.15.6

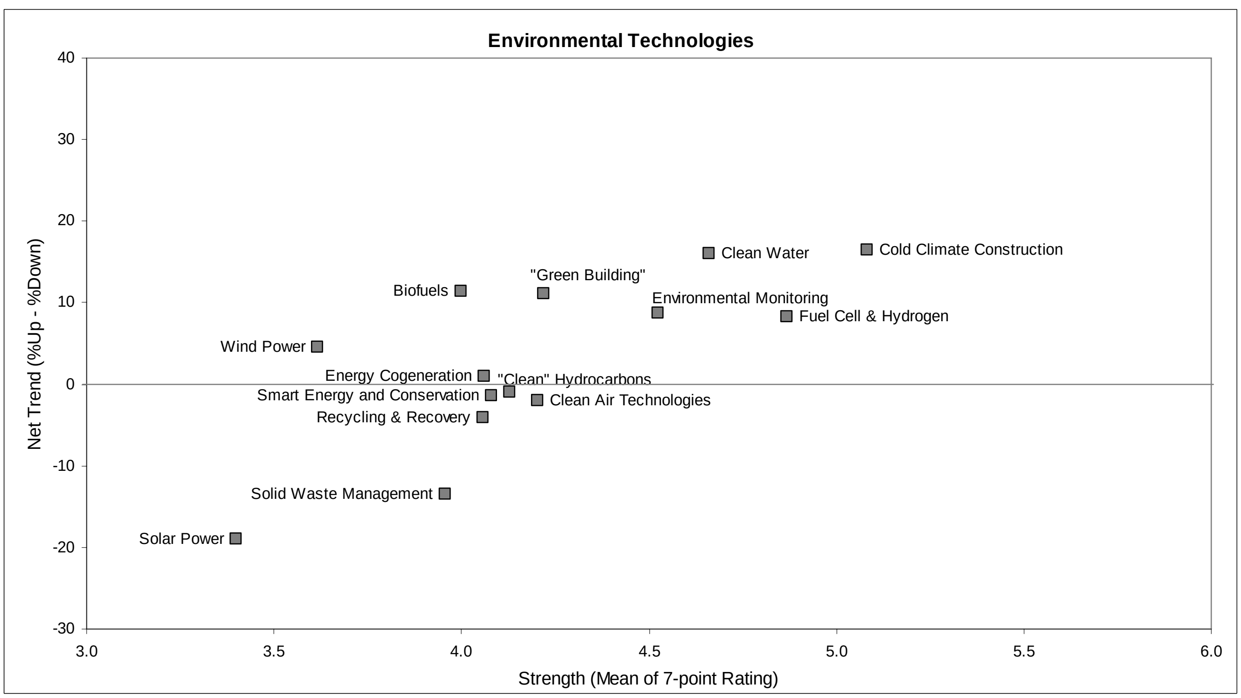


Figure 5.15.7

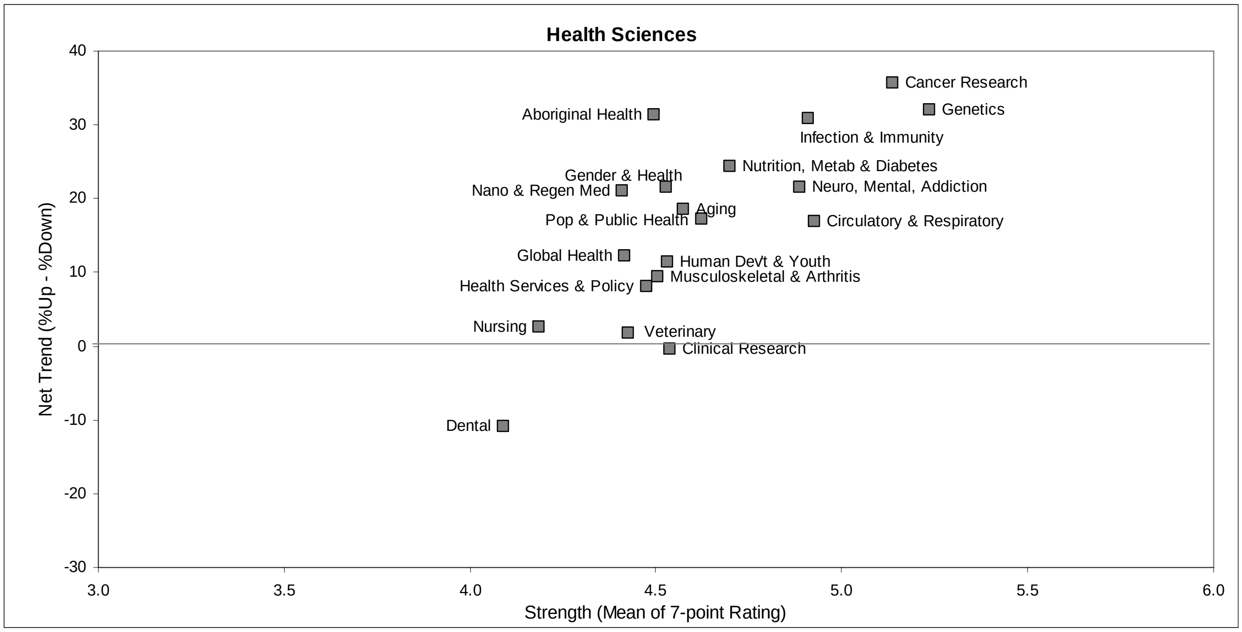


Figure 5.15.8

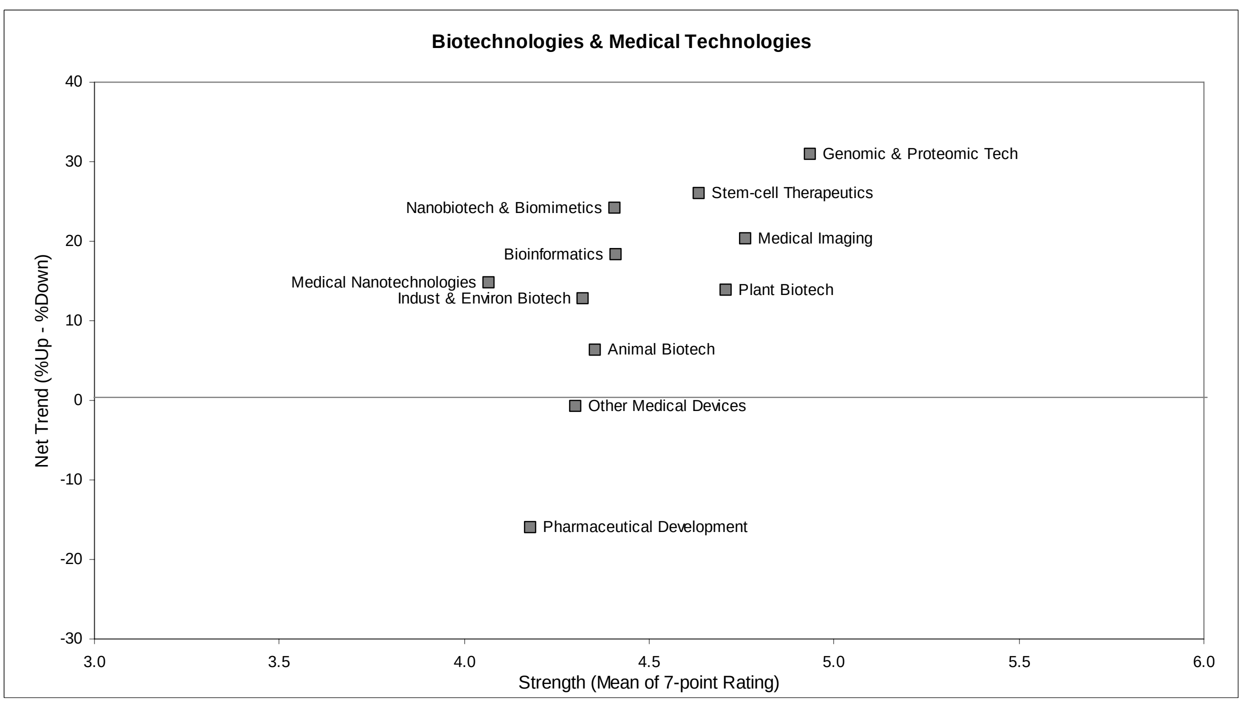


Figure 5.15.9

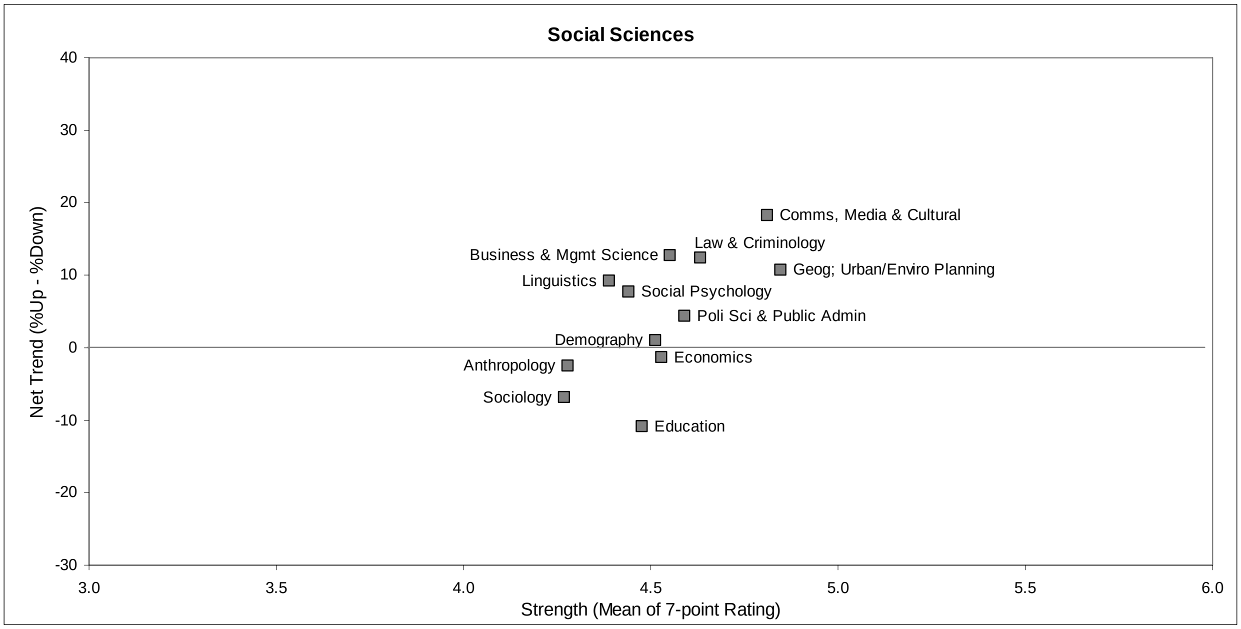


Figure 5.15.10

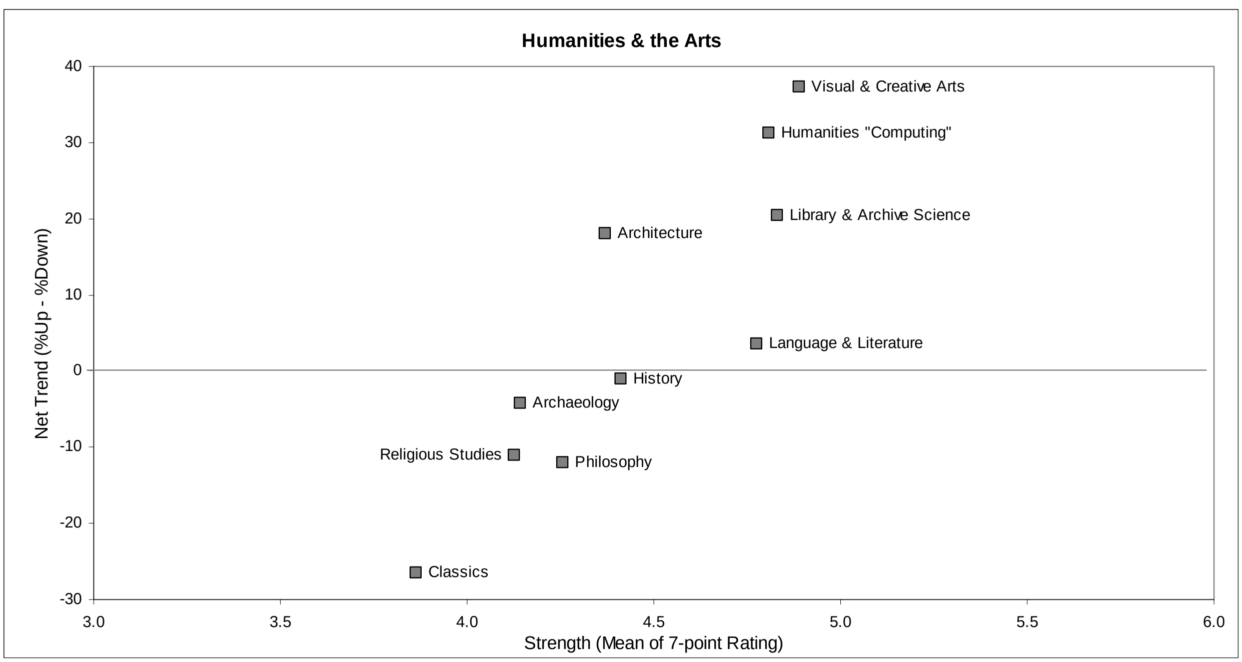


Figure 5.15.11

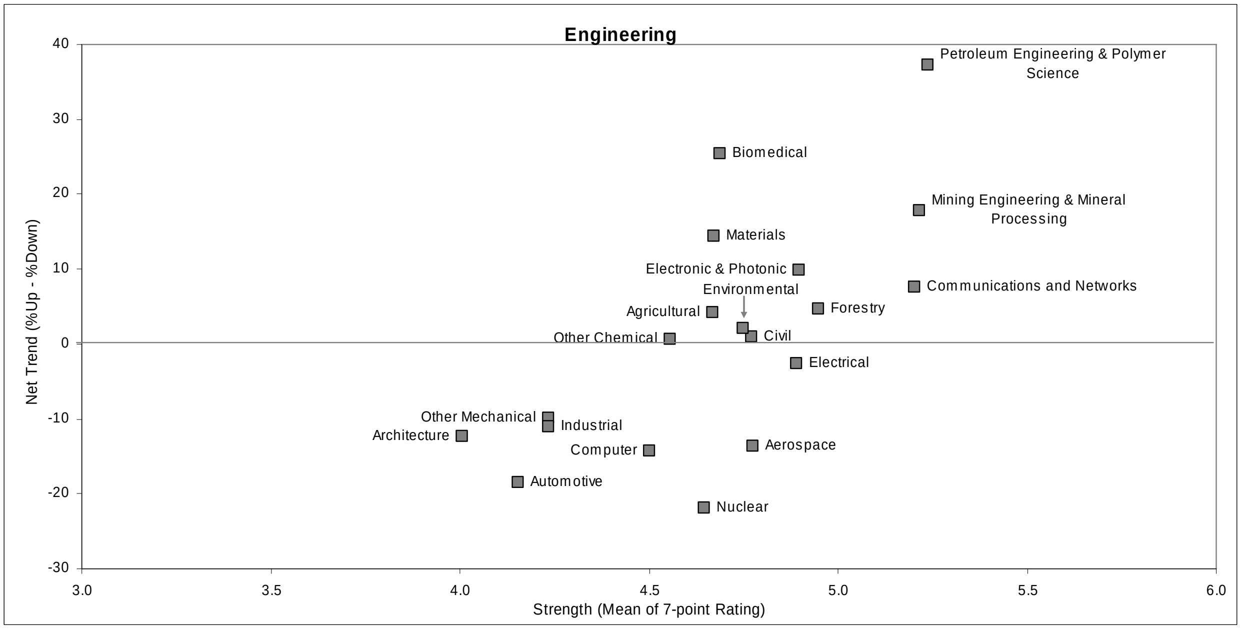


Figure 5.15.12

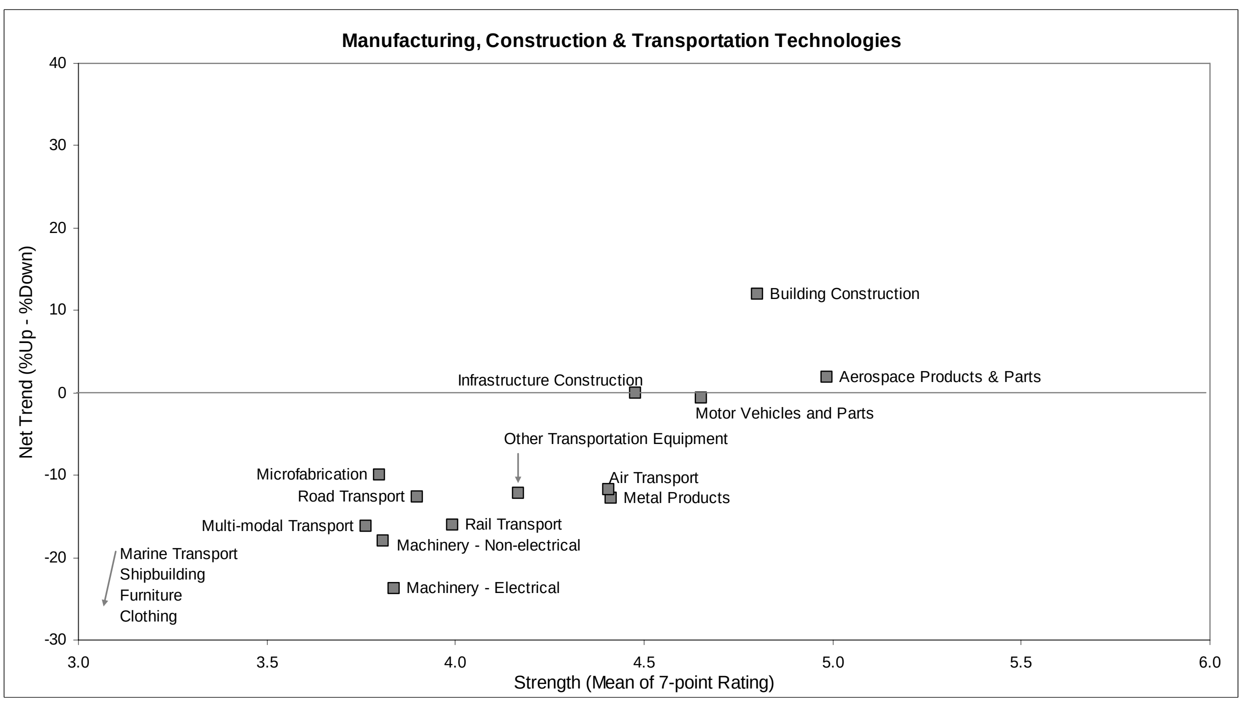


Figure 5.15.13

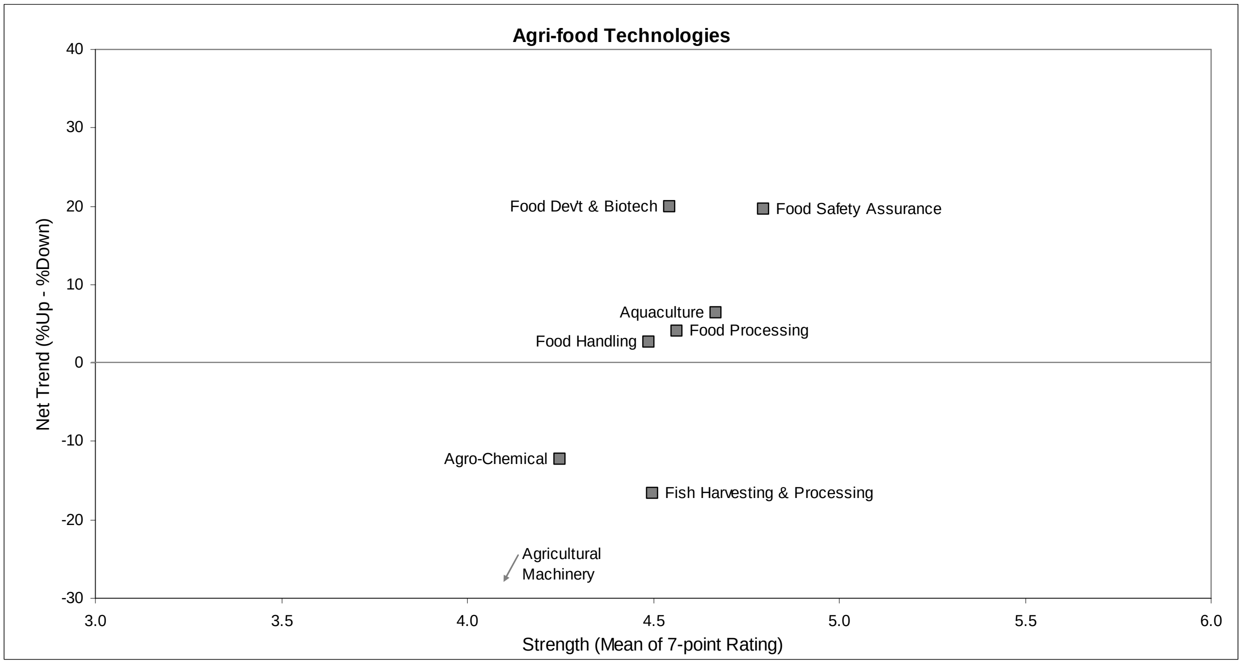
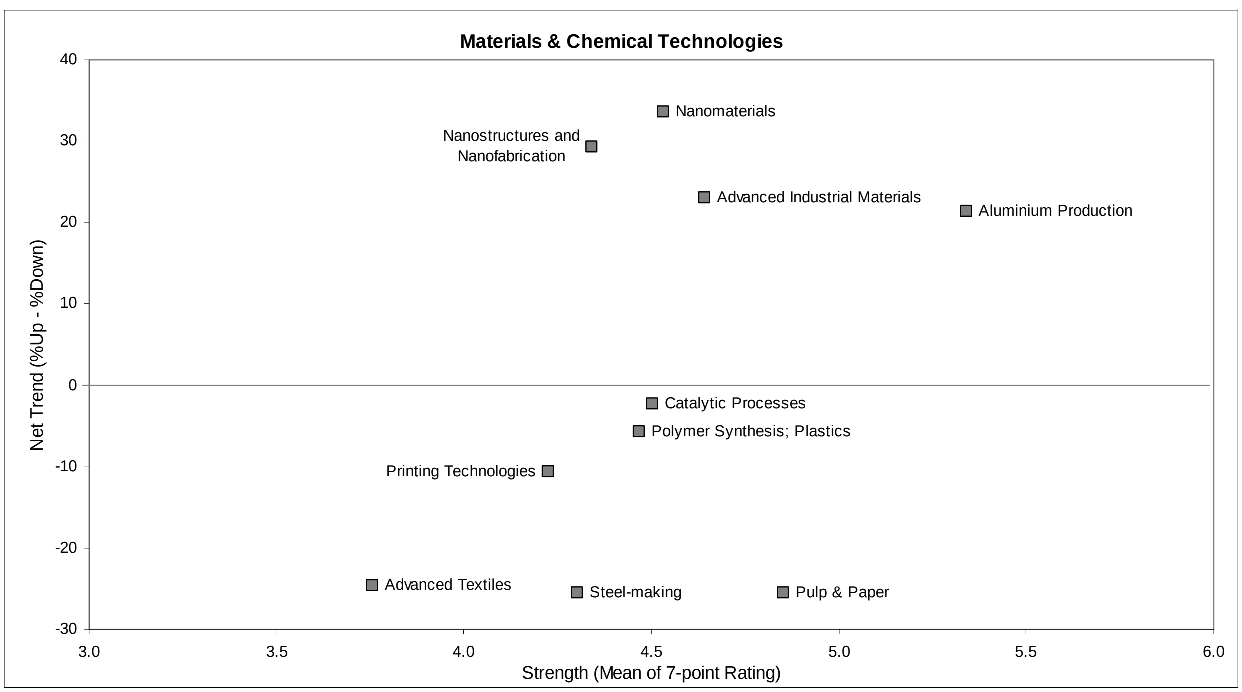


Figure 5.15.14



Bibliometrics and Technometrics — The Measurement of S&T Output[5]

Bibliometrics (the analysis of published papers) and technometrics (the analysis of patent data) are well-established methods in the evaluation of the strengths of an S&T system. This report uses two databases produced by Thomson Scientific to compute bibliometric statistics. The first is the Science Citation Index® (SCI), which provides extensive coverage of high-quality scientific research in the natural sciences, health sciences and engineering. It currently indexes approximately 3,700 of the world's leading science and technical journals. The second database is the Social Sciences Citation Index (SSCI). It includes bibliographic information for over 1,700 of the world's leading social sciences journals and also covers individually selected items from approximately 3,300 of the leading science and technology journals. The journals in these two databases are considered to be the most important peer-reviewed journals in their respective fields and account for more than 80 percent of the world's citations.[6]

The fields and areas of science employed in our bibliometric analysis largely reflect the categories used since the early 1970s by the US National Science Foundation (NSF) for the publication of the Science and Engineering Indicators. These categories rely on a mutually exclusive mapping of journals in specific fields. Some of these categories had to be modified while others were newly created so as to match, as closely as possible, the sub-areas we have used in the online survey.[7]

The following bibliometric indicators are used in this report:

- **Number of papers:** The number of scientific papers with authors associated with geographic areas (based on author addresses — e.g., countries, state, province).
- **Specialization Index (SI):** The SI is a ratio that measures the "intensity" of research in Canada in a given field, relative to the (average) intensity of research in that field in the world. The intensity of research in Canada in field "X" is defined as the number of papers published in field "X" in Canada, expressed as a percentage of the number of papers published in all fields in Canada (over a given time period.). A similar definition applies to the world. The SI is simply the Canadian intensity divided by the world intensity (Science Metrix, 2006, p. 5). An SI above 1.0 means that Canada is more *specialized* in a particular research area than the world average, while an index value below 1.0 means the opposite. For

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[5] All data in this section were compiled by Science-Metrix (www.science-metrix.com) and use data from the Observatoire des sciences et des technologies (www.ost.qc.ca).

[6] In the broad field of humanities, bibliometric data have to be interpreted with care due to the preference for publication in books in some domains of the humanities. Bibliometric analysis is focused on scholarly journals and can give misleading results in fields where a significant portion of academic output is published in books and monographs. We have therefore omitted the humanities sub-fields from the bibliometric analysis, though they are well-covered in the survey results.

[7] Two areas are measured much more precisely than the other sub-areas. These are nanoscience and nanotechnology-related sub-areas, and genomics. In the case of genomics, the output is substantially greater than that of other fields since these data were extracted from the 'expanded version' of the SCI. (Although this has a positive effect on the number of papers produced, it does not affect either the Specialization Index (SI) or the Average Relative Impact Factor (ARIF) growth calculations, since relevant comparables were used to compute these statistics in the case of genomics.)

example, if five percent of all Canadian papers are in agriculture and four percent of all papers published in the world are in this discipline, then Canada's Specialization Index for agriculture would be .05/.04 or 1.25. (Note that these are not actual figures.) The higher the SI, the more intensely represented is the research in the discipline in Canada, relative to the world. The SI is a zero-sum game at the country level — i.e., specialization in some fields necessarily means under-specialization in others. (An indicator analogous to SI is also used for patents in this report.)

- **Average Relative Impact Factor (ARIF):** This indicator is a proxy for the quality of published research. Each journal in the databases we use has an impact factor (IF), which is calculated annually by Thomson Scientific based on the total number of citations the journal receives relative to the number of papers it publishes. The IF of scholarly papers is calculated by ascribing to them the IF of the journals in which they are published. In order to account for different citation patterns across fields and subfields of science — e.g., there are more citations in biomedical research than mathematics — the IF of each paper is divided by the world average IF of the papers in its particular subfield in order to obtain a Relative Impact Factor (RIF). The ARIF for a field in Canada is then computed using the average of RIFs of the papers pertaining to that field for Canada. When Canada's ARIF in a field is above 1.0, it means that Canadian research publications score better than the world average. When Canada's ARIF is below 1.0, it means that Canadian research in the field is (on average) published in journals that are not cited as often as the world average.

The use of ARIF has been debated and its limitations have been examined in great detail. Science-Metrix, OST and other recognized organizations in the field of bibliometrics regularly make use of this indicator because of its timeliness and cost-effectiveness, and because, despite its limitations, ARIF it is a robust indicator of expected impact and it has proven to be a solid proxy for publication quality. Although the number of papers by a country, or its institutions, in the top one percent of cited papers is sometimes used in international scoreboards (**Box 5.2**), practitioners in the field of bibliometrics tend to prefer metrics such as the ARIF (or other relative and inclusive metrics based on citations) in view of their comprehensiveness and robustness for comparing the various specialties of science across countries.

Box 5.2

The Scientific Impact of Nations

In 2004, an influential paper entitled "The Scientific Impact of Nations" was published in *Nature* by Sir David King, Chief Scientific Advisor, UK. The paper provides an overview of existing literature and data to measure the impact and outcomes from research investment over the past decade in 31 countries. King's analysis focuses almost exclusively on bibliometric data (number of publications and citations) between 1997 and 2001 to obtain a measure of productivity and quality of science. The group of 31 countries analyzed (including G-8 nations and 15 member countries of the EU) accounts for 98 percent of the world's most highly cited papers. King reports that the top eight produce 85 percent of the top one percent of most cited papers.

Canada stands sixth both by rank of the top one percent cited publications and by share of total publications. King provided a comparison among G-8 countries by disaggregating all scientific publications into the broad categories of clinical medicine; preclinical medicine and health; biological sciences; environment; mathematics; physical sciences; and engineering. Most of King's country comparisons omit the US in view of its stand-alone scale. Among the seven remaining countries — Canada, the UK, Germany, France, Italy, Japan and Russia — in respect of aggregate share of citations, Canada ranked as follows: environmental sciences (tied for 2nd), pre-clinical medicine and health (3rd), biology (5th), clinical medicine (5th), mathematics (tied for 4th), physical sciences (tied for 6th) and engineering (7th). On a per capita basis or per researcher basis, some of Canada's rankings would be higher.

Bibliometric Perspective on Canada's Research Strengths

Figure 5.16 depicts Canada's position relative to world science with respect to research intensity (SI on the x-axis) and research output quality (ARIF on the y-axis). The size of the circles on the chart is proportional to the number of Canadian papers published in the various fields over the eight years from 1997 through 2004. The top right quadrant illustrates the domains in which Canada is relatively specialized and in which it published in journals that are more highly cited than the world average. This is a quadrant of unambiguous relative strength for Canadian published research. The broad fields where Canada has the best overall performance are psychology and psychiatry, earth and space sciences, biomedical research and biology.

The top left quadrant identifies domains where Canada does not publish as "intensively" as the world average but where quality is high. Chemistry is clearly a field of excellence and is followed by physics — although in both of these domains, Canada has below average specialization. The broad field of clinical medicine lies on the boundary between the two upper quadrants — i.e., Canada's relative specialization is at about the world average.

The lower quadrant on the right hand side contains those fields where Canada specializes but where it tends to publish in journals that are not cited as often as the world average. Canada is highly specialized in the health-related social sciences, and although its impact is lower than the world average, Canada also specializes in the non-health-related social sciences. A significant amount of social science research deals with location- and culture-specific questions, which would explain, in part, why research in smaller countries like Canada is disproportionately published in locally specialized journals that are relatively less cited than the world average.

Finally, the lower left quadrant of **Figure 5.16** is where Canada neither specializes nor publishes in highly cited journals. At the aggregate level, Canada's greatest weakness is in engineering research, where its research intensity is relatively low and where its publications appear in journals that are less cited than the world average in this field. There are, however, important exceptions within sub-areas of engineering.

Figure 5.16

Position of Canada in Science, Engineering and Social Sciences, 1997–2004

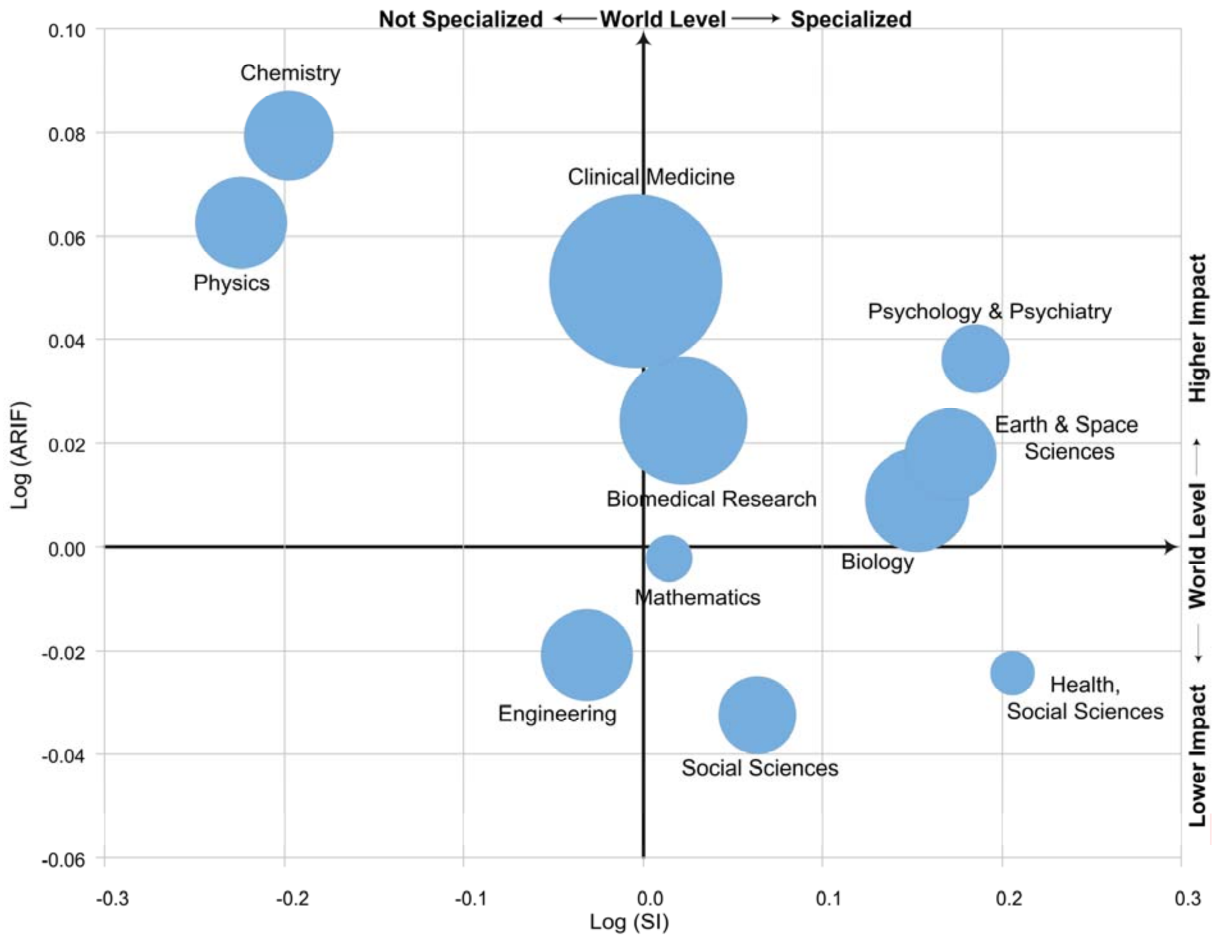


Figure 5.17 tabulates, by quadrants, the 125 sub-areas of research that underlie the macro picture in **Figure 5.16**. **Appendix 5** shows these results graphically. The top right quadrant includes the areas of unequivocal strength as measured with bibliometrics — i.e., Canada is above the world average in both specialization (SI) and quality (ARIF). The other quadrants are defined analogously. The sub-areas in each quadrant are not listed in any order with respect to SI or ARIF; rather, they are grouped according to the principal clusters introduced earlier in this chapter. The numerical data from which the table is derived are found in **Appendix 5**.

Figure 5.17

Sub-Areas Allocated by Bibliometric Quadrant (The sub-areas indicated by asterisk are those for which there was no clear equivalent among the 197 sub-areas in the online survey.)

Quadrant I: SI>1, ARIF>1

Health & Related

Clinical Research
Radiol, Nuclear Medicine*
Genetics, Genom, Proteom
Genetics (Medical)
Circ & Resp Health
Neurobio / Neurosci
Nutrition, Metabol, Diabet
Musculoskeletal & Arthritis
Human Dev't & Youth
Pharmacology *
Fertility *
Nursing Science
Orthopedics *
Rehabilitation *
Kinesiology
Psychiatry *
Social Sciences, Biomed *

ICT

Computer Science

Environment

Marine Biology, Hydrobio *
Oceanography
Hydrology
Ecol & Evol Biology
Climate Sci & Meteorology
Environmental Science *

Nat Res / Environment

Physical Geog, Rem Sens
Geochem & Geochron
Soil Science

Natural Resources

Geology
Forestry Engineering

Other

Psychology *
Psychology, Mathematical *
Psychology, Clinical *
Social Psychology
Social Sciences, Interdis *
Social Work *
Social Issues *
Women's Studies *
Anthropology
Transport Studies *
Ergonomics *
General Engineering *
Acoustics *
Operations Research *
Math Statistics
Pure Math
Animal Biology
Veterinary Science
Biochemistry

Quadrant II: SI<1, ARIF>1

Health

Cancer Research
Infection & Immunity
Mental Health, Addiction
Gastroenterology *
Pathology *
Obstetrics & Gyn *
Dermatology *
Otorhinolaryngology *
Urology *
Tropical Medicine *
Pharmacy *
Gen Biomed Research *
Biomedical Engineering
Dental Science

ICT

Optics; Lasers
Electron / Photon Eng.

Natural Resources

Petroleum / Polymer Eng

Other

General Chemistry *
Applied Chemistry *
Analytical Chemistry
Inorganic Chemistry *
Organic Chemistry
Polymer Chemistry
Physical Chemistry
Chemical Physics *
General Physics *
Applied Physics *
Condensed Matter Physics
Nucl. Phys & Elem. Part.
Astro Phys, Cosmology
Nanoscale Physical Sci.
Nanoscale Biosciences
Cell Biology
Microbiology
Microscopy *
Nuclear Engineering
Other Mechanical Eng.
Psychol, Educational *

Figure 5.17 (continued)

Quadrant III: SI>1, ARIF<1

Health

Physiology

Embryology *

Aging

Popul & Public Health

Health

Health Services & Policy

Environment

Geog; Urban & Envir. Plan.

Natural Resources

Geophysics & Seismology

Mining & Mineral Process

Nat Res / Environment

Earth & Planetary Sci *

Other

Physiology

Embryology *

Aging

Popul & Public Health

Health

Health Services & Policy

Environment

Geog; Urban & Envir. Plan.

Natural Resources

Geophysics & Seismology

Mining & Mineral Process

Nat Res / Environment

Earth & Planetary Sci *

Quadrant IV: SI<1, ARIF<1

Health

Surgery *

Ophthalmology *

Parasitology *

Nano and Regen Med

Environment

Environmental Eng.

Natural Resources

Metals & Metallurgy *

Other

Comms, Media & Culture

Culture

Aerospace Engineering

Materials Engineering

Plasma Physics

Applied Math

Demography

Law & Criminology

In **Figure 5.18**, we list separately the top 30 sub-areas in terms of publication quality (ARIF) and publication intensity (SI). Some clear patterns emerge: the top 30 areas fall mainly into the clusters as identified from the survey results. In terms of publication quality, the top 30 include 11 sub-areas of health and related life sciences and three in environment. In terms of relative specialization, there are nine sub-areas related to natural resources and the environment, and seven in health and related life sciences. A significant cluster of five psychology sub-areas appears in the list of greatest specialization and there are 11 sub-areas of chemistry and physics in the list of highest quality as measured by ARIF.

The highlighted sub-areas in **Figure 5.18** are fields in which Canada publishes more intensely than the world average and also has publication quality above the world average — these are doubly strong. For example, clinical research, general psychology, forestry engineering, marine biology, oceanography, hydrology, geology, environmental sciences and ecology are all areas in which Canada excels in terms of both publication quality and intensity. In terms of social sciences, Canada is particularly strong in biomedical social sciences, social psychology and women's studies, where publication intensity is high and output quality is on par with or above the world level.

We also note some areas in which Canada specializes but does not publish in heavily cited journals — e.g., mining engineering and mineral processing, civil engineering, population and public health, and experimental psychology. Other areas in the social sciences where Canada specializes — though not in the top 30 as ranked by SI — include political science (SI = 1.31, ARIF = 0.68) and family studies (SI = 1.14, ARIF = 0.70). Further investigation would be required to determine the extent to which the weakness measured by ARIF in these cases is due to the localized nature of many social science disciplines. This may limit the extent of Canadian publication in the most cited journals, which often have a predominately U.S. perspective.

Conversely, Canada produces exceptionally high quality research in some areas where our specialization is relatively low, notable examples being inorganic chemistry, nuclear engineering and cancer research.

One cluster that does not show up in the top 30 lists in **Figure 5.18** is ICT. The sub-categories used to obtain scientific publication metrics do not capture many of the relevant scientific sub-areas in the complex universe of modern computer sciences. We have constructed an omnibus bibliometric category for Computer Sciences that groups five sub-areas included in the online survey (software development and theory, hardware, database and info systems, computer-human interfaces, AI and robotics). The merged category has strong bibliometric parameters — an SI of 1.24 and ARIF of 1.01, both above the world average. In addition, two areas related to ICT — optics and laser physics (ARIF = 1.02) and electronic and photonic engineering (ARIF = 1.01) — are fields in which Canada publishes at the world level.

Figure 5.18

Top 30 Sub-areas in Descending Order of ARIF and of SI

The sub-areas indicated by asterisk are those for which there was no clear equivalent among the 197 sub-areas in the online survey. Shaded Lines are fields for which both publication quality and intensity exceed the world average.

Top 30 ordered by ARIF

		ARIF	SI
1	Inorganic Chemistry	**1.43**	0.55
2	Clinical Research	**1.41**	1.10
3	Gastroenterology*	**1.41**	0.72
4	Psychology, Educational*	**1.40**	0.81
5	General Physics*	**1.29**	0.65
6	Pathology*	**1.26**	0.82
7	Obstetrics & Gynecology*	**1.25**	0.76
8	General Chemistry*	**1.25**	0.75
9	Nuclear Engineering	**1.25**	0.56
10	Psychology, General*	**1.23**	1.33
11	General Engineering*	**1.23**	1.10
12	Analytical Chemistry	**1.23**	0.66
13	Pharmacy*	**1.23**	0.37
14	Condensed Matter Physics	**1.22**	0.49
15	Social Sciences, Biomedical*	**1.21**	1.95
16	General Biomedical Research*	**1.21**	0.90
17	Cancer Research	**1.21**	0.88
18	Marine Biology & Hydrobiology*	**1.20**	1.87
19	Oceanography	**1.20**	1.37
20	Applied Chemistry*	**1.19**	0.84
21	Polymer Chemistry	**1.19**	0.69
22	Organic Chemistry	**1.18**	0.62
23	Dermatology*	**1.18**	0.46
24	Psychology, Mathematical*	**1.16**	2.06
25	Human Dev't & Youth Health	**1.16**	1.23
26	Circulatory & Respiratory Health	**1.16**	1.09
27	Nuclear Phys & Elem Particles	**1.15**	0.87
28	Nanoscale Physical Science	**1.15**	0.49
29	Astron, Astro Phys, Cosmol	**1.14**	0.99
30	Ecology & Evolution Biology	**1.13**	1.47

Top 30 ordered by SI

		SI	ARIF
1	Forestry Engineering	**3.06**	1.03
2	Industrial Relations & Labour*	**2.49**	0.75
3	Mining & Mineral Proc Eng	**2.48**	0.97
4	Hydrology	**2.36**	1.00
5	Psychology, Mathematical*	**2.06**	1.16
6	Kinesiology	**2.05**	1.02
7	Civil Engineering	**2.05**	0.83
8	Experimental Psychology	**1.99**	0.94
9	Geology	**1.98**	1.05
10	Operations Research*	**1.98**	1.03
11	Social Sciences, Biomedical*	**1.95**	1.21
12	Marine Biology & Hydrobiology*	**1.87**	1.20
13	Social Psychology	**1.86**	1.06
14	Earth & planetary Science*	**1.82**	0.89
15	Psychiatry*	**1.78**	1.05
16	Environmental Science*	**1.74**	1.08
17	Psychology, Biological*	**1.71**	0.95
18	Animal Biology	**1.70**	1.07
19	Soil Science	**1.70**	1.05
20	Physiology	**1.65**	0.98
21	Ergonomics*	**1.63**	1.05
22	Transport Studies*	**1.62**	1.03
23	Health Services & Policy	**1.61**	0.76
24	Women's Studies*	**1.56**	1.00
25	Linguistics	**1.56**	0.83
26	Entomology*	**1.53**	0.98
27	Population & Public Health	**1.53**	0.92
28	Psychology, Clinical*	**1.52**	1.09
29	Rehabilitation*	**1.48**	1.00
30	Ecology & Evolution Biology	**1.47**	1.13

At the other end of the spectrum, **Figure 5.19** lists those areas where Canada is neither specialized nor represented above the world average in the most highly cited journals — e.g., surgery, ophthalmology, materials engineering, metallurgy and aerospace engineering. The latter relative weakness is notable in view of the industrial importance of the aerospace sector in Canada.

Figure 5.19

Areas for which both the ARIF and SI are Below the World Average (The sub-areas indicated by asterisk are those for which there was no clear equivalent among the 197 sub-areas in the online survey.)

Ordered by Decreasing ARIF

	ARIF	SI
Parasitology*	**0.99**	0.83
Plasma Physics	**0.99**	0.60
Aerospace Engineering	**0.98**	0.70
Environmental Engineering	**0.98**	0.94
Ophthalmology*	**0.95**	0.80
Applied Mathematics	**0.95**	0.99
Nano and Regenerative Medicine	**0.93**	0.59
Surgery*	**0.92**	0.98
Materials Engineering	**0.91**	0.61
Communications, Media & Culture	**0.91**	0.61
Law & Criminology	**0.90**	0.76
Demography	**0.78**	0.95
Metals & Metallurgy*	**0.77**	0.98

Ordered by Decreasing SI

	SI	ARIF
Applied Mathematics	**0.99**	0.95
Metals & Metallurgy*	**0.98**	0.77
Surgery*	**0.98**	0.92
Demography	**0.95**	0.78
Environmental Eng	**0.94**	0.98
Parasitology*	**0.83**	0.99
Ophthalmology*	**0.80**	0.95
Law & Criminology	**0.76**	0.90
Aerospace Engineering	**0.70**	0.98
Communications, Media & Culture	**0.61**	0.91
Materials Engineering	**0.61**	0.91
Plasma Physics	**0.60**	0.99
Nano and Regenerative Medicine	**0.59**	0.93

We have also computed growth figures for publication volume for both Canada and the world that compare total publications over the period 2001–2004 with the period 1997–2000. These data are complex and somewhat difficult to interpret, and are summarized in **Appendix 5.** They are also compared in **Appendix 6** with the net trend indicator derived from the survey data. The committee would invite the various expert communities to examine these data and to provide interpretation as to their significance.

In conclusion – when the bibliometric data are viewed in their entirety, Canada's broad strength in published research is apparent. We note that:

- For 38 percent of the 125 areas analyzed, *both* publication quality (ARIF) and intensity (SI) were above the world average. In only 10 percent of the 125 disciplines were quality and intensity both below the world average.
- Almost 70 percent of the 125 disciplines had publication quality ratings above the world average.
- In only 11 of the 125 disciplines was publication quality rated at less than 90 percent of the world average.

Technometrics — Evaluating Strengths Through Patent Data

Technometrics — the analysis of patent data — assesses an important dimension of the output of commercial innovation. This report uses the US Patent and Trademark Office (USPTO) database as the source for patent indicators. Its categories were established based on inventions at the turn of the last century. Many of those categories are not sufficiently precise to adequately represent today's inventions.

Figure 5.20 depicts the position of Canada with respect to technology intensity (SI) — i.e., Canada's specialization in a particular patent area relative to global specialization in that area — and the quality of its patents. The proxy for quality is Average Relative Citation (ARC), which measures the number of times these patents are cited compared with other patents in their same technological domains (**Box 5.3**).

Box 5.3

Technometric Indicators

Number of patents: Unlike scientific publications, patents have two fields that contain relevant geographic information: the inventor's address field and the assignee's address field. These fields are used to compute statistics on two different indicators, namely, invention and intellectual property (IP). This report presents data on IP — i.e., where the owners of a patent are, which is a good indicator of the potential economic impact of inventions.

Average Relative Citations (ARC): The number of citations received for each patent was counted for the year in which the patent was granted and the two years that followed. For patents granted in 1995, for example, citations received in 1995, 1996 and 1997 were counted. (The only exception is the year 2003, which contains a citation window of two years, and 2004, which contains a citation window of one year.) Scores are calculated relative to the number of citations received by patents in the same field.

The database used by Science-Metrix contains information on all the patents granted by the USPTO since 1976. The statistics presented in this report concern utility patents (except for patents in the 'Plant' class, which are included in the agriculture category) that have been *granted* — not patent applications.

Canada is particularly strong in optics and photonics, (complementing ICT research and technology strengths noted earlier); in energy production technologies; in civil engineering; in rail; and in marine technologies (**Figure 5.20**). Although patent activity has subsided in telecommunication technologies following the dotcom collapse in 2000, this field — together with optics and photonics — provides a strong base for future industrial growth.

Canada's most prominent weakness is in nuclear technology. Part of this may be due to the inability of US patent classes to capture nuclear technologies, but it can also reflect the fact that nuclear technologies were set aside in the 1990s as moderate fuel prices and environmental pressure caused interest in nuclear power to decline. Still, these phenomena were widespread and it is surprising that Canada is not faring better compared with world competition.

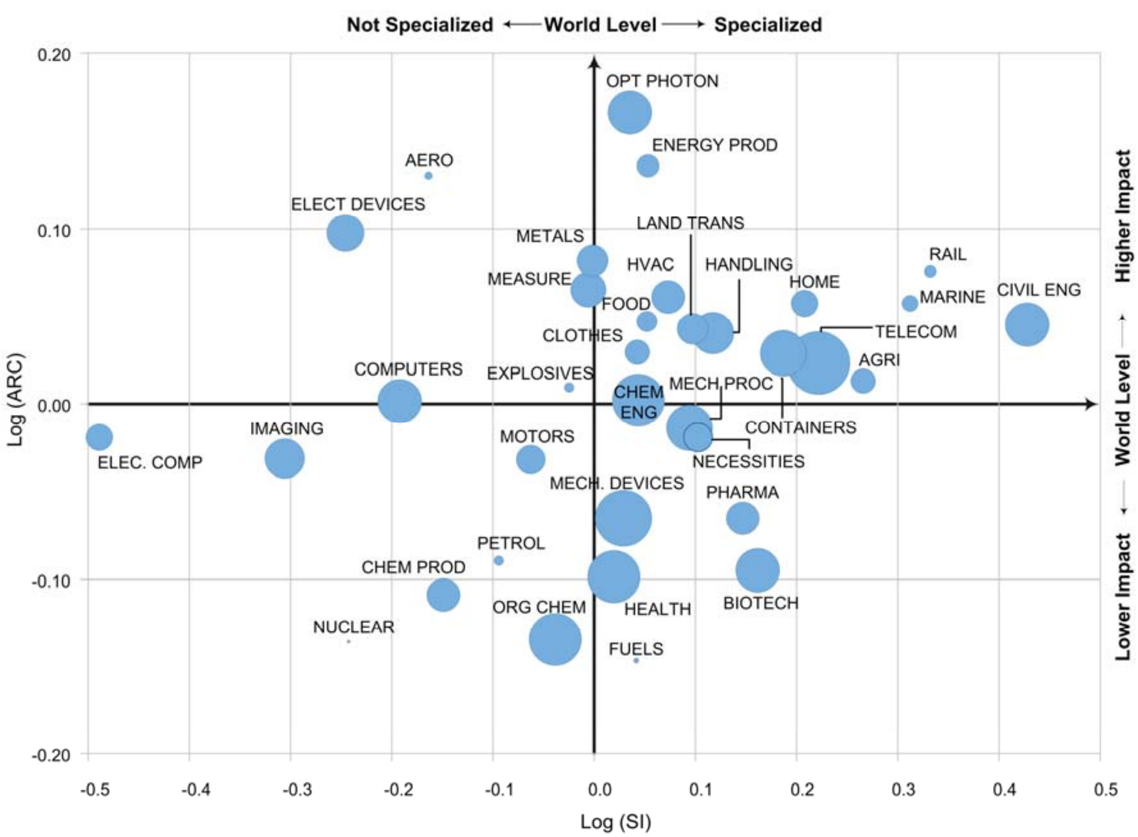
Canada produces considerable intellectual property in the pharmaceutical sector and in biotechnology, but this is not cited as often as other patents in these fields, suggesting that their aggregate technological importance, as indicated by Average Relative Citations, is lower than the world average.

Canada's patenting activity is relatively weak in many fields where it produces good science. For example, despite excellence in chemistry research, Canada's patenting metrics are below the world average in chemical products, organic chemistry and petroleum-related technologies.

We have also computed figures for patent growth in Canada, which are summarized in **Appendix 5**. These data show that in the past five years, Canada has been gaining share of USPTO patents granted in the ICT, health and biotechnology sectors.

Figure 5.20

Canadian Patenting in a Global Context, 1995–2004 (The size of the circles is proportional to the number of patents granted from 1995 to 2004.)



Survey and Metrics Compared

The bibliometric analysis was designed to be comparable with the survey results in sub-areas of scientific research. Although perfect comparability was unattainable, we were able to create bibliometric categories that reasonably overlap almost 90 percent of the research sub-areas included in the survey.[8] The 78 comparable sub-areas, and their associated survey and bibliometric data, are tabulated in **Appendix 6**.

At issue is whether the survey and the bibliometric lenses are in reasonable accord as to the strength of the common set of sub-areas. The answer is not straightforward for at least the following reasons:

- The concept of *strength* in our bibliometric analysis was explicitly two-dimensional: (i) the specialization index (SI) is an indicator of the relative intensity of published research done in Canada in a given field; and (ii) the average relative impact factor (ARIF) is a proxy for its quality.
- Survey respondents, on the other hand, were asked to consider jointly both the quality and intensity (or quantity) of Canadian research in a sub-area in arriving at a *blended* assessment of strength relative to other advanced countries. This combined judgment of respondents was mapped into a one-dimensional measure of strength on a single seven-point scale.
- There is no unambiguous way to collapse the two bibliometric dimensions, SI and ARIF, into a single indicator of strength that could be directly compared with the survey's seven-point scale. For example, if a field has a low SI and a high ARIF (or vice versa) should it be considered strong or weak?
- There is also a more subtle non-comparability that results from the definition and boundaries of the sub-areas. Survey respondents will themselves have read different things into the labels attached to the sub-areas in the questionnaire. And the bibliometric definitions of the sub-areas (many of which were specially created for this study) involve judgments on which journals to include or exclude to compute the rating for a particular field.

For these reasons, the degree of concordance or divergence between the bibliometric and survey measures of strength can be estimated only very roughly. In particular, we have made no attempt to combine the SI and ARIF parameters into a single bibliometric index of strength since there is no uniquely appropriate way for the two to be combined. Instead, we compared the survey strength rating — i.e., the weighted average rating on the seven-point scale — with each of the two bibliometric strength parameters, SI and

[8] To facilitate bibliometric comparison, we collapsed the five survey sub-areas of computer science into one combined "computer" category; combined elementary particle and nuclear physics; and combined climate science and meteorology. We also omitted the 10 Humanities sub-areas, since these were not analyzed bibliometrically.

ARIF, separately. We adopted the rough and ready procedure detailed in **Appendix 6**, which allocates sub-areas among nine cells according to whether:

- The survey strength rating of the sub-area is in the top 30 percent, the bottom 30 percent or the middle 40 percent as ranked by mean value on the seven-point scale; and
- The bibliometric "strength" parameter — whether ARIF or SI — is in the top 30 percent, bottom 30 percent or middle 40 percent.

The results are summarized in **Figure 5.21(a)** and **(b)**.

The main diagonal blocks in **Figure 5.21** — i.e., lower left, middle, and upper right — denote areas of rough concordance between the survey and the bibliometric parameters. For example, both the survey and ARIF ratings indicate that Cancer Research (upper right cell in **Figure 5.21[a])** is an area of strength in Canada, while Experimental Psychology (lower left cell) is in the bottom 30 percent of sub-areas for both survey and ARIF. Conversely, the upper left and lower right blocks in the matrix identify areas of significant divergence. For example, Analytical Chemistry is strong on ARIF but has a weak rating from the survey. Geophysics & Seismology is the opposite — relatively weak according to ARIF but strong in the survey.

Figure 5.21(b) is the companion matrix that compares the survey strength rating with the bibliometric rating of specialization in Canada relative to the world (SI). There is no systematic similarity between the two tables. In fact, SI and ARIF are not positively correlated themselves.

We make no attempt to interpret the possible reasons for divergence between the survey and each of the bibliometric indicators in **Figures 5.21**. This is better done by the various expert communities. We would only observe that the areas of clear divergence between the bibliometric and survey measures do not appear to fit any systematic pattern and certainly would not invalidate the identification of four clusters of Canadian S&T strength derived from the survey responses.

In the foregoing, we compared the survey and bibliometric lenses applied to areas of scientific research, where journal publication is usually the key output. Might a similar comparison be made between the technometric data and the survey results in respect of Canada's strengths in areas of technology application?

Figure 5.21(a)

Survey and Bibliometrics Compared – Strength vs ARIF

(Within blocks, sub-areas in decreasing order of ARIF)

Survey Strength Rating \ Average Relative Impact Factor (ARIF)	Weak (Bottom 30%)	Mid-rated (Middle 40%)	Strong (Top 30%)
Strong (Top 30%)	ARIF (Weak) Survey (Strong) Geophysics & Seismology Mining & Mineral Processing Communications, Media & Culture Geog; Urban & Enviro Planning Electrical Engineering	ARIF (Mid) Survey (Strong) Climate Science & Meteorology Geology Physical Geog, Remote Sensing Forestry Engineering Mental Health, Addiction Neurobiology / Neurosciences Optics; Lasers Geochemistry & Geochronology Electronic & Photonic Engineering Hydrology	ARIF (Strong) Survey (Strong) Cancer Research Oceanography Circulatory & Respiratory Health Astron, Astro Physics, Cosmology Infection & Immunity Genetics, Genomics, Proteomics Genetics Petroleum Eng / Polymer
Mid-rated (Middle 40%)	ARIF (Weak) Survey (Mid) Applied Math Business & Management Science Plant Biology Environmental Engineering Aging Law & Criminology Population & Public Health Agricultural Engineering Materials Engineering Political Sci & Public Administration Civil Engineering	ARIF (Mid) Survey (Mid) Animal Biology Cell Biology Soil Science Biochemistry Pure Math Microbiology Biomedical Engineering Computer Sciences Economics Other Chemical Engineering Aerospace Engineering	ARIF (Strong) Survey (Mid) Clinical Research Condensed Matter Physics Inorganic Chemistry Nuclear Engineering Human Development & Youth Health Polymer Chemistry Nutrition, Metabolism & Diabetes Organic Chemistry Ecology & Evolution Biology Physical Chemistry
Weak (Bottom 30%)	ARIF (Weak) Survey (Weak) Experimental Psychology Education Nano and Regenerative Medicine Sociology Linguistics Demography Health Services & Policy	ARIF (Mid) Survey (Weak) Dental Science Social Psychology Anthropology Kinesiology Other Mechanical Engineering Math Statistics Veterinary Science Industrial Engineering Nanoscale Biosciences Plasma Physics Physiology	ARIF (Strong) Survey (Weak) Analytical Chemistry Nanoscale Physical Science Nuclear Phys & Elementary Particles Nursing Science Musculoskeletal Health & Arthritis

Figure 5.21(b)

Survey and Bibliometrics Compared – Strength vs SI

(Within blocks, sub-areas in decreasing order of SI)

Survey Strength Rating	Bibliometric Specialization Index (SI): Weak (Bottom 30%)	Mid-rated (Middle 40%)	Strong (Top 30%)
Strong (Top 30%)	SI (Weak) Survey (Strong) Cancer Research Electronic & Photonic Eng Petroleum Eng / Polymer Communications, Media & Culture Optics; Lasers	SI (Mid) Survey (Strong) Genetics Geophysics & Seismology Oceanography Electrical Engineering Circulatory & Respiratory Health Genetics, Genomics, Proteomics Astronomy, Astro Phys, Cosmology Infection & Immunity Mental Health, Addiction	SI (Strong) Survey (Strong) Forestry Engineering Geology Hydrology Mining & Mineral Processing Climate Sci & Meteorology Geochemistry & Geochronology Geog; Urban & Enviro Planning Neurobiology / Neurosciences Physical Geog, Remote Sensing
Mid-rated (Middle 40%)	SI (Weak) Survey (Mid) Biomedical Engineering Law & Criminology Aerospace Eng Organic Chemistry Physical Chemistry Polymer Chemistry Condensed Matter Physics Inorganic Chemistry Materials Engineering Nuclear Engineering	SI (Mid) Survey (Mid) Business & Management Science Other Chemical Engineering Political Science & Public Admin Computer Sciences Economics Human Development & Youth Health Plant Biology Biochemistry Clinical Research Nutrition, Metabolism, Diabetes Pure Math Applied Math Cell Biology Environmental Eng Microbiology	SI (Strong) Survey (Mid) Civil Engineering Animal Biology Ecology & Evolution Biology Population & Public Health Soil Science Aging Agricultural Engineering
Weak (Bottom 30%)	SI (Weak) Survey (Weak) Nanoscale Biosciences Nuclear Phys & Elementary Particles Other Mechanical Engineering Analytical Chemistry Dental Science Nano and Regenerative Medicine Nanoscale Physical Science Plasma Physics	SI (Mid) Survey (Weak) Musculoskeletal & Arthritis Nursing Science Anthropology Math Statistics Veterinary Science Education Sociology Demography	SI (Strong) Survey (Weak) Experimental Psychology Kinesiology Health Services & Policy Linguistics Physiology Social Psychology Industrial Engineering

Weak (Bottom 30%) Mid-rated (Middle 40%) Strong (Top 30%)

Bibliometric Specialization Index (SI)

There is an important distinction to be drawn between (a) assessment of Canada's strength in areas of *technology application* and (b) the prevalence of inventive activity in particular areas in Canada. The two measures are very different. Survey respondents were expressing opinions on the quality and quantity of particular technologies and technical capabilities deployed in Canada — e.g., wireless networks; medical imaging; automotive technologies; pulp and paper production; pipelines. Most major sectors of Canada's economy are technologically sophisticated, but typically the technology is sourced from throughout the world or is based on inventions that have originated elsewhere.

The technometric measures address a different dimension of S&T strength — i.e., developing patentable goods and services in Canada. There is no necessary correlation between Canada's strength in areas of technology application and its strength in patenting. The two will be related in some areas of technology, but for the purposes of our study we consider them to be complementary. We therefore have not attempted to identify any divergence between the technometric and survey ratings.

Survey and Metrics — Conclusion

The principal conclusion of the expert opinion survey is that Canada's S&T strengths fall primarily into four broad clusters: natural resources; information and communications technologies; health and related life sciences; and environment.

The bibliometric analysis of scientific research publication is broadly consistent with the main survey finding. Canada publishes intensively in areas related to natural resources and the environment, in many of which publication quality is above the world average. Canada is somewhat less intensively represented in health and related life sciences, but the quality tends to be high overall. The ICT cluster does not show prominently in the bibliometric analysis in part because of the limitations of sub-field classification and primarily because of the more technological orientation of ICT. Canada's strength in the latter was demonstrated in the technometric data.

There are several other areas of notable strength revealed in both the survey and bibliometric data. The two lenses were, however, not always in accord. The bibliometric analysis reveals the exceptionally high quality of Canadian published research in many domains of chemistry and physics, areas less highly rated in the survey. Conversely, in some of the newer transdisciplinary fields — e.g., communications, media and cultural sciences — the survey results suggested greater Canadian strength than bibliometric data show.

Overall, the results indicate that the survey and bibliometric lenses are both reinforcing and complementary.

View from Abroad

A foreign perspective on Canada's S&T strengths is an important complement to the survey and bibliometric analysis. The view from abroad may be more objective. And the areas in which foreign interests seek to collaborate with Canada are presumably those where we are perceived to have some special strengths.

We were unable, in the time available, to systematically canvas a substantial and informed body of foreign views on Canada's S&T strengths. The survey results include 69 responses from abroad but this number is too small and non-representative to be a reliable basis for conclusions. There is, at present, no formal database that describes all of Canada's international agreements in respect of S&T, let alone the multitude of informal and semi-formal collaborations between scientists in Canada and colleagues around the world.

We have therefore had only very limited ability to draw upon the relevant views from abroad. Based on information provided by Canada's S&T Counsellors and Trade Commissioners, we have summarized in **Figure 5.23** a number of S&T Memoranda of Understanding and formal agreements. These include agency-to-agency agreements and collaborations involving a number of countries. Some flavour of the substance is provided in **Figure 5.23**.

It is emphasized that the activities outlined in the table do not include any measure of intensity of collaboration. The US is of course by far the most important S&T partner for Canada based, for example, on the number of joint publications, co-patents, and commercial and academic interchanges. The UK is in second place.

The agreements listed in **Figure 5.23** concur reasonably well with the four clusters of strength that have been identified. There are many agreements related to health and life sciences, to natural resources and to ICT. We note in particular the diverse collaborations with China. China's R&D expenditure has more than doubled since 1996 to more than 1.4 percent of GDP in 2004, and its S&T productivity (publications, citations, patents) will increase significantly in the next few years. Also of note, Canada's most recent S&T agreement was signed with India in 2005. Although India is developing at a slower pace than China, it is also destined to have a significant impact on global S&T.

Figure 5.23

International S&T Agreements, Collaborations and Memoranda of Understanding with Canada

Country / Cluster	Denmark	Finland	India	Italy
Natural Resources			• Canada-India S&T Agreement (Earth, Life Sciences, ICT) *(2005)*	
Health and Life sciences	• Genome Canada–Danish Ministry of S,T&I *MOU extended in May (2005)*	• CIHR (Neurosci) and the Academy of Finland	• Canada-India S&T Agreement • CIHR and the Indian Council for Medical Research *(2005)*	• Canada–Italy Joint Research Projects (12 institute-to-institute joint projects) *2005*; 7 Projects in the Health and Life Sciences
ICT			• Canada-India S&T Agreement	• Canada–Italy Joint Research Projects 2 Projects in ICT
Environmental S&T			• Canada-India S&T Agreement	
Other		• CSA and Tekes (National Technology Agency of Finland)		• CSA and Agenzia Spaziale Italiana • NRC & Consiglio Nazionale d. Ricerche • Canada–Italy Joint Research Projects 3 Projects in Advanced Materials, Nanotechnology

Note:
1. See various acronyms used throughout this document: CIHR = Canadian Institutes of Health Research; CSA = Canadian Space Agency; NRC = National Research Council of Canada; ICT = Information and Communications Technologies; CCSPI = Canada-California Strategic Partnership Initiative
2. In the list of Memoranda of Understanding (MOUs) or Agreements, there are some that are umbrella MOUs. These are the frameworks under which further bilateral agreements are signed between specific organizations/institutions with similar interests (see case of India and Italy).

Country / Cluster	Netherlands	Norway	People's Republic of China	Spain
Natural Resources		• AquaNet and Norwegian Institute of Fisheries and Aquaculture Research	• NRC & Ministry of S&T *(2003)* • Council of Forest Industries, UBC and U of Tongyi *(2001)* • Council of Forest Industries, UBC & Shanghai *(2001)* • Geological Survey of Canada and China Seism Bureau *(2002)*	• Cooperation NRC and Spanish NRC *(2003)* • Cooperation agreement between Genome Canada and Genome Spain *(2002)*
Health and Life Sciences	• Genome Canada and Netherlands Genomics Initiative		• CIHR and NSF of China *(2005)* • Industry Canada (see ICT)	• Genome Canada and Genome Spain *(2002)*
ICT	• *Informal:* CANARIE and SURFNet history of collaboration		• NRC & Ministry of S&T *(2003)* • Government of Alberta and Ministry of S&T *(2001)* • Industry Canada & Hong Kong (Biotech and ICT) *(2002)*	
Environmental S&T			• NRC and Ministry S&T *(2003)* • Cooperation Enviro Protection & Climate Change *(2001)*	• Cooperative agreements between provincial and regional government and academic organizations in environmental technologies
Other			• Government of Alberta and Ministry of S&T *(2001)* • Atomic Energy Canada Ltd. And China National Nuclear Corporation *(2003)*	• Canadian Light Source and Spanish Synchrotron

Country / Cluster	Singapore	Sweden	United Kingdom	United States
Natural Resources				
Health and Life Sciences		• Genome Canada and Karolinska Inst. *(2001)*	• Structural Genomics Consortium (UK, Canada, Sweden). *(2003)*	• CIHR and NIH (several) • CIHR and Gates Foundation • Cda–Calif. Strategic Partnership
ICT				• CommNexus San Diego - Wireless Innovation Network of BC • Cda–Calif. Strategic Partnership • Ottawa–Arizona, Photonics Commercialization Alliance
Environmental S&T			• Extensive bilateral collaboration	• UBC and Arizona State University • CSA and NASA / US National Oceanic and Atmospheric Administration (over 50 agreements)
Other	• Alberta Ministry of Innovation and Sciences and A*STAR (some elements relate to ICT) • NRC and A*STAR *MOU lapsed in January 2005 but several projects are still ongoing*	• CANEUS and Angström Aerospace Corporation		• Defence Research and Development Canada and US Department of Homeland Security • CSA and NASA / US National Oceanic and Atmospheric Administration (over 50 agreements) • Natural Resources Canada and US Department of Energy (Energy R&D, International Nuclear Research Initiative) *(2003)* Cda–Calif. SPI Inter-American Collaboration in Materials Research (Includes Mexico and certain South American Countries)

6. CANADA'S S&T INFRASTRUCTURE

This chapter identifies the components of S&T infrastructure that are believed to represent advantages for Canada relative to other economically advanced countries. Canada's S&T infrastructure encompasses a broad spectrum of facilities, programs and policies that enable people and institutions to advance knowledge and apply it for the benefit of Canadian society. Research facilities and laboratories across the country constitute the tangible infrastructure needed to undertake leading-edge research and to train the next generation of Canadian scientists and technologists. Complementing this is "soft" infrastructure, which includes a wide array of government programs and policies, as well as other intangibles ranging from the regulatory system to the science literacy of Canadians.

We identify three major specific categories of infrastructure that underpin Canada's broad S&T capacity:

- Infrastructure that facilitates the production of knowledge — e.g., universities and research granting agencies;
- Infrastructure that promotes the commercialization and translation of research results — e.g., industrial research support programs and tax incentives; and
- Infrastructure that supports other public policy objectives that draw upon, or significantly affect, S&T activity — e.g., related to health, public safety, resource use, national data collection and analysis, and various regulatory systems.

Results of the Opinion Survey

The section of the survey dealing with infrastructure was built around the three broad categories identified above. These were in turn divided into 48 sub-categories. Respondents were asked to rate, on a seven-point scale, the degree of advantage that each of the sub-categories represented for Canada relative to other economically advanced countries.

Responses in this portion of the questionnaire were heavy, with most infrastructure components rated by more than 700 respondents and none by fewer than 470. We report results according to the percentage of respondents who rated a particular element of infrastructure as a strong advantage for Canada — i.e., ratings 5, 6 or 7. For completeness, we also include summary figures for ratings of disadvantage (1, 2 or 3) and *neither* an advantage or disadvantage (4).

Knowledge Production and Support

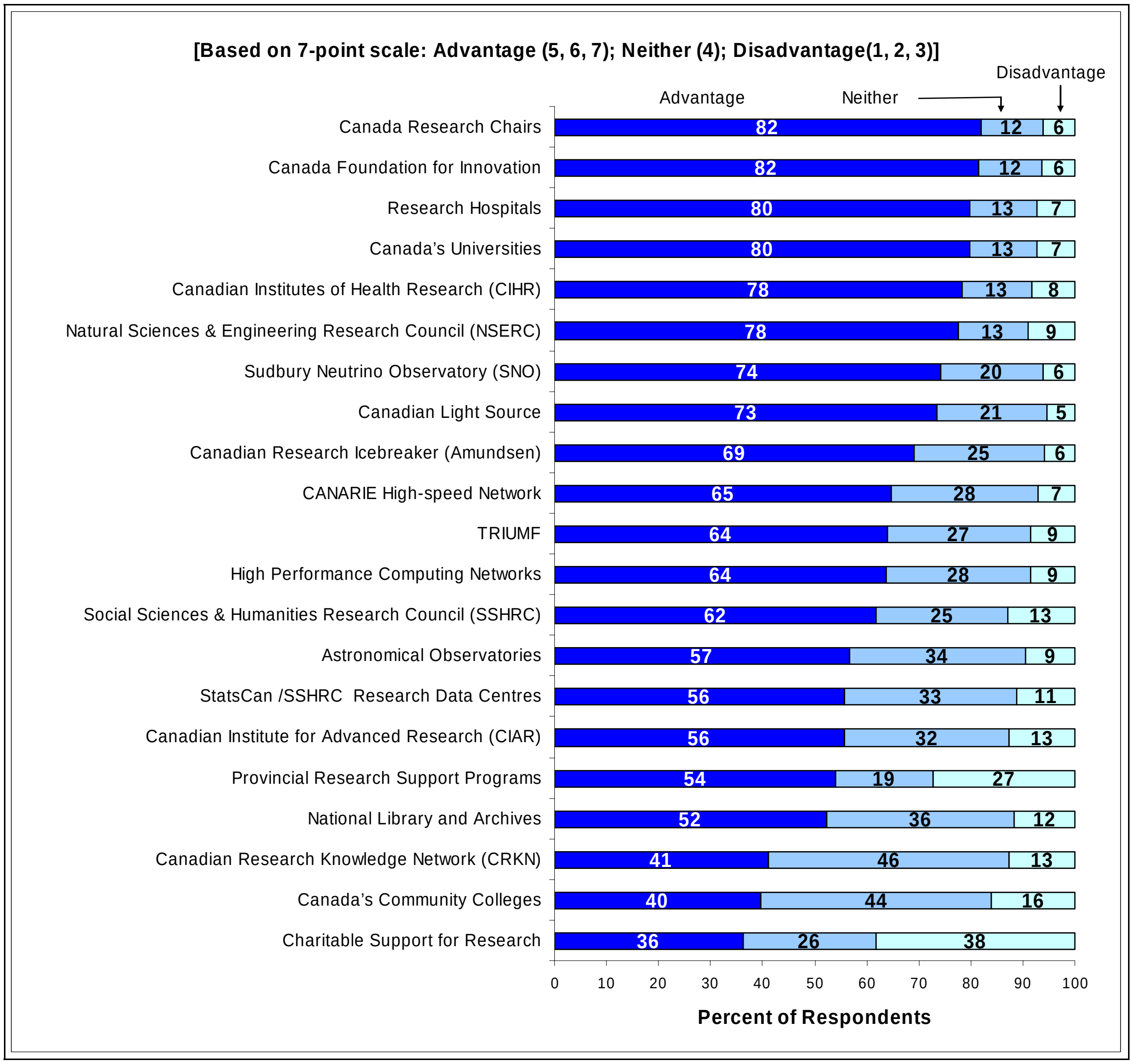
Respondents were largely in agreement that Canadian universities, research hospitals, the granting agencies, the Canada Foundation for Innovation (CFI) and the Canada Research Chairs program represented strong advantages for Canada in respect of knowledge generation and the production of highly trained people (**Figure 6.1**). The

> The most important strength for S&T is funding good basic science because the most important developments can not be predicted. *Fellow, Canadian Academy of Health Sciences*

ratings were consistent across the three main groups of affiliation: government, industry and university. The Canada Research Chairs program, CFI, research hospitals and Canada's universities, as well as two of the research granting agencies (NSERC and CIHR), all rank in the top 10 for each affiliation group (**Figure 6.2**). These six were also ranked in the top 10 by respondents from most provinces.

Figure 6.1

Survey Results on S&T Knowledge Production and Support



CFI has allowed Canadian researchers to acquire internationally competitive capital equipment infrastructure. Despite some recent limited operation funds to support this, there seems to be a great discrepancy between the sum invested in capital equipment and in money invested in operation, in particular manpower. This will, if not fixed, in a few years lead to an exodus of top researchers and the recognition that billions of tax dollars were invested without significant benefit to Canadian society. *Fellow, RSC Academy of Sciences*

Provincial co-funding of CFI-supported facilities at universities, hospitals, colleges and other research institutions, as well as specialized provincial research bodies — e.g., the Alberta Heritage Foundation for Medical Research, the Michael Smith Foundation for Health Research and the Fonds québécois de la recherche sur la nature et les technologies — have also been major factors in the rejuvenation of Canada's research infrastructure. CFI-funded projects generally require 60 percent of the total funds to be provided from other sources, provinces being, directly or indirectly, the principal co-contributors.

Conditions that facilitate multidisciplinary teams and projects are another important form of intangible infrastructure that are also well-aligned with the contemporary trend in science. A case in point is the Canadian Institutes of Health Research (CIHR), created in 2001. The CIHR adopted a multidisciplinary focus from the outset and created a number of Institutes to address cross-cutting issues such as aging, aboriginal health, youth and gender — issues that previously did not receive much attention within scientific circles in Canada.

…many of the front-line, exciting and innovative areas of scientific investigation as it relates to human health require a multi-disciplinary approach that spans both the physical/life sciences and the health sciences. Proposals at the interface of NSERC-funded and CIHR-funded research are increasingly falling between the cracks because neither agency has the mandate or the capacity to adequately respond to and fund such requests. *Fellow, RSC Academy of Sciences*

Figure 6.2

Knowledge Production and Support — Survey Results by Affiliation and Age

	Percentage Rating Strong Advantage (Ratings of 5, 6 or 7)							
Infrastructure	**Total**	**Univ**	**Bus**	**Govt**	**<35**	**35–44**	**45–54**	**>55**
Canada Research Chairs	82	**86**	**72**	84	79	83	82	83
CFI	82	**86**	**74**	79	82	85	82	80
Research Hospitals	80	82	78	81	77	80	80	80
CIHR	78	80	78	83	84	71	78	80
NSERC	78	78	78	75	74	75	77	80
SSHRC	62	63	55	57	70	57	58	64

Note: Bolded figures indicate statistically significant variations from the overall rating — i.e., less than one percent probability that the difference was due simply to chance.

Survey results demonstrate the perceived overall strength of Canada's research infrastructure for knowledge production. There are differences of degree among provinces, which probably reflect varying degrees of regional awareness and relevance **(Figure 6.3)**. For example, when a "Big Science" facility (**Box 6.1**) is located in a particular province, respondents from that province might be expected to give a stronger rating. A case in point: the Canadian Light Source in Saskatoon was rated as "strong" by 88 percent of survey respondents from Saskatchewan and Manitoba while by only 73 percent of all respondents.

Figure 6.3

Knowledge Production and Support — Regional Perspectives

	Percentage Rating Strong Advantage (Ratings of 5, 6 or 7)							
Infrastructure	**Total**	**BC**	**AB**	**S/M**	**ON**	**QC**	**ATL**	**INTL**
Canada Research Chairs	82	82	83	84	80	86	80	85
CFI	82	82	83	79	82	86	79	69
Universities	80	82	83	76	79	83	72	82
Research Hospitals	80	80	88	75	79	80	74	80
CIHR	78	80	82	77	77	77	81	74
NSERC	78	73	83	76	77	81	76	76
SSHRC	62	61	56	56	61	67	63	72
CIAR	56	48	54	52	58	52	65	64
Prov. Research Support	54	49	60	**38**	53	**67**	**40**	55
Community Colleges	40	33	42	38	43	33	41	36
Charitable Support	36	33	39	34	39	34	34	36
Big Science Facilities								
SNO	74	74	**58**	78	76	73	80	79
Light Source	73	71	77	**88**	69	69	81	78
Ice Breaker	69	60	63	73	69	72	80	67
CANARIE	65	73	58	67	61	64	75	69
TRIUMF	64	73	65	73	60	54	74	79
Observatories	57	59	53	59	54	57	62	60

Note: Bolded figures indicate statistically significant variations from the overall rating — i.e., less than one percent probability that the difference was due simply to chance.

Box 6.1

"Big Science" in Canada

Canada is home to several major S&T facilities that contribute to both the advancement of knowledge and Canada's international reputation for research excellence. For example:

- **The CCGS *Amundsen*:** A state-of-the-art icebreaker that is also a platform for Arctic research initiatives. The *Amundsen* is being used by a Canadian-led international research consortium to advance understanding of the role of climate change on Arctic ecosystems.

- **The Canadian Light Source (CLS):** Canada's national synchrotron research facility, used to probe the structure of matter to analyze physical, chemical, geological and biological processes. CLS's initial focus is in three key areas: (1) biotechnology, pharmaceuticals and medicine; (2) mining, natural resources and the environment; and (3) advanced materials, information technologies and micro systems.

- **The Sudbury Neutrino Observatory (SNO):** The SNO detector, located two kilometres down a mineshaft in the Canadian Shield, provides unique ways to measure the properties of neutrinos from the sun and other astrophysical objects, thereby increasing our understanding of the evolution of the universe. SNOLAB is an expansion of the existing underground facility for the next generation of experiments exploring the frontiers of particle physics and astrophysics.

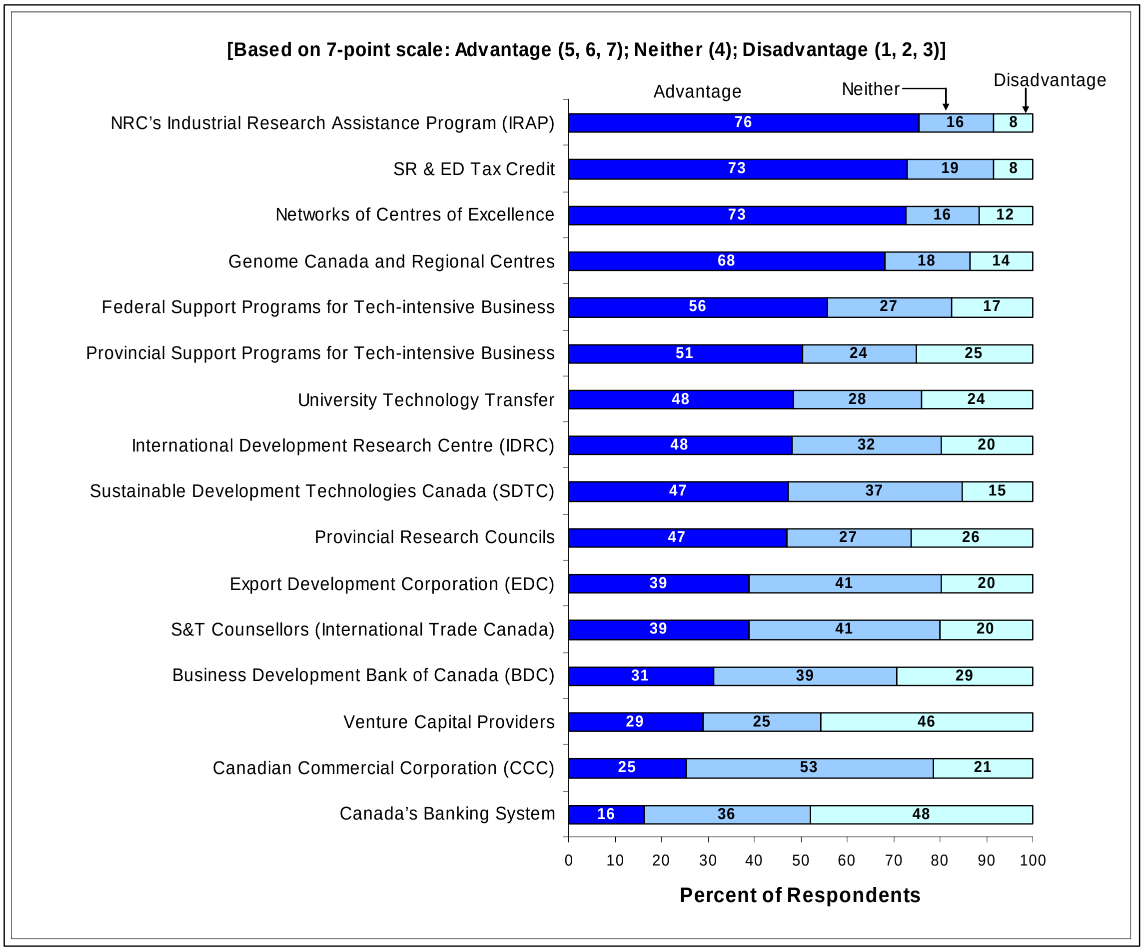
- **TRIUMF (Tri-University Meson Facility):** One of three subatomic physics research facilities in the world that specialize in producing extremely intense beams of particles. Scientists at TRIUMF are developing new radiopharmaceuticals, computer software, remote-controlled equipment, analysis of mineral samples, and many other high-tech applications.

- **CANARIE (Canadian Network for the Advancement of Research in Industry and Education):** Canada's advanced Internet organization that facilitates the development and use of next generation research networks and the applications and services to run on them. Its design has been replicated by many network operators, both in the research and commercial domains. The latest evolution, CA*net 4, will support innovation in the development of network-based applications that are essential for national and international collaboration, data access and analysis, distributed computing, and remote control of instrumentation required by researchers.

- **Astronomical Observatories:** The NRC's Herzberg Institute of Astrophysics, with support from the CFI, is playing a key role in the international partnership behind the Atacama Large Millimetre Array (ALMA) in Chile: 64 radio antennas that will work together as one of the world's most powerful radio telescopes to shed light on the formation of planets, stars, early galaxies and organic molecules in space. The NRC also helps to fund and operate the Canada–France–Hawaii Telescope.

Figure 6.4

Survey Results on Support for Commercialization/Translation of S&T



Support for the Commercialization and Translation of S&T

Survey respondents gave particularly high ratings to four components of infrastructure that support the commercialization or translation of research into applications that benefit the economy or society (**Figure 6.4**):

- The Industrial Research Assistance Program (IRAP) promotes technology development in small and medium-size businesses through advisory services and financial support.
- The Scientific Research and Experimental Development tax credit (SR&ED) — see **Box 6.2.**
- The Networks of Centres of Excellence (NCE) program supports multi-year collaborative research programs in key areas and involving universities, the private sector and government at locations across Canada. (There are currently 24 active NCEs.)

- Genome Canada is the primary funding and information resource relating to genomics and proteomics in Canada. It has five Genome Centres across the country. Together with these and other partners, including business, Genome Canada invests in and manages large-scale research projects in key areas such as agriculture, environment, fisheries, forestry, health and new technology development.

Although the overall ranking of Canada's commercialization/translation infrastructure was similar across affiliations and regions, certain elements of the system — including IRAP and the SR&ED tax credit — showed more variation (**Figure 6.5**). The rating of IRAP, for example, while nearly uniform across most of the country, was relatively low from respondents in Quebec., whereas Quebec respondents rated Provincial Research Councils significantly more favourably than did others.

Figure 6.5

Support for Commercialization/Translation of S&T — Several Perspectives

	Percentage Rating Strong Advantage (Ratings 5, 6 or 7)										
Infrastructure	**Total**	**Univ**	**Bus**	**Gov**	**BC**	**AB**	**M/S**	**ON**	**QC**	**ATL**	**INTL**
IRAP	76	**71**	**82**	**82**	80	84	80	76	**66**	82	70
SR&ED	73	**66**	**84**	78	74	72	71	74	78	63	67
NCE	73	73	69	79	76	71	72	75	72	65	66
Genome Canada	68	65	65	74	75	67	67	66	71	60	76
Fed Supp for Tech Bus	56	**48**	**64**	59	61	52	59	52	61	53	63
Prov Supp for Tech Bus	51	48	57	52	48	48	38	51	60	40	52
Univ Tech Transfer	48	51	46	45	**61**	46	42	46	50	42	54
IDRC	48	47	42	46	48	36	50	52	46	48	48
Sust. Dev. Tech Cda.	47	46	47	45	44	46	43	46	56	52	32
Prov. Resh. Councils	47	49	48	44	40	50	36	42	**65**	40	52
Export Dev Corp	39	**31**	**48**	43	38	40	41	38	43	36	23
S&T Counsellors	39	**28**	**46**	45	44	39	33	35	41	33	52
Business Dev Bank	31	26	36	35	22	30	34	27	**43**	27	41
Venture Capital	29	26	30	28	22	33	33	28	31	25	39
Cdn Commercial Corp	25	18	**33**	27	17	27	24	26	32	22	14
Commercial Banks	16	14	16	16	10	11	21	15	18	18	37

Note: Bolded figures indicate statistically significant variations from the overall rating — i.e., less than one percent probability that the difference was due simply to chance.

Respondents also differed on the importance of the SR&ED tax credit, with those having a business affiliation ranking it first among all categories of infrastructure: 84 percent claimed it to be a strong advantage for Canada. Academic respondents, on the other hand, accorded this program a significantly lower rating: only 66 percent rated SR&ED as a strong advantage. It is apparent from these and other infrastructure ratings that a respondent's affiliation can have a significant influence on the perceived advantage conferred by the infrastructure. Those groups for whom the infrastructure provides a direct benefit tend to rate it as a stronger advantage — a correlation that is of course not surprising.

Box 6.2

Industrial R&D Promotion Through Tax Incentives — SR&ED Tax Credit

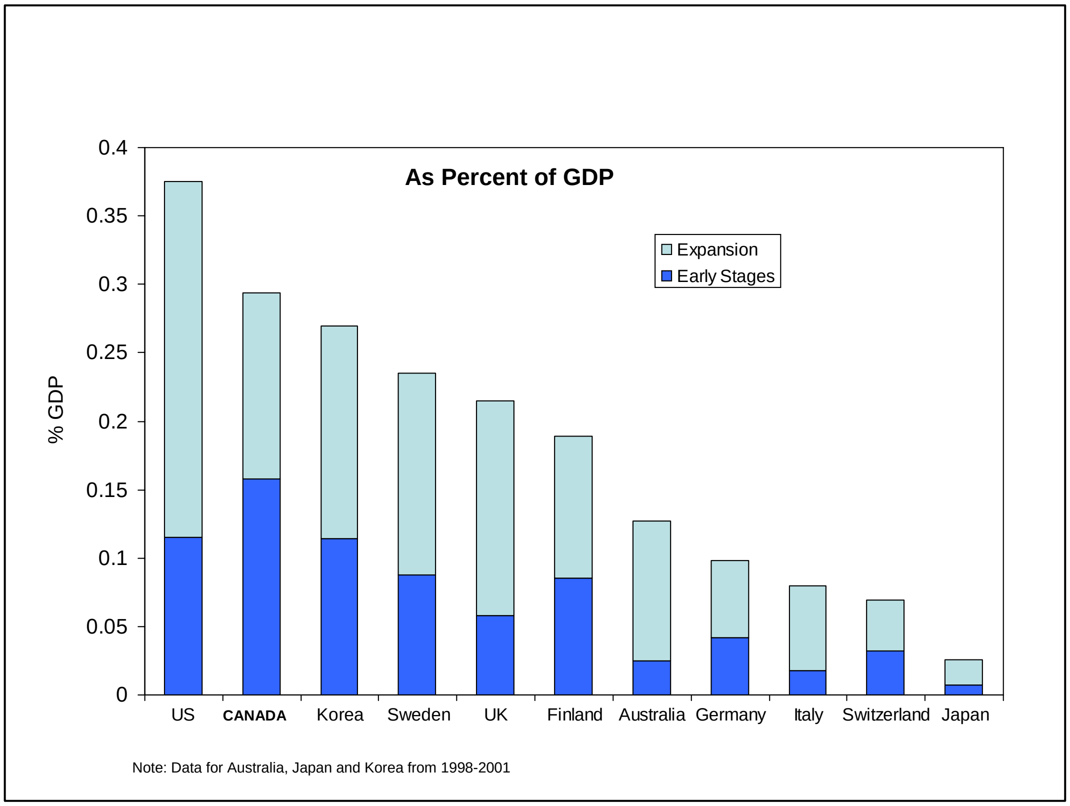
Tax credits are an incentive intended to promote industrial R&D. Canada's Scientific Research and Experimental Development (SR&ED) tax credit system has been in place since the mid-1980s. Each year, about 11,000 claimants make use of the system, which represents a tax expenditure (i.e., tax revenue foregone) estimated to be roughly $2.5 billion annually. While there have been some adjustments to the program during the last 10 years to improve its effectiveness, the basic rate and structure have remained largely unchanged.

Over that period, almost all the provinces have either improved or added their own SR&ED tax incentives. Most analyses suggest that the combined federal and provincial rates are sufficiently high to place Canada among the most attractive places in the world to carry out industrial R&D. As the number of OECD countries offering R&D tax credits increases, the competition among global tax jurisdictions for R&D-related investment heats up. A recent study commissioned by the Information Technology Association of Canada (ITAC) and the Ottawa Centre for Research and Innovation (OCRI) examined the SR&ED tax credit system and raised issues regarding refundability to claimants, as well as the program's effectiveness in boosting incremental industry spending (Toms and Watters, 2006).

One finding from the survey that is perhaps surprising is the relatively low rating given to Canada's financial support infrastructure for S&T. For example, fewer than 30 percent of survey respondents cited venture capital providers as a strongly advantageous element of Canada's infrastructure, among the lowest ratings of any element in the entire survey. Yet many analyses have shown that Canada's venture capital flows (as a percent of GDP) rank second only to the US. Canada's venture investment in early stage projects is particularly strong (**Figure 6.6**). Further study is required to fully understand the widespread negative perceptions held by the S&T community, not only of venture capital providers but also of commercial banks and of the government institutions engaged in funding commercial activity in Canada.

Figure 6.6

Venture Capital Investment: 2000–2003



Source: OECD Science, Technology and Industry Scoreboard 2005

> Canada could build on its health care system and health researchers for translating research into commercial applications to provide assistance to others countries building their health care systems. The potential for this application has not been fully realized. *Fellow, Canadian Academy of Health Sciences*

The principal focus of the infrastructure that is evaluated in **Figure 6.4** is support for the commercial application of S&T. But infrastructure is also required to translate Canadian research and technical capability in ways that support international development. The International Development Research Centre (IDRC) has, over many years, established a strong reputation internationally for Canada in this regard. **Box 6.3** describes one specific example in which the capabilities of IDRC, CFI and the Canadian International Development Agency (CIDA) combine to achieve development objectives.

Box 6.3

S&T as a Lever of Development

A key component of Canada's international aid policy is the export of Canadian scientific and technical expertise to build capacity in developing countries. A recent survey conducted by Statistics Canada shows that, in 2004–05, the federal government spent 2.8 percent of its R&D budget, or just over $150 million, on projects intended to directly benefit developing countries (Statistics Canada, 2005).

The great majority of the funds were allocated through IDRC and CIDA. Most of the projects were in the areas of public health, agriculture production and technology, information and communications technology, environmental and energy management, and education.

These projects often came in the form of partnerships. In one example, a Canada–Africa team is searching for a vaccine for HIV/AIDS. Dr. Frank Plummer and his team at Winnipeg's International Centre for Infectious Diseases are trying to pin down the genetic and molecular structure that makes some people immune to HIV. An investment from CFI's International Access Fund has helped broaden the search for a vaccine by supporting the construction of a new laboratory at the University of Nairobi that will be used for research and the training of both Canadian and African graduate students.

Government S&T Facilities and the Regulatory System

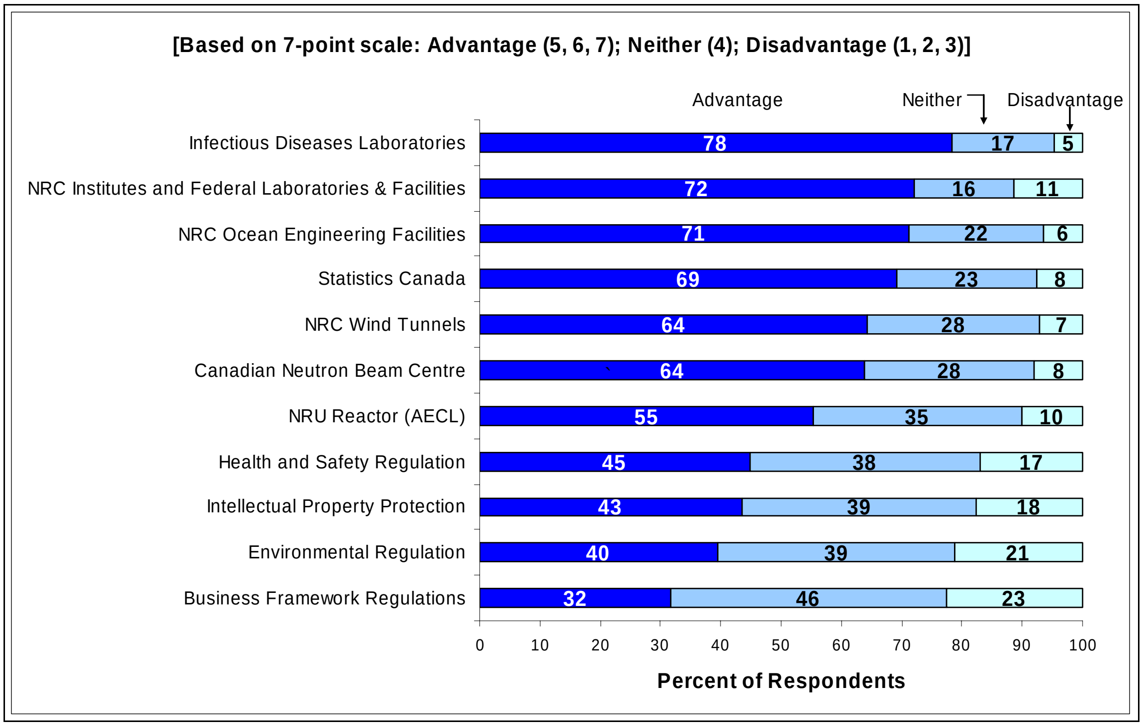
In addition to government support for infrastructure related to knowledge production and commercialization of research, the public sector maintains an extensive S&T infrastructure in support of many policy objectives related to, for example, health and safety, standards setting, regulatory policy and enforcement, and national lab facilities (**Box 6.4**). The survey results in respect of this category of infrastructure are summarized in **Figure 6.7**. The Infectious Diseases Laboratories were ranked highest, with strong support regardless of region or affiliation (**Figure 6.8**). A substantial proportion of respondents also ranked NRC facilities and federal laboratories and Statistics Canada as important advantages for Canada.[9]

> Canada could use data accumulated as part of its universal health care system — merged to other key data sets, including education and social services — to develop world class research potential in many areas, including pharmaceutical safety and effectiveness research, child well being, and genetic / behavioural / environmental influences on health. *Canada Research Chair*

[9] Survey respondents were able to add to the infrastructure categories in the questionnaire. A number of specific facilities were suggested, including individual government labs, the Canadian Space Agency, the Perimeter Institute, various mathematics institutes, NEPTUNE (a new sea floor observatory), among others. The most frequently mentioned individual facility was the Canadian Institute for Scientific and Technical Information (CISTI), a part of NRC. Several respondents also suggested that immigration policy was an important element of soft infrastructure that could facilitate or inhibit the attraction of S&T skills to Canada.

Figure 6.7

Survey Results on Federal S&T Infrastructure and the Regulatory System



By contrast, the four regulatory elements in the survey — health and safety, intellectual property, environment, and business framework — received remarkably low support compared with the great majority of infrastructure rankings. Fewer than half of respondents rated them as providing a relative advantage for Canada (see bottom bars in **Figure 6.7**).

Regulation is often perceived as an inhibitor, even though rules to protect intellectual property and to safeguard competition, to take just two examples, are needed for markets to function efficiently and fairly. And environmental and health and safety regulations, in addition to serving important social objectives, can also stimulate innovation and new market opportunities. The challenge is to design regulations that achieve their objectives while minimizing unintended negative consequences — i.e., *smart* regulations. The survey results suggest that, from the perspective of a significant proportion of S&T stakeholders, Canada's regulatory frameworks are falling short. These views are broadly held irrespective of affiliation or region (**Figure 6.8**).

Figure 6.8

Support for Federal S&T Infrastructure and the Regulatory System — Several Perspectives

	Percentage Rating Strong Advantage (Ratings of 5, 6 or 7)										
Infrastructure	**Total**	**Univ**	**Bus**	**Gov**	**BC**	**AB**	**M/S**	**ON**	**QC**	**ATL**	**INTL**
Infectious Diseases Labs	78	75	76	77	85	81	91	76	71	85	77
NRC Inst. and Fed Labs	72	68	68	69	61	76	80	72	70	81	81
NRC Ocean Eng. Facilities	71	67	66	72	66	67	69	70	71	81	81
Statistics Canada	69	71	**58**	67	70	69	60	68	62	77	75
NRC Wind Tunnels	64	59	66	66	51	55	71	65	65	78	72
Canadian Neutron Beam Centre	64	65	64	55	65	67	68	62	56	68	82
NRU Reactor	55	57	53	53	41	60	56	56	52	66	72
Regulatory System											
Health and Safety Regulation	45	44	44	41	34	45	44	45	48	44	56
Intellectual Property Protection	43	40	47	40	39	46	43	**38**	50	44	62
Environmental Regulation	40	40	39	37	33	44	46	39	37	38	50
Business Framework Regulation	32	29	32	31	26	26	27	31	33	25	**59**

Note: Bolded figures indicate statistically significant variations from the overall rating — i.e., less than one percent probability that the difference was due simply to chance.

The results reported from the survey do not cover all relevant dimensions of S&T infrastructure. Canada's public school system is of course the first — and for many, the only — contact with formal training in the foundations of science and technology. As such, schools are a fundamental element of Canada's S&T infrastructure. And by international standards most appear to be doing a good job. This is illustrated by the strong Canadian results in a recent evaluation of mathematics, science and literacy skills of 15-year olds around the world (**Box 6.5)**.

Skills obviously represent a key element of the soft infrastructure required in order to be competitive globally. Competition among institutions worldwide to attract and retain the best research talent is an indication of the importance of this intangible, yet fundamental, type of infrastructure. Programs such as the Canada Research Chairs and the CFI New Opportunities Fund have been effective in attracting and retaining top-quality faculty at Canadian universities. While these programs are attracting researchers at the peak of their careers, they are not designed to address broader and more systemic issues that may prevent Canada from taking full advantage of its people and talent. In this regard, there continue to be subtle barriers linked to culture and role stereotypes that distort the

Box 6.4

The Role of Government Science

Government science plays an important role in advancing the social, economic and strategic interests of Canada. In the report *Building Excellence in Science and Technology (BEST): The Federal Roles in Performing Science and Technology*, the Council of Science and Technology Advisors (1999) identified four key roles for the government in performing S&T:

- Support for decision making, policy development and regulations
- Development and management of standards
- Support for public health, safety and environmental or defence needs and
- Enabling economic and social development.

In fulfilling these roles, the Government of Canada maintains an extensive system of laboratories, institutes, specialized research facilities and statistical services. Federal intramural R&D spending was almost $2.3 billion in 2004.

Government S&T is increasingly conducted in partnership and collaboration with other government bodies, the private sector, universities and academic researchers. Two factors are driving this trend: (1) the increasingly complex and interdisciplinary nature of science and of the issues to which it is applied; and (2) limited financial resources in relation to rising demands and costs (*Science and Technology in Support of Mission Critical Goals,* 2005, p. 5).

Government science is also facing challenges in the area of human resources due to the number of scientists and engineers who will be retiring in the next few years. Replacement recruiting faces the challenge of a very competitive market for the required S&T skills (*Science and Technology in Support of Mission Critical Goals*, 2005, p. 12).

educational choices and career opportunities of certain groups. For example, recent cross-country evidence from the OECD (2006 [b]) demonstrates significant and persistent gender imbalances with women underrepresented in fields such as computing science and engineering and men underrepresented in the life sciences.

Other Lenses — Published Studies and the View from Abroad

Over the past five years, many studies have provided assessments of aspects of Canada's infrastructure strengths. Often industry-centric, they identify an array of hard and soft infrastructure components.[10] One theme in the literature on infrastructure that supports S&T innovation is the important role played by geographic concentrations of specialized capabilities (**Box 6.6**).

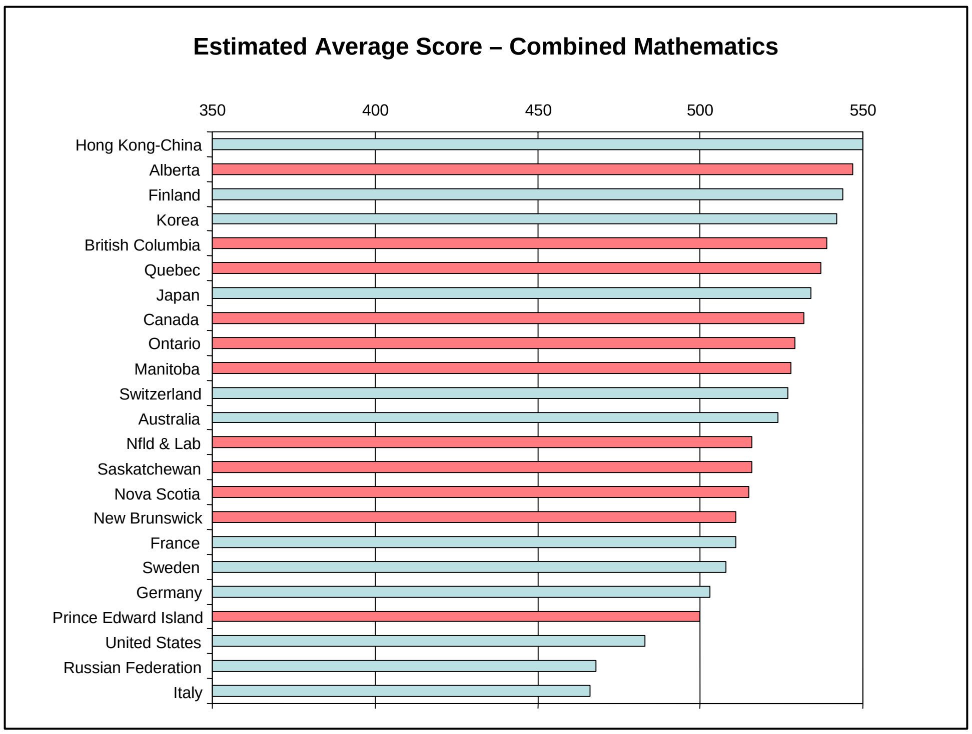
[10] Recent examples include: the *Assessment of Canadian Research Strengths in Nanotechnology* (Office of the National Science Advisor, 2005); the *OECD Case Study on Innovation in Energy Technology* (2006 [d]); *Indicators of Innovation in Canadian Natural Resources Industries* (Sharpe and Guilbaud, 2005); and *OECD Economic Survey of Canada* (2006[a]).

Box 6.5

Canada's Grade School System is an S&T Strength

The Program for International Student Assessment (PISA) is overseen by the OECD and administers tests to 15-year olds in reading, mathematics, science and general problem solving. The PISA methodology is considered to be among the most rigorous and reliable in the international testing field.

The most recent administration of the tests — PISA 2003 — placed special emphasis on mathematics. Among a total of 41 participating countries, students from only two countries (Hong Kong–China, and Finland) outperformed Canada's 15-year olds in mathematics to a statistically significant degree. While all provinces performed at or above the OECD average, there were some significant provincial differences, and Alberta, notably, had a mean score just marginally below the survey's top performer, Hong Kong–China. Canada's overall ranking in mathematics was well above that of the US and other G-7 countries with the exception of Japan.



Canadian 15-year olds also performed well in other domains measured by PISA. Only Finland outperformed Canada in reading, while four countries had higher average scores in science and problem-solving (Finland, Japan, Hong Kong–China and Korea). Compared with PISA 2000, the average reading performance of Canadian 15-year olds remained unchanged in 2003. On the other hand, the average science performance was lower in PISA 2003. While this decrease cannot be seen as a trend, PISA 2006 will provide further insight in this domain.

A recurring conclusion of these studies is the high quality of Canada's infrastructure for the production of knowledge at universities and research hospitals, and in "Big Science" installations such as astronomical observatories, the Sudbury Neutrino Observatory and the Canadian Light Source. Several studies also mention the role played by NRC Institutes and government labs in helping create the critical mass of expertise needed to sustain the development and growth of various industry sectors.

Trade commissioners stationed at Canadian Embassies and Consulates across the world support these findings, reporting that a number of nations are studying and adopting elements of Canada's S&T infrastructure. Several foreign governments and organizations have also published reports referring to elements of Canada's S&T infrastructure as models to emulate. One example is the recent report by the Swedish Institute for Growth Policy Studies — *Innovation Policy in Canada* (Liljemark, 2005). A 2006 article in the Australian Financial Review echoed the Swedish point of view, citing the CFI as a "brilliant foresight project" (Aitkin, 2006). Other elements of infrastructure that have attracted much attention abroad include the Canada Research Chairs and the Networks of Centres of Excellence. The NRC's Industrial Research Assistance Program is also widely regarded as a good model of effective technology development in smaller companies.

The published literature and the observations of foreign authorities are much less comprehensive than the survey findings but they are consistent with those findings and thus reinforce them.

Box 6.6

The Importance of Geographic Clusters

There has been an explosion of interest in recent years in geographically based "cluster" formation and development. Evidence from around the world indicates that clusters (as variously defined) work to generate and sustain innovation (Phillips et al., 2004). As such, they are an important element of a country's S&T infrastructure.

According to work by Porter and Stern, the R&D productivity of firms is importantly shaped by local policies and by the nature of local institutions, a constellation of factors called *national innovative capacity* (2003, p. 1). Porter and Stern find that the development and commercialization of new technologies take place disproportionately in clusters of interconnected companies and institutions in a particular field. These institutions often include a university and leading-edge government laboratories.

The NRC's Plant Biotechnology Institute (PBI), the University of Saskatchewan and Agriculture and Agri-Food Canada are the institutions at the heart of the 20-year-old Saskatoon agricultural biotech cluster. The PBI is one of the institutions that originally developed canola. Saskatoon ranks as the sixth most competitive city in the world in food processing and accounts for 30 percent of Canada's activity in the agriculture biotech field (NRC, 2006).

The Saskatoon ag-biotech cluster was one of the 26 Canadian cases used in an extensive study by the Innovation System Research Network (ISRN). ISRN researchers assessed the relative importance of local, national and global relationships and knowledge flows in spurring the development of regional clusters. While the researchers concluded that the presence of local universities and research institutions is not a *sufficient* condition for cluster development, experts on the Saskatoon cluster point to the federal government's decisions to consolidate and refocus the national agricultural research units there in the 1980s and to the catalytic role of such institutions in the cluster's growth (Phillips, 2004).

The ISRN researchers found that concentrations of dynamic, innovative firms rely equally on both strong local and global linkages and knowledge flows (Wolfe, 2005). Based on a study of the Saskatoon cluster, Phillips concluded that Canada has operated in a niche in the global ag-biotech industry — playing a role as an *entrepôt* undertaking and assembling the know-why, know-how and know-who of varietal breeding and primary production (Phillips, 2004, p. 30).

7. Areas of Potential S&T Strength for Canada

This chapter addresses the question, "What are the scientific disciplines and technological applications that have the potential to emerge as areas of prominent strength for Canada and generate significant economic or social benefits?"

Our findings in this regard are more speculative than those described elsewhere in the report — first, because we have not had the opportunity to carry out a thorough foresight analysis; and second, because of the substantial uncertainties in our understanding of how, and over what time period, particular strengths in S&T lead to "significant economic or social benefits."

Our findings here are based primarily on the results of the online survey, which probed informed opinion on S&T areas in which Canada is expected to develop prominent strength over the next 10 to 15 years. We also summarize recent international and Canadian literature that provides additional insight into new fields of research and applications expected to grow in importance globally over the next decade and beyond.

Identifying Emerging Areas — Literature Review

A large volume of recent literature aims to identify the next "big ideas", the S&T forces expected to have a major impact in the near to medium term. The committee has reviewed some of the most salient of these recent reports but notes that Canada itself has little history of systematic national foresight and we have not been able to undertake a comprehensive inquiry for this report.

International foresight reports — even though they may not refer to Canada specifically — have value for our present purposes. They tell us where leading authorities from several countries believe S&T is headed globally. They consequently provide a context for answering some key questions, such as: Where are Canada's emerging strengths synchronized with anticipated big waves of innovation? Is Canada gaining or losing ground in the fields that are going to matter most in the coming years?

A significant report prepared recently by the RAND Corporation, *Global Technology Revolution 2020* (2006), concludes that the technologies and applications with the greatest potential for significant global impact by 2020 fall, not surprisingly, into the four broad categories of biotechnology, information technology, materials technology and nanotechnology. With the exception of nanotechnology, these major *enabling* technologies have been singled out, for at least the last 25 years, as areas of exceptional opportunity. And experience has borne this out.

The International Council for Science (ICSU) has also recently analyzed rapidly developing new areas of science and application and identified nanotechnology, molecular biosciences, natural and man-made hazards, and cognitive neurosciences (ICSU, 2004).

The National Research Council of Canada, in its report, *S&T for the 21st Century* (2005), concludes that, while ICT will continue to have significant impact on the global economy, the rising wave is biotechnology. This report also says that energy and environmental technologies seem likely to form the basis of a subsequent global innovation wave "…as humankind reaches the 'tipping point' in its concerns about environmental health — climate change, global warming, water pollution, natural disasters …" (NRC 2005 (b) p. 40).

Creation of new areas of science from multiple disciplines and technologies is a recurring theme in the latest literature. The NRC predicts that disciplinary convergence will increasingly dominate S&T development: "New technologies will often be a blend of two or more disciplines and advances in one field will enable advances in another (e.g., the influence of informatics on genomics research)." The NRC report also says that S&T convergence will make multidisciplinary collaboration essential and potentially "the most important challenge facing the future of S&T development to 2020" (NRC 2005 (b), p. 44–45).

Yet another perspective on emerging S&T can be found in *Beyond the Horizon: Identifying Emerging Priorities for S&T Integration* (Anonymous, 2005), a report stemming from a series of workshops in 2005 involving federal government scientists representing a broad range of fields. Their list of emerging opportunities, together with those drawn from the reports referred to above, are summarized in **Figure 7.1**.

Figure 7.1

Emerging S&T Opportunities — Typical Broad Categories

Report	Year of Publication	Most Promising Emerging Areas of S&T and Applications
RAND Corporation's *Global Technology Revolution 2020*	2006	• Biotechnology • Information technology • Materials technology • Nanotechnology
National Research Council of Canada: *S&T for the 21st Century*	2005	Primary transformative technologies: • Biotechnologies • Information and communication technologies • Energy and environmental technologies Primary enabling sciences and technologies: • Nanoscience and nanoengineering • Materials science • Photonics • Microfluidics • Quantum information
Beyond the Horizon: Identifying Emerging Priorities for S&T Integration	2005	• Nanotechnology • High-capacity computing • Human–machine interface • Artificial intelligence • Nutrigenomics, proteomics and metabonomics • Technologies for remote and *in situ* sensing
International Council for Science (ICSU) *Foresight Analysis*	2004	• Nanotechnology • Molecular biosciences • Natural and man-made hazards • Cognitive neurosciences

Another relevant report has been produced by a group of international experts, under the aegis of Microsoft Research Cambridge in the UK (*Towards 2020 Science*, 2005). It assesses the role that computing and computer science is expected to play in achieving scientific advances in the areas of greatest challenge and opportunity in the 21st century. In early 2006, *Nature* published this report in a series of seven articles: www.nature.com/nature/focus/futurecomputing/index.html. *Towards 2020 Science* notes that the synthesis of computing with other disciplines has already begun to produce new fields and advances. The fusion is expected to be particularly strong in the life sciences — biology, biotechnology and medicine: "Indeed we believe computer science is poised to become as fundamental to biology as mathematics has become to physics" (Microsoft Research Cambridge, 2005, p. 8).

The Microsoft study, notwithstanding the business interests of its sponsors, contains a message of importance to Canada — computing will have an even stronger transformative effect on biological sciences and medicine in the coming years. Given Canada's traditional and sustained strengths in both life sciences and ICT, this country is well-positioned to be a strong performer in this area.

The previously cited report by the RAND Corporation — *Global Technology Revolution 2020* — identifies Canada as one of seven "scientifically advanced" countries that stand to gain the most from foreseen advances in technology and will be best equipped to absorb the world's leading new technologies (**Figure 7.3**). Of 56 technology applications identified as being on the feasible horizon for 2020, RAND concluded that 16 (**Figure 7.2**) have the greatest combined likelihood of being widely available commercially, enjoying a significant market demand, and affecting multiple sectors (e.g., water, food, governance, environment, population, social structure). Underlying the top technology trends are global communications (i.e., Internet connectivity; the globalization of scientific conferences and publications) and instrumentation advances (the development and cross-fertilization of ever more sensitive and selective instrumentation).

The RAND analysts divided the 29 countries studied into four groups of varying levels of S&T capacity: advanced, proficient, developing and lagging. The study noted that S&T capacity is an important determinant of the potential for new technological application but not the full story: "The ability to acquire a technology application does not equal the ability to implement it. Doing research and importing know-how is a necessary initial step. But successful implementation also depends on the drivers within a country that encourage technological innovation and the barriers that stand in its way".

Although the report said that Canada and the other six scientifically advanced countries as a group have the largest number of drivers and the fewest barriers (**Figure 7.3**), it did note that three categories of barriers could affect our ability to acquire and implement the key technologies: laws and policies; social values, public opinion and politics; and, privacy concerns.

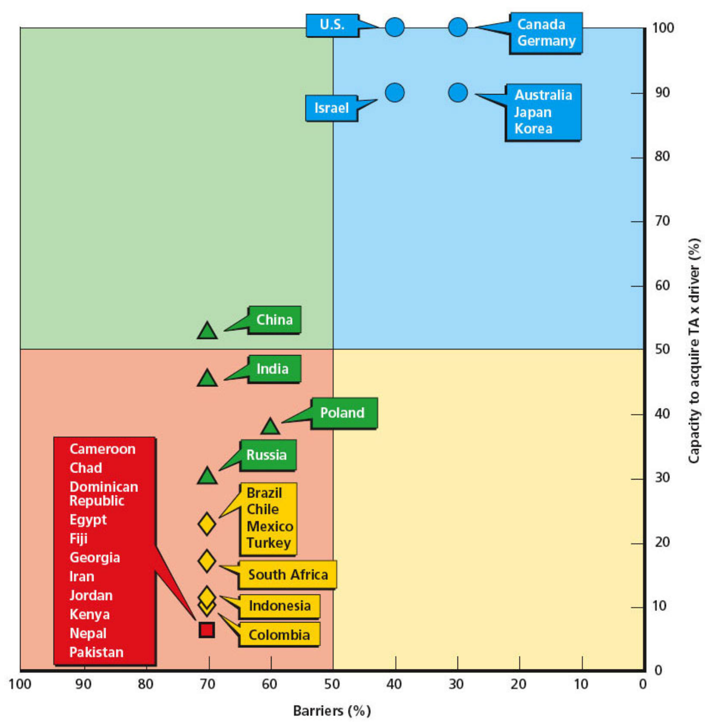
Figure 7.2

Sixteen Technology Applications Scoring Highest in the RAND Study

Cheap solar energy
Rural wireless communications
Genetically modified crops
Filters and catalysts for water purification
Cheap housing for adaptable shelter and energy
Rapid assays to detect specific biological substances
Green manufacturing
Ubiquitous radio-frequency identification tagging of products and people
Hybrid vehicles
Drug delivery targeted to specific tumours or pathogens
Improved diagnostic and surgical methods
Quantum-mechanical cryptography for secure information transfer
Communication devices for ubiquitous information access
Pervasive sensors
Tissue engineering
Computers embedded in clothing or other wearable items

Figure 7.3

The Capacity of Countries to *Implement* the Top 16 Technology Applications



NOTE: The blue quadrant indicates a high level of S&T capacity plus many drivers and few barriers; the green quadrant indicates a high level of S&T capacity with many drivers and many barriers; the yellow quadrant indicates the lack of a high level of S&T capacity plus few drivers and few barriers; the red quadrant indicates the lack of a high level of S&T capacity with more barriers than drivers.
RAND *MG475-4*

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Source: RAND Corporation 2006. *The Global Technology Revolution 2020.*

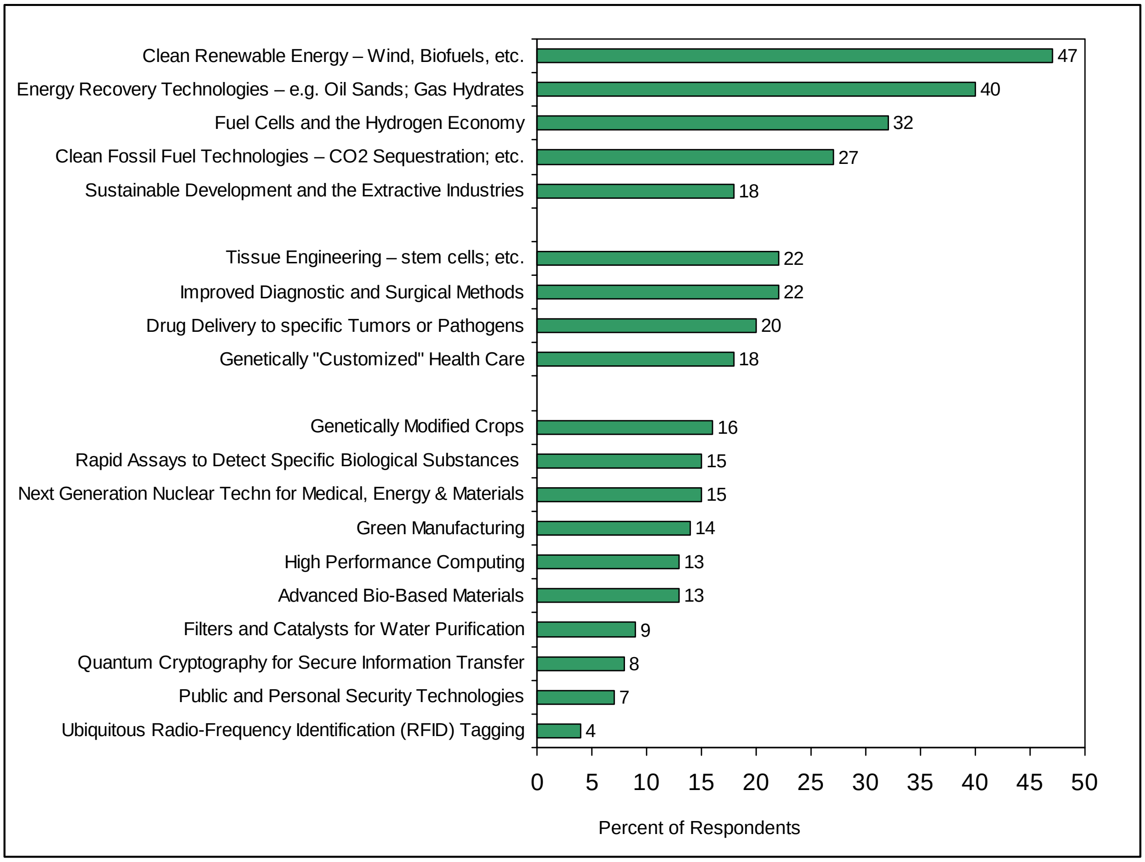
Results of the Opinion Survey

The online survey questionnaire presented respondents with a list of 19 areas of research or technological applications that are likely to be of increasing significance over the next 10 to 15 years. Respondents were asked to choose up to *five* areas in which they believed "Canada is best-placed to be among the global leaders in development and/or application." The committee chose nine of the 16 key technologies from the RAND Corporation report (**Figure 7.2**) that we judged to be most relevant for Canada. We complemented these with a number of areas suggested by various experts who were consulted. Respondents were also able to add areas that they believed were potentially more significant than those listed in the questionnaire menu.

By a wide margin, survey respondents identified energy technologies as the area where Canada is best positioned to develop prominent strength in the future (**Figure 7.4**). The four top-ranked emerging areas all fell into the energy category and three of them related to sustainable energy.

Figure 7.4

Survey Results on Emerging Opportunities — Percentage of Respondents Including the Listed Areas in their Top Five



"Clean renewable energy" topped the list — it was included by 47 percent of respondents in their top five. Second was "energy recovery technologies" (40 percent), followed by "fuel cells and the hydrogen economy" (32 percent) and "clean fossil fuel technologies" (27 percent). Also in this general grouping is the field of "sustainable development of the extractive industries" (18 percent), which is of obvious importance to Canada. The four c*lean energy* categories lie at the intersection of two global drivers — concern over climate change, and Canada's position as a resource superpower, and more particularly as a major fossil energy producer.

The committee has taken particular note that the top ranking given to clean energy as an emerging area of potential Canadian leadership is inconsistent with respondents' modest assessment of Canada's current strength in the field of "green energy" (see **Chapter 5, Figure 5.12**). This calls into question whether the survey responses reflect a hard-headed assessment of where Canada is *best-positioned* to be a global leader or whether the responses reveal a powerful aspiration as to where Canada *ought* to be a leader. In any event, there is a significant gap between aspiration and current reality. If Canada is to become an international leader in clean energy, there is much work to be done.

The second highest cluster was a set of healthcare technologies, including tissue engineering (22 percent), improved diagnostic and surgical methods (22 percent), targeted drug delivery (20 percent) and genetically customized health care (18 percent).

In **Figure 7.5**, we deepen the analysis of survey responses to test their consistency across major affiliation groups and regions. Although all respondents ranked the energy technologies in the top four positions, the ranking order did vary according to their affiliation, age and region.

Figure 7.5 reveals a number of notable features in the responses. For example:

- Business-affiliated respondents put clean renewable energy at the top of the list by a wide margin — almost 60 percent included it in their five most promising opportunities. It is noteworthy that respondents from both business and government gave very strong rankings to opportunities in the energy sector. University-affiliated respondents were somewhat less enthusiastic, although the sector was still their top choice overall.
- Another noteworthy pattern is the stronger endorsement of genetically engineered crops and genetically customized health care by government respondents, in rather sharp contrast to those with business affiliation.
- Younger respondents (under age 35) were far more likely to choose clean renewable energy than the group of respondents over the age of 55. Conversely, the older age group ranked energy recovery technologies as the leading emerging strength. The older group was also much more likely than those under 35 to select "improved diagnostic and surgical methods" in their top five — not surprising. But the younger group saw greater potential in "green manufacturing" than those over 55.
- There were some significant regional variations around the survey averages. For example, BC respondents were far more likely to select "fuel cells and the hydrogen economy" in the top five. Albertans were much more likely than the average to select "energy recovery technologies" and "clean fossil fuel technologies," while Quebecers were significantly less likely to name these.

Figure 7.5

Various Perspectives on Survey Results on Emerging Opportunities

	Percentage of Respondents Including Item in Top Five												
Item	**Total**	**Univ**	**Bus**	**Gov**	**<35**	**>55**	**BC**	**AB**	**M/S**	**ON**	**QC**	**ATL**	**INT**
Clean Renewable Energy — Wind, Biofuels, etc.	47	**44**	**58**	49	55	**42**	52	50	57	**41**	53	49	45
Energy Recovery Technologies — e.g. Oilsands; Gas Hydrates	40	**36**	**51**	**51**	29	**47**	34	**62**	47	42	**30**	41	36
Fuel Cells and the Hydrogen Economy	32	**27**	**39**	**40**	35	31	**45**	26	25	32	30	32	30
Clean Fossil Fuel Technologies — CO2 Sequestration; etc.	27	25	32	31	25	28	29	**55**	28	25	**18**	27	28
Tissue Engineering — stem cells; etc.	22	25	21	22	22	22	18	18	16	24	**29**	**12**	20
Improved Diagnostic and Surgical Methods	22	21	23	22	16	24	17	27	14	**26**	24	**10**	16
Drug Delivery to Specific Tumours or Pathogens	20	22	21	16	22	20	27	18	14	18	**29**	15	13
Sustainable Development and the Extractive Industries	18	15	21	22	16	17	21	18	27	16	15	20	19
Genetically "Customized" Health Care	18	19	**14**	21	17	20	23	16	12	18	22	11	23
Genetically Modified Crops	16	14	14	**24**	15	19	13	**24**	**39**	16	**9**	17	17
Rapid Assays to Detect Specific Biological Substances	15	17	17	16	10	13	13	13	24	14	18	12	13
Next Generation Nuclear Technologies for Medical, Energy and Materials	15	14	17	19	13	**20**	11	14	23	**19**	11	11	9
Green Manufacturing	14	14	15	14	**23**	12	20	11	11	12	15	16	25
High Performance Computing	13	13	11	16	14	14	15	11	7	13	15	14	14
Advanced Bio-Based Materials	13	13	16	16	14	13	10	9	**25**	14	14	14	14
Filters and Catalysts for Water Purification	9	8	12	12	8	10	7	11	10	11	6	11	6
Quantum Cryptography for Secure Information Transfer	8	7	4	9	10	9	6	11	4	8	7	3	12
Public and Personal Security Technologies	7	6	8	**13**	6	8	5	6	1	8	8	10	7
Ubiquitous Radio-Frequency Identification (RFID) Tagging	4	3	**7**	5	2	3	2	4	4	3	5	5	3

Note: Bolded figures are statistically significant deviations from the total – i.e., less than one percent probability that the difference was due simply to chance.

Respondents from Manitoba and Saskatchewan were significantly more likely than the average to see opportunity in “genetically modified crops” and “advanced bio-based materials.” In all these cases, one can see the strong influence of existing regional specialization on the perception of future opportunity.

- There were some significant regional variations around the survey averages. For example, BC respondents were far more likely to select “fuel cells and the hydrogen economy” in the top five. Albertans were much more likely than the average to select “energy recovery technologies” and “clean fossil fuel technologies,” while Quebecers were significantly less likely to name these. Respondents from Manitoba and Saskatchewan were significantly more likely than the average to see opportunity in “genetically modified crops” and “advanced bio-based materials.” In all these cases, one can see the strong influence of existing regional specialization on the perception of future opportunity.
- Among items less frequently selected for the top five, it is noteworthy that government officials were twice as likely as the average respondent to include “public & personal security technologies.” Those with business affiliation were twice as likely as the average to select “RFID tagging products”. (The commercial significance of RFID is already becoming apparent.)

Other Emerging Areas Cited by Respondents

The committee recognizes that responses to the survey question reflect a degree of “menu bias” owing to the pre-selected set of 19 items from which to choose one’s top five. To mitigate this bias, we invited participants to suggest areas not included in the list. About 200 respondents proposed additional items.

Some noteworthy themes emerge in these responses. Consistent with the overall results, energy and environmental areas were the most common and included energy efficient buildings; endangered species recovery; ecosystem modelling; environmental sensing; environmentally friendly pesticides; and environmental remediation.

Medical research and applications made up the next largest cluster in the “other” responses, mirroring the trend in the ranking of the 19 pre-specified items. Some of the promising areas in this category were basic and clinical neuroscience research; drug design biotechnologies; diabetes research; novel approaches to antibiotic therapy; and treatments related to aging populations.

Other significant clusters included information and communications technologies — e.g., geomatics hardware and software (which also has important application to environmental management and to natural resources industries); defence systems for mission integration; e-commerce; and quantum information processing. There were several suggestions related to natural resources (e.g., robotic mining and deep water drilling) and several mentions of ocean and marine S&T and Arctic research.

The responses with respect to future opportunity illustrate the growing importance of transdisciplinary applications and the creation of new specialties from combinations of fields or methods that have traditionally been separate. A number of the suggested areas for emerging Canadian leadership involve this type of cross-cutting research — nanotechnology for diagnostics and therapeutics; biophotonic components for medicine; bioinformatics; applications of pure mathematics to computer science; and humanities computing.

These additional suggestions usefully highlight many specific areas of promise. Their overall pattern is consistent with both the menu-based responses and with the major clusters of Canada's S&T strength identified in **Chapter 5**. The additional items proposed by survey respondents thus add further weight to those conclusions.

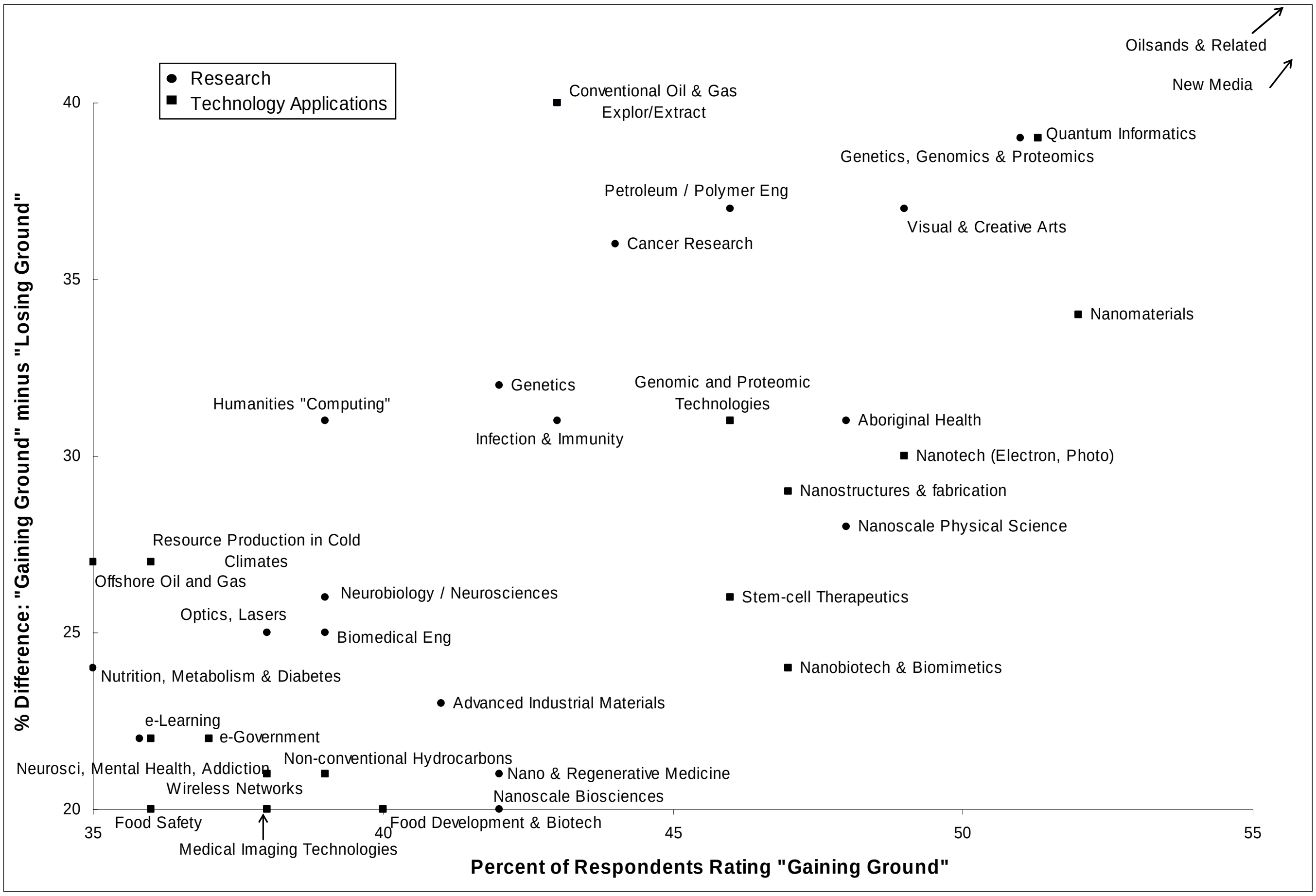
A final perspective on areas of future promise for Canada can be gleaned from the trend ratings assigned by survey respondents to 197 sub-areas of research and technology application as reported in **Chapter 5** and comprehensively tabulated in **Appendix 4**. The areas for which respondents were most united in their view that Canada has been gaining ground are mapped in **Figure 7.6**. (Included are the areas for which at least 35 percent of respondents believed Canada was gaining ground and for which the "up minus down" net trend indicator was 20 percent or more.)

It is notable that almost all the disciplines and technologies in the figure are associated with ICT and its applications, the bio-based and health sciences, various applications of nanotechnology, and natural resources. There are no representatives of the newer breed of environmental sciences and technologies needed to fulfill the aspirations summarized in **Figure 7.4**.

The committee notes, in conclusion, the opportunity provided by Canada's close S&T relationships with the United States. The countless cross-border research collaborations involving individuals and groups, as well as the dense web of commercial relationships, create for Canada a unique advantage. By keeping closely attuned to emerging areas in the United States, Canada can be better positioned than other countries to recognize leading-edge developments in S&T and to adapt them quickly to areas of greatest importance for Canada.

Figure 7.6

Areas Judged to Have the Highest Growth Prospects



8. Concluding Observations

In this final chapter we draw together some broad themes arising from our work, including several observations by the survey respondents, stated in their own words. We also recall some of the more pointed questions raised by our findings as well as aspects of the analysis that might usefully be extended or deepened.

Canada's S&T Strength, Overall

Participants in the online survey were asked to rate Canada's overall strength in S&T, and its trend. The results, reflecting 1,490 responses to the question, are depicted in **Figure 8.1**, disaggregated by age and affiliation.

- The integrated view of Canada's strength *overall* in science and technology is somewhat more pessimistic than survey respondents' opinion of S&T strengths in *specific* areas of research, technology application and infrastructure. Fewer than half of respondents ranked Canada strong overall in S&T (ratings 5, 6 and 7) and roughly a quarter believe we are weak (ratings 1, 2 and 3) relative to the average of other economically advanced countries.
- The perception of overall trend is rather pessimistic — almost 40% believe Canada is losing ground, while only 28% see us gaining. The net trend, again, is considerably more pessimistic than is the case for the (average) outlook in the specific areas of research and technology application (see bottom of **Figure 8.1**).
- The overall perception is reasonably consistent across affiliations and ages. Those under 35 perceive greater strength but are not much more optimistic than the average as to trend — i.e., 38% down vs. 33% up.
- The views of those with government and business affiliation are remarkably similar and are more pessimistic regarding both strength and trend than those with academic affiliation.

Some Overarching Themes

Amid the wealth of detailed evidence assembled for this report, certain themes have been recurrent in various guises.

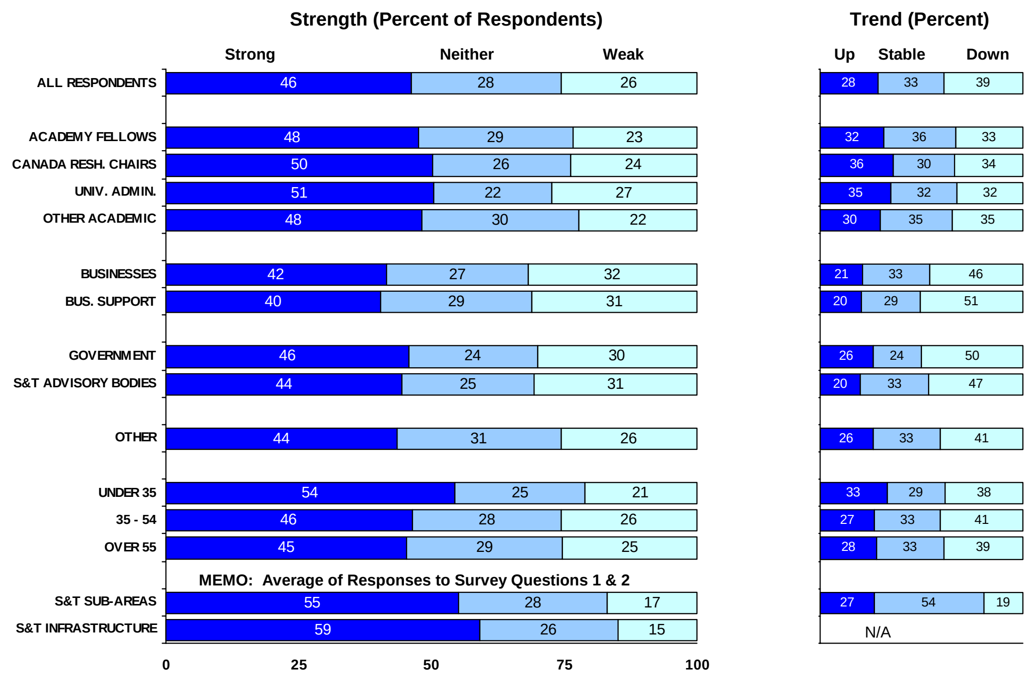
> Canada is particularly outstanding in interdisciplinary work in general, due in part to our strong culture of sharing platforms, technologies, and other resources. *Fellow; RSC Academy of Social Sciences*

The Significance of Interdisciplinarity — There is a paradigm shift underway in how science is done around the world. Inter- and multi-disclipinarity are becoming the norm in the approach to research problem-solving. The activities and aspirations of researchers are shifting to areas like biotechnology and nanoscale science wherein the traditional foundation disciplines — physics, chemistry, biology and others — become, in effect, submerged as component competencies that are required to address the new areas. This dynamic process of flow and fusion complicates the task of assessing S&T strengths based on backward-looking data and categories.

Figure 8.1

Perspective on Canada's S&T Strength Overall

Responses to the Survey Question: "Taking into account all aspects of S&T – knowledge generation and application; supporting infrastructure; and positioning for the future – what is your opinion of Canada's current overall strength in S&T relative to other advanced countries – and the overall trend …?"



Canadian strengths are often supported by a good system of networking of scientists and industry. CANARIE and the NCEs are tools that really support collaborative research. Collaboration among institutes, industry and academe is something that has noticeably improved over the last 10 years. CFI has also been key to get universities involved. In addition, some business groups (Fuel Cell Canada, New Media BC) play a strong role in promoting collaboration particularly with other countries.
Officer of IRAP or Technology Partnerships Canada

Collaboration and Networking — A counterpart of interdisciplinarity is the growing importance of collaboration across disciplines, across borders, and across the divides that have traditionally separated institutions — particularly those of academia, business and government. Effective *soft* infrastructure to support collaboration is thus an increasingly significant dimension of S&T strength. Canada has been a pioneer in networked collaboration through such innovations as the Canadian Institute for Advanced Research, the Networks of Centres of Excellence, the Canada Foundation for Innovation, and many other initiatives by the granting agencies, provinces and universities themselves.

Strong in Research . . . Weaker in Commercialization and Translation — A central conclusion from the evidence in this report is that Canada has built significant strength in many fields of research and there is optimism that we are gaining ground in several of the newer areas — e.g., genomics, nanoscale materials science, digital media. Based on survey commentaries (**Box 8.1**) and in the view of the committee, we do less well in converting strength in basic science into sustained commercial success — i.e., growing firms in technologically sophisticated areas that keep their base in Canada as they attain critical scale. This is a long-standing deficiency in Canada's innovation system that requires resolution for the full benefit of Canada's considerable S&T strengths to be realized.

Looking Forward

Work is never complete. While we believe this study has advanced the understanding of Canada's S&T strengths and capabilities, much remains to be done with respect to the methodology for work of this kind; the implications of our findings; and the important issues still unaddressed.

Methodology – The application of the *four lens* methodology was weakest with respect to the view from abroad. More complete and current data on formal S&T agreements and collaborations could be maintained and guided by an objective of identifying Canadian strengths through the types of collaboration others seek with us. The survey method could also be used effectively with foreign participants but they would need to be selected to ensure they had specific knowledge of Canadian S&T — e.g., Canadians studying and working abroad; foreign participants in collaborations or initiatives like the Canada-California Strategic Partnership Initiative; S&T analysts in foreign companies or governments; other academies of science.

The second principal weakness of methodology in this study relates to the technometric analysis. This is painstaking work in view of the need to knit together categories appropriate for today from patent classes that may have been defined in the 19th century. The limited time for our study precluded a very thorough technometric analysis.

A third gap in our analysis has been the absence of a "foresight" exercise to inform an assessment of the best opportunities for Canada in five to ten years' time. Although there are limits to the ability of such exercises to predict accurately, there is value in the activity itself arising from the dialogs it would generate.

Implications of Findings — The survey results, in addition to providing a detailed map of where Canada's S&T strengths are perceived to lie, pointed to some potentially significant weaknesses — e.g., the perceived shortcoming of the financial institution infrastructure to support S&T; the state of Canada's capabilities related to transportation technologies; perceived weaknesses in important components of the forest products industry and the pharmaceutical sector; and the guarded view of survey respondents concerning the S&T benefits, or otherwise, of Canada's regulatory systems. We express no view on any of these questions but simply raise them here as an agenda for others to consider.

In this vein, we also recall the note of pessimism implicit in the overall rating of Canada's S&T strength, and more particularly that about 40% of respondents believe we have been losing ground (**Figure 8.1**).

The committee made few attempts to interpret what lies behind the survey results. Particularly in **Chapter 5**, they contain a wealth of information that can be further analysed and interpreted by the various stakeholder communities. We believe that one of the most useful aspects of our report is the foundation it provides to develop a much deeper, and more broadly shared, understanding of Canada's S&T system. To this end, the set of Strength vs. Trend charts for the 197 sub-disciplines (**Figure 5.15**) might stimulate a number of dialogs within and among expert communities as to why the survey respondents, collectively, placed the various disciplines and technologies where they did.

Still to be Addressed — This report leaves two large issues unresolved — one implicit, the other explicit. The explicit question, raised by the survey, is the gap between an aspiration to develop a leading capability in clean energy technologies and the current reality. This is a significant challenge that has been clearly identified.

The second, and much broader issue — expressed for example, by survey respondents in **Box 8.1 —** is the difficulty of knowledge transfer from researchers in universities to innovators in industry. An in-depth study of Canadian weaknesses and strengths, their causes and possible remedies could build on this study by first focusing on the areas of S&T where Canada is currently strong. Where are the hurdles in translating Canadian strengths in S&T into innovation and wealth creation that will enhance the quality of life of Canadians? How can those barriers be overcome?

We leave the final word to our survey respondents — **Box 8.2**

Box 8.1

The Challenge of Commercialization / Translation — Voices of the Survey

The survey questionnaire invited participants to comment, in their own words, on any aspects of Canada's S&T capabilities, existing or prospective. More than one-third of respondents — 538 individuals — chose to do so. Several excerpts from their commentaries are found throughout the report to illustrate, or amplify, points in the text. Here, we collect a small sample that exemplifies a persistent challenge for Canada.

- "The absence of strong, broad spectrum, industry-based and funded research and development in Canada places the nation at a tremendous disadvantage relative to other leading economies." *University Administrator*

- Canada is gaining relative to the United States in all areas of basic research but not in commercial exploitation of research. *Fellow, RSC Academy of the Arts and Humanities*

- "Canada does very good basic and applied research but struggles with translating discoveries into marketable products and services. There is a serious lack of technology development and demonstration capacity in Canada." *Fellow, Canadian Academy of Engineering*

- "The discussions of translating research into commercial applications have tended to a simplistic 'discover - invent - spin out' sequence. The relationship between the S&T system and commercial success is far more complex. There are feedbacks all through successful processes. We risk missing out on real gains by setting targets driven by a narrow conception." *Fellow, RSC Academy of Sciences*

- "Translating research into commercial application has been Canada's weakness. There has been a gap between the business community and academic community and a bridge hasn't been established. The intended bridges (NRC, NSERC, NRCan) have been much closer to the academic community than to the business community." *Officer of IRAP or Technology Partnerships Canada*

- "We seem to be afraid to pick and/or back potential winners; relying instead on a passive, entitlement approach for industrial R&D support (SR&ED), which has not proven effective in stimulating groundbreaking IR&D the way the original IRAP did with such projects as Digital Switching and Fibre-optics at Northern Telecom in the 70s and 80s." *Federal Government Employee*

- "I believe Canada is weak in translating research into commercial application. This weakness seems to be more of a result of economic, financial, cultural issues than specific S&T capability." *Employee of a large business firm*

Box 8.2

Thoughts on S&T Strategy — Voices of the Survey

- "We have transformed the country since 1997 from a mediocre performer (broadly speaking) on the R&D stage internationally to a country that is perceived to be on the rise in terms of basic-research investment and output. But, we've only built some momentum. We MUST continue to invest nationally to harvest the fruits of that momentum." *Fellow, RSC Academy of Sciences*

- "We spend a lot of money on discovery research, and we are globally competitive there. Where we are very weak is in the translation either to commercial applications or public good." *Fellow, RSC Academy of Sciences*

- "Canada has a significant advantage in some areas of basic science and needs to ensure that this is preserved as it attempts to develop strength in applications." *Program Member, Canadian Institute for Advanced Research*

- "It is important to support humanities and social science research in conjunction with 'pure' S&T to make sure we are pursuing socially valuable programs and that we know how to integrate the products that emerge in a complex, diverse, society." *Fellow, RSC Academy of the Arts and Humanities*

- "The next generation of technological advances in the fields of engineering, medicine and the sciences will require a multidisciplinary systems approach." *Recipient of Technology Development Funding*

- "Canada desperately needs a science strategy based upon our strengths and the commercial opportunities that will arise." *Fellow, RSC Academy of Sciences*

- "I would hope that a possible outcome of this survey and others that may follow is the development of a research strategy or philosophy. Where do we see Canadian S&T in 5 or 10 years? How can we improve the current situation? How can we foster collaborations between government labs, universities and industry? There has to be an open dialogue that addresses these issues." *Canada Research Chair*

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* The abbreviations "N.d." and "N.p." refer respectively to references that have no date provided on the publication and have not been published.

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APPENDICES

Appendix 1: Letter and Charge from Industry Canada

Minister of Industry | Ministre de l'Industrie

Maxime Bernier
Ottawa, Canada K1A 0H5

Dr. Howard Alper
Chair
Council of Canadian Academies
180 Elgin Street, 14th Floor
Ottawa, Ontario K2P 2K3

Dear Dr. Alper:

As you are aware, I am waiting for confirmation of support from the ministers of the lead departments of the four assessment topics identified to date, before referring them to the Council of Canadian Academies. Given the unanticipated delays, we are developing a new approach that will allow the government to put forward high-quality assessment topics and expedite the decision-making process.

In the interim, I have decided to reference an assessment question to the Council. I understand that the Council would be pleased to provide, by the end of August, a preliminary assessment of Canada's science and technology (S&T) strengths and capacity, demonstrating areas in which we excel. I also anticipate your advice on the methodological approach required to conduct a more detailed and definitive assessment of Canada's S&T strengths in the longer term, in keeping with the enclosed terms of reference.

This work will provide both the Council and the government with foundational information that will assist the Council with subsequent assessments and support the development of the S&T strategy. I look forward to facilitating future assessments, and reviewing the results of this effort later this summer.

Sincerely,

Maxime Bernier

Enclosure

c.c. Dr. Peter Nicholson

Canada

COUNCIL OF CANADIAN ACADEMIES
ASSESSMENT OF CANADA'S SCIENCE AND TECHNOLOGY STRENGTHS

Purpose of the Assessment

To provide Industry Canada with independent and authoritative information on Canada's prominent S&T strengths, and to provide the Council with some foundational information that will be valuable context for its subsequent work.

This project is not a priority setting exercise. Rather it is an assessment of S&T assets which would be one input to eventual priority setting.

Proposed Assessment

Industry Canada would welcome the advice of the Council in gaining a better understanding of Canada's S&T strengths and capacity. In particular, it would be helpful to better understand:

- the scientific disciplines in which Canada excels in a global context;
- the technology applications where Canada excels in a global context;
- the S&T infrastructure that currently provides Canada with unique advantages; and
- the scientific disciplines and technological applications that have the potential to emerge as areas of prominent strength for Canada and generate significant economic or social benefits.

The Council is invited to consider whether the answers to these questions are clear based on current knowledge and empirical evidence. In this case, Industry Canada would welcome a report that provides responses to these questions based on the views of experts and the assessment of bibliometrics or other sources of readily available information.

If the Council determines that the answers to these questions are not clear based on current knowledge and empirical evidence, Industry Canada would welcome recommendations on the type of information sources that could be developed for this purpose. In this case, the Council would be well placed to consult relevant experts and help Industry Canada to develop a vision for the kind of next generation strategic intelligence applications that would empower Canada to innovate to its full potential.

The Council will deliver an initial opinion as to Canada's principal S&T assets (i.e. where Canada excels) by August 30, 2006. These preliminary views will be complemented with advice as to methodology for conducting a more detailed and definitive assessment of Canada's S&T strengths. This report may lead to a more detailed subsequent investigation.

Industry Canada's primary requirement is to assess sciences with potential for commercial application, but the Council may wish to adopt a broader definition of sciences, so long as Canada's "hard science" assets are well covered.

The report will be authored by the Council, with the advice of the Scientific Advisory Committee. Industry Canada will help ensure that the Council has access to relevant sources of information inside government. The Council may also approach government sources directly.

Timing

A preliminary report on the Council's findings is required by August 30, 2006. Upon completion of this report and on the advice of the Council, Industry Canada would be pleased to consider tasking the Council on a longer term basis to give this important matter further consideration.

June 20, 2006

Appendix 2: Contributors to S&T Strength

To appreciate the importance of the choice of indicators of S&T strength, it is necessary to take into account the full breadth of the concept of S&T strength. In **Figures A2.1(a)** and **A2.1(b)**, key elements of one model of this broad concept are shown. The large number of elements in these diagrams illustrates that the S&T system is not a single linear chain of cause and effect. Although, in reality, there are dozens of feedback loops in **Figure A2.1**— e.g., higher education is both a driver of the system as well as one of its key results — to show them would render the figures unreadable. The terminology in the three central boxes — Inputs, Outputs, and Outcomes & Impacts — should be interpreted as a convenient set of labels to group elements rather than as implying some form of simple linear causality from input to outcome.

Each element in **Figure A2.1** could be developed into an indicator of S&T strength. Indeed, in the literature — and in **Chapter 4** of the report — combinations of many of these indicators have been used to evaluate or assess the strength of S&T in a country.[1]

[1] An example for the use of a multitude of performance indicators can be found on the website www.innovationecologies.com. (Note: this database is currently in *beta* version.)

Figure A2.1(a)

Selected answers to the question: "How Does One Measure S&T Strengths?" Each element on this chart could form the basis for an indicator. This chart can be combined with **Figure 2.1(b)** but there is no simple linear cause and effect relationship between the two.

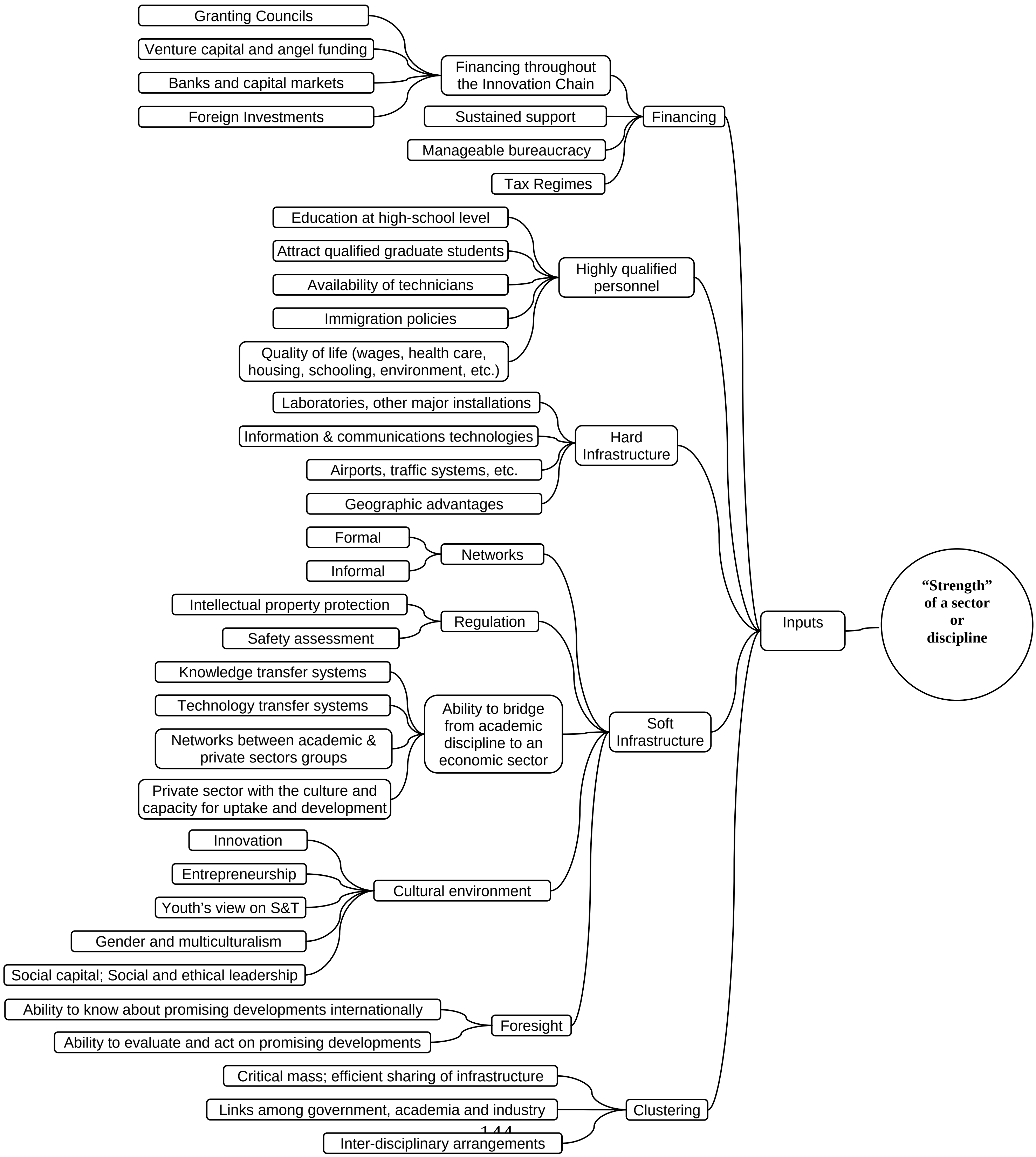
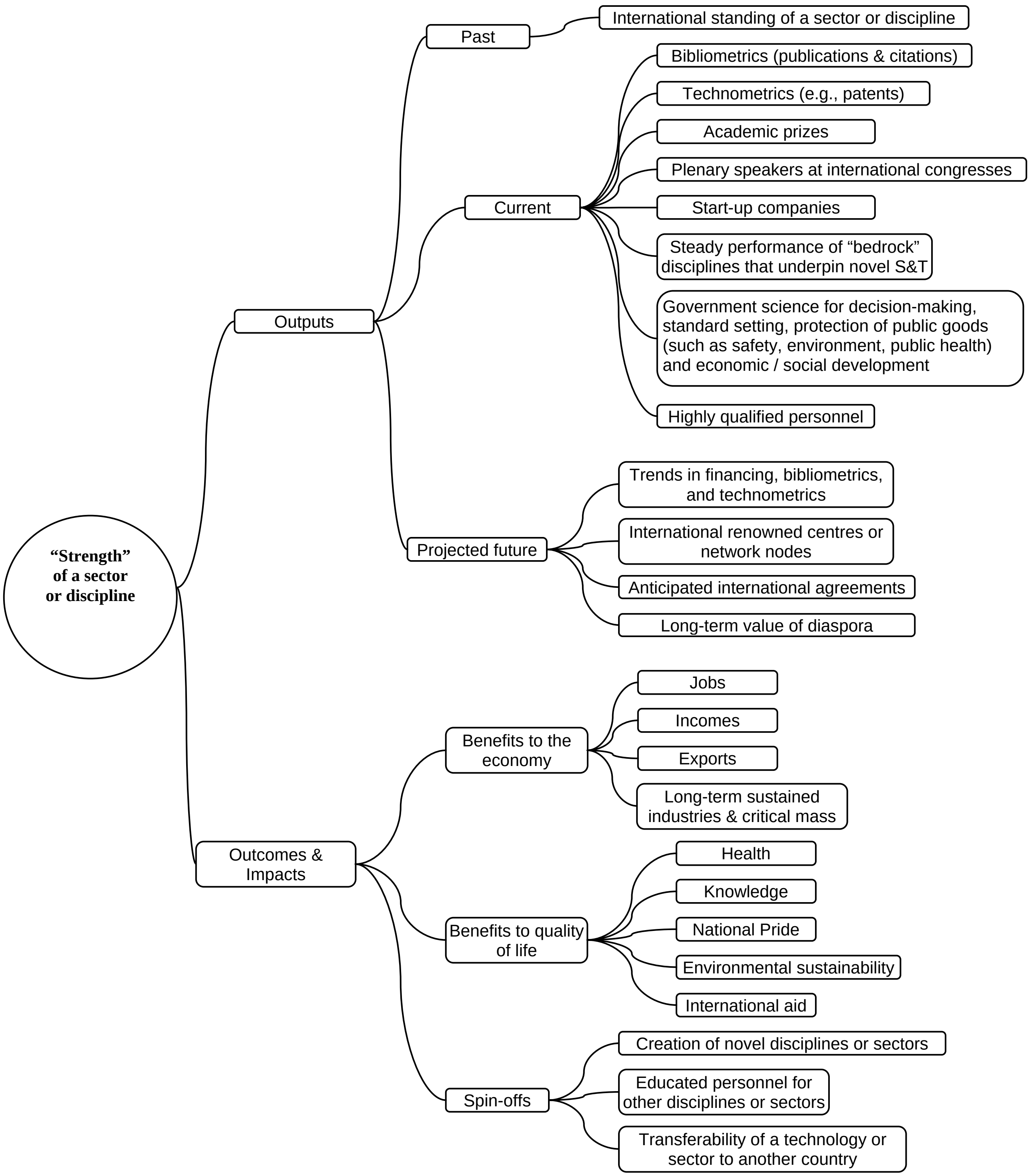


Figure A2.1(b)

Additional answers to the question: “How Does One Measure S&T Strength?”

NOTE: Feedback loops were excluded from this chart to render it more legible.



Appendix 3: Survey on Canada's S&T Strengths and Capacity

To help set the context for the government's consideration of Science and Technology (S&T) policy, the Council of Canadian Academies has been asked to report on:

- the scientific and engineering disciplines (including social sciences and humanities) in which Canada excels in a global context;
- the technologies where Canada excels in a global context;
- the S&T infrastructure that currently provides Canada with unique advantages; and
- the scientific and engineering disciplines and technologies that have the potential to emerge as areas of significant strength for Canada and generate important economic or social benefits.

We are canvassing a broad spectrum of informed opinion to help ensure that government S&T policy has a sound base of evidence. We would therefore appreciate your completion of the following questionnaire.

- The questionnaire is to be completed online
- The questionnaire should take about 20 minutes to complete
- Data in the final report will be aggregated in order to preserve anonymity of individual respondents
- The Council's report to government will be made public

Responses to the survey will be combined with other data and analysis to draw a multi-faceted picture of Canada's S&T capabilities in an international context.

Please submit your completed questionnaire as quickly as possible (but not later than August 8) to allow adequate time for analysis before the August 30 deadline for submitting our first report to the government.

We thank you for taking the time to share your experience and wisdom to help develop an authoritative and up-to-date picture of Canada's S&T assets.

<u>Instructions</u>: This survey is intended to record your personal opinion of Canada's standing — relative to our peer group of advanced countries — in a broad range of S&T fields and components of infrastructure. We do not expect you to do any research to respond. Rather, we are seeking your informed judgment.

To facilitate tabulation of responses, as well as comparison with bibliometric and other statistical data, we have adopted a taxonomy of major fields and sub-fields that seeks an adequate degree of "granularity" but inevitably involves compromises. Since no classification is ideal — particularly as increasing multi-disciplinarity blurs the traditional boundaries — we provide for "other" categories to be added by you if necessary.

QUESTION 1

WHAT ARE THE AREAS OF PARTICULAR SCIENTIFIC OR TECHNOLOGICAL STRENGTH FOR CANADA?

Below are listed broad research disciplines and areas of technological application. Think of these as "gateways" to the various fields with which you have some familiarity. Choose as many as you wish. For each "gateway box" selected you will be presented with a menu of relevant sub-areas that cover the broad area. You should then rate Canada's standing in all those sub-areas where you are comfortable expressing a view.

Note that you need not be truly expert in a particular area to render an opinion. We are seeking as wide a range of informed opinions as possible. Of course, if you do not feel sufficiently knowledgeable in a particular area, simply leave it blank.

Please note you will also be provided with an opportunity to return to this "gateways" menu (if you wish) at the end of the sub sections you have selected.

BROAD AREAS ("GATEWAYS") MENU
(Select the broad areas you wish to assess by clicking the relevant boxes, then press the "Continue" button and rate the sub-areas that pop up)

BROAD RESEARCH DISCIPLINES

- ❍ Physical, Mathematical and Computer Sciences
- ❍ Earth, Ocean, Atmospheric and Space Sciences
- ❍ Life Sciences
- ❍ Health Sciences
- ❍ Engineering
- ❍ Social Sciences
- ❍ Humanities and the Arts

AREAS OF TECHNOLOGICAL APPLICATION

- ❍ Information and Communications Technologies (ICT)
- ❍ ICT-enabled Services Technologies
- ❍ Manufacturing, Construction and Transportation Technologies
- ❍ Energy, Mining and Forestry
- ❍ Chemicals and Materials Technologies
- ❍ Agri-food Technologies
- ❍ Environmental Technologies
- ❍ Biotechnologies and Medical Technologies
- ❍ Nanotechnologies

For each of the following sub-areas for which you are comfortable expressing a view, please first provide your opinion of Canada's current overall strength relative to other advanced countries (i.e., roughly the OECD group.) Please consider both the quality and the extent of the work carried out in Canada.

Second, please rate your opinion of the overall trend in Canada's relative strength over roughly the past five years — are we gaining ground, falling behind, or remaining stable?

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a sub area, please leave it blank.

Canada's Overall Strength Relative to Other Advanced Countries							Recent Trend		
VERY STRONG			ABOUT THE SAME			VERY WEAK	GAINING GROUND	STABLE	FALLING BEHIND
7	6	5	4	3	2	1	❍	❍	❍

Q1.EQ.1
Physical, Mathematical & Computer Sciences

<u>**SUB-AREAS**</u>

Chemistry - Analytical
Chemistry - Physical
Chemistry - Inorganic
Chemistry - Organic
Chemistry - Polymer
Computers - Artificial Intelligence, Robotics
Computer Software Development & Theory
Computer Databases, Information Systems
Computer - Human Interfaces
Computer Hardware(see also Engineering)
Mathematics - Applied
Mathematics - Pure
Mathematical Statistics
Physics - Astronomy, Astrophysics, Cosmology
Physics - Condensed Matter
Physics - Elementary Particles
Physics - Nuclear
Physics - Optical; Laser
Physics - Plasma
Physics - Quantum Informatics
Nanoscale Physical Science
Other

Q1.EQ.2
Earth, Ocean, Atmospheric & Space Sciences

<u>SUB-AREAS</u>

Geology
Geochemistry & Geochronology
Geophysics & Seismology
Hydrology
Oceanography
Climate Science
Meteorology
Physical Geography, Remote Sensing
Soil Science
Space Science
Other

Q1.EQ.3
Life Sciences (See also Health Sciences in BROAD AREAS ("GATEWAYS") MENU)

<u>SUB-AREAS</u>
Genetics, Genomics & Proteomics
Biochemistry
Cell Biology
Microbiology
Plant Biology
Animal Biology
Systems Biology & Bioinformatics
Ecology & Evolutionary Biology
Physiology
Kinesiology
Neurobiology / Neurosciences
Experimental Psychology
Nanoscale Biosciences
Other

Q1.EQ.4
Health Sciences (See also Life Sciences in BROAD AREAS ("GATEWAYS") MENU)

Note that the majority of the sub-areas below are the focus areas of individual CIHR Institutes.

SUB-AREAS

Aboriginal Health
Aging
Cancer Research (including cancer control)
Circulatory & Respiratory Health
Clinical Research (cross-cutting)
Dental Science
Gender & Health
Genetics (see also Life Sciences)
Global Health (i.e. issues of health and care in developing countries)
Health Services & Policy
Human Development, Child & Youth Health
Infection & Immunity (including pandemic processes)
Musculoskeletal Health & Arthritis
Nanomedicine and Regenerative Medicine
Neurosciences, Mental Health, Addiction
Nursing Science
Nutrition, Metabolism & Diabetes
Population & Public Health
Veterinary Science
Other

Q1.EQ.5
Engineering

(This section addresses research in Engineering. Aspects of technological application of engineering are addressed under Areas of Technological Application listed in the BROAD AREAS ("GATEWAYS") MENU).

SUB-AREAS

Aerospace Engineering
Automotive Engineering
Other Mechanical Engineering
Civil Engineering
Industrial Engineering
Petroleum Engineering & Polymer Science
Other Chemical Engineering
Mining Engineering & Mineral Processing
Agricultural Engineering
Forestry Engineering
Environmental Engineering

Biomedical Engineering
Electronic & Photonic Engineering
Computer Engineering (e.g. hardware, systems, architecture)
Communications and Network Engineering
Electrical Engineering (e.g. power systems)
Nuclear Engineering
Materials Engineering and Sciences
Architecture
Other

Q1.EQ.6
Social Sciences (See also Health Sciences in BROAD AREAS ("GATEWAYS") MENU)

SUB-AREAS

Anthropology
Business and Management Science
Communications, Media & Cultural Sciences
Economics
Education
Geography; Urban & Environmental Planning
Political Science & Public Administration
Law & Criminology
Social Psychology ('Experimental Psychology' is included under Life Sciences)
Linguistics
Sociology
Demography
Other

Q1.EQ.7
Humanities and the Arts

SUB-AREAS

Architecture
Archaeology
Classics: Ancient & Medieval Studies
Visual & Creative Arts
History
Humanities "Computing"
Library & Archive Science
Language & Literature
Philosophy
Religious Studies
Other

For each of the following sub-areas for which you are comfortable expressing a view, please provide your opinion of Canada's overall strength relative to other advanced countries (i.e., roughly the OECD group). When rating these areas of technological application, please first consider, in combination: (a) how close Canadian performance is to the frontier of global best practice; (b) how extensively (relative to international peers) is the technology represented in Canada; and where applicable, (c) how competitive are Canadian-based suppliers in world markets.

Second, please rate your opinion of the overall trend in Canada's relative strength over roughly the past five years — are we gaining ground, falling behind, or remaining stable?

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a sub area, please leave it blank.

Canada's Overall Strength Relative to Other Advanced Countries							Recent Trend		
VERY STRONG			ABOUT THE SAME			VERY WEAK	GAINING GROUND	STABLE	FALLING BEHIND
7	6	5	4	3	2	1	❍	❍	❍

Q1.EQ.9
Information & Communications Technologies (ICT)
(See also ICT-enabled Services Technologies in BROAD AREAS ("GATEWAYS") MENU)

<u>SUB-AREAS</u>

Microelectronics Components and Systems
Computer and Related Equipment (design, production)
Software Development (general)
Data Systems - Architecture, Processing, Security
ICT Systems Engineering
Robotics, Automation and Artificial Intelligence
Telecommunication Equipment (design, production)
Wireless Networks
Broadband Networks
Telecommunications Services (as distinct from hardware platforms)
Satellite-based Systems and Services
Other

Q1.EQ.10
ICT-enabled Services Technologies

<u>**SUB-AREAS**</u>

e-Commerce
e-Health Services
e-Government
e-Learning
ICT-enabled Commercial Services (e.g. finance, retailing, law, logistics)
'New Media', Multimedia, Animation and Gaming
Other

Q1.EQ.11
Manufacturing, Construction and Transportation Technologies
(See also BROAD AREAS ("GATEWAYS") MENU, which includes other manufacturing, construction and transportation areas.)

<u>**SUB-AREAS**</u>

Aerospace Products and Parts
Motor Vehicles and Parts
Shipbuilding
Other Transportation Equipment
Machinery - Electrical
Machinery - Non-electrical
Metal Products (primary and fabricated)
Furniture and Related Products
Clothing
Microfabrication
Building Construction (commercial and residential)
Infrastructure Construction (e.g. transportation; utilities)
Rail Transport Technologies
Road Transport Technologies
Marine Transport Technologies
Air Transport Technologies
Multi-modal Transport Systems and Technologies
Other

Q1.EQ.12
Energy, Mining and Forestry
(See also Environmental Technologies in BROAD AREAS ("GATEWAYS") MENU)

<u>**SUB-AREAS**</u>
Conventional Oil and Gas Exploration and Extraction
Offshore Oil and Gas Technologies
Oilsands and Related Production
Other Non-conventional Hydrocarbons (e.g. coal bed methane)
Pipelines
Hydrocarbon Refining
Nuclear Power
Hydroelectric Power
Electricity Distribution Technologies (e.g. grid design and management)
Mining Exploration Technologies
Mineral Extraction and Primary Processing
Technologies for Resource Production in Cold Climates
Timber Harvesting Technologies
Forest Conservation Technologies / Methods
Sawmills and Other Primary Processing
Other

Q1.EQ.13
Chemical and Materials Technologies
(See also Biotechnologies and Nanotechnologies in BROAD AREAS ("GATEWAYS") MENU))

<u>**SUB-AREAS**</u>
Advanced Industrial Materials (e.g. ceramics, coatings, composites)
Catalytic Process Technologies
Polymer Synthesis & Fabrication; Plastics
Advanced Textiles
Steel-making Technologies
Aluminium Production Technologies
Pulp & Paper
Printing Technologies
Other

Q1.EQ.14
Agri-Food Technologies
(See also Biotechnologies in BROAD AREAS ("GATEWAYS") MENU)

SUB-AREAS
Aquaculture
Fish Harvesting & Processing Technologies
Agricultural Machinery
Agro-Chemical Technologies (e.g. fertilizers, pesticides)
Food Transportation, Storage and Marketing Technologies
Food Processing Technologies
New Food Development & Food Biotechnologies
Food Safety Assurance Technologies
Other

Q1.EQ.15
Environmental Technologies
(See also Energy, Mining and Forestry and Biotechnologies in BROAD AREAS ("GATEWAYS") MENU)

SUB-AREAS
Smart Energy & Conservation Technologies (e.g. grid management; metering)
Energy Cogeneration
"Clean" Hydrocarbon Technologies (including CO_2 sequestration)
Wind Power
Biofuels
Solar Power
Fuel Cell & Hydrogen Technologies
Cold Climate Building and Construction Technologies
"Green Building" Technologies
Clean Water Technologies
Clean Air Technologies
Solid Waste Management Technologies
Recycling & Recovery Technologies
Environmental Monitoring Technologies & Systems
Other

Q1.EQ.16
Biotechnologies & Medical Technologies
(See also Health Sciences, Agri-Food Technologies, Environmental Technologies, and Nanotechnologies in BROAD AREAS ("GATEWAYS") MENU)

SUB-AREAS

Pharmaceutical Development
Stem-cell Therapeutic Technologies
Medical Imaging Technologies
Other Medical Devices
Plant Biotechnologies
Animal Biotechnologies (non-human)
Genomic and Proteomic Technologies (general)
Industrial & Environmental Biotechnology (e.g. bio-based products other than food and medicine)
Bioinformatics
Other

Q1.EQ.17
Nanotechnologies

SUB-AREAS
Nanotechnology related to Electronics, Photonics
Nanomaterials Technologies
Nanostructures and Nanofabrication Technologies
Nanobiotechnology and Biomimetic Materials
Medical Nanotechnologies
Other

Would you like to return to the Broad Areas ("GATEWAYS") to select other areas to assess?

If you do choose to select other areas, please note that you may see the sub areas you have already assessed (and you can just press the "Continue" button (as needed) until you get to the new sub-areas you have selected)

❍ Yes
❍ No

QUESTION 2

WHICH ELEMENTS OF CANADA'S S&T INFRASTRUCTURE CONFER SIGNIFICANT ADVANTAGES?

The following list includes both "soft" infrastructure (e.g. networks; government programs) and "hard" infrastructure (e.g. major research facilities).

For those elements where you are comfortable expressing a view, please rate your opinion of the degree of advantage they provide for Canadian research and/or technological application relative to other advanced countries (i.e., roughly the OECD group).

You should consider in combination: (a) how close the specific infrastructure is to global best practice (i.e. the quality element); and, where applicable, (b) the extent of deployment of the infrastructure in Canada relative to deployment in other advanced countries (i.e. the "extent of use" element).

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a particular element, please leave it blank.

Degree of Advantage for Canada Relative to Other Advanced Countries

SIGNIFICANT ADVANTAGE			NEITHER			SIGNIFICANT DISADVANTAGE
7	6	5	4	3	2	1

<u>Knowledge Production and Support</u>

Canada's Universities
Canada's Community Colleges
Research Hospitals
Natural Sciences & Engineering Research Council (NSERC)
Social Sciences & Humanities Research Council (SSHRC)
Canadian Institutes of Health Research (CIHR)
Provincial Research Support Programs
Charitable Support for Research
Canada Foundation for Innovation
Canada Research Chairs
Canadian Institute for Advanced Research (CIAR)
CANARIE High-speed Network
High Performance Computing Networks
Canadian Research Knowledge Network (CRKN)
StatsCan/SSHRC Research Data Centres
National Library and Archives

WHICH ELEMENTS OF CANADA'S S&T INFRASTRUCTURE CONFER SIGNIFICANT ADVANTAGES?

For the following elements where you are comfortable expressing a view, please rate your opinion of the degree of advantage they provide for Canadian research and/or technological application relative to other advanced countries (i.e., roughly the OECD group).

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a particular element, please leave it blank.

Degree of Advantage for Canada Relative to Other Advanced Countries

SIGNIFICANT ADVANTAGE			NEITHER			SIGNIFICANT DISADVANTAGE
7	6	5	4	3	2	1

"Big Science" Facilities
TRIUMF (UBC)
Sudbury Neutrino Observatory (SNO)
Canadian Light Source (Saskatoon)
Astronomical Observatories
Canadian Research Icebreaker (Amundsen)

WHICH ELEMENTS OF CANADA'S S&T INFRASTRUCTURE CONFER SIGNIFICANT ADVANTAGES?

For the following elements where you are comfortable expressing a view, please rate your opinion of the degree of advantage they provide for Canadian research and/or technological application relative to other advanced countries (i.e., roughly the OECD group).

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a particular element, please leave it blank.

S&T Commercialization/Translation and Support
SR & ED Tax Credit
University Technology Transfer
Venture Capital Providers
Canada's Banking System
Business Development Corporation (BDC)
Export Development Corporation (EDC)
Canadian Commercial Corporation (CCC)
S&T Counsellors (International Trade Canada)

NRC's Industrial Research Assistance Program (IRAP)
Federal Support Programs for Technology-intensive Business (e.g. TPC; Regional Agencies)
Provincial Government Support Programs for Technology-intensive Business
Provincial Research Councils
Genome Canada and Regional Centres
Sustainable Development Technologies Canada
International Development Research Centre (IDRC)
Networks of Centres of Excellence

WHICH ELEMENTS OF CANADA'S S&T INFRASTRUCTURE CONFER SIGNIFICANT ADVANTAGES?

For the following elements where you are comfortable expressing a view, please rate your opinion of the degree of advantage they provide for Canadian research and/or technological application relative to other advanced countries (i.e., roughly the OECD group).

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a particular element, please leave it blank.

Degree of Advantage for Canada Relative to Other Advanced Countries

SIGNIFICANT ADVANTAGE			NEITHER			SIGNIFICANT DISADVANTAGE
7	6	5	4	3	2	1

Other Federal S&T Infrastructure
NRC Institutes and Federal Laboratories & Facilities
Infectious Diseases Laboratories
Canadian Neutron Beam Centre
NRU Reactor (AECL)
NRC Wind Tunnels
NRC Ocean Engineering Facilities
Statistics Canada

WHICH ELEMENTS OF CANADA'S S&T INFRASTRUCTURE CONFER SIGNIFICANT ADVANTAGES?

For the following elements where you are comfortable expressing a view, please rate your opinion of the degree of advantage they provide for Canadian research and/or technological application relative to other advanced countries (i.e., roughly the OECD group).

Please note, if you do not feel sufficiently knowledgeable to express an opinion about a particular element, please leave it blank.

Degree of Advantage for Canada Relative to Other Advanced Countries

SIGNIFICANT ADVANTAGE			NEITHER			SIGNIFICANT DISADVANTAGE
7	6	5	4	3	2	1

Regulatory System
Intellectual Property Protection (e.g. patents, copyright)
Environmental Regulation
Health and Safety Regulation
Business Framework Regulations (e.g. start-up; bankruptcy)

WHICH ELEMENTS OF CANADA'S S&T INFRASTRUCTURE CONFER SIGNIFICANT ADVANTAGES?

Are there any other areas where Canadian S&T infrastructure confers significant advantages or disadvantages?

Degree of Advantage for Canada Relative to Other Advanced Countries

SIGNIFICANT ADVANTAGE			NEITHER			SIGNIFICANT DISADVANTAGE
7	6	5	4	3	2	1

Other ____________________________
Other ____________________________
Other ____________________________
❍ Don't know/No response

QUESTION 3

WHAT ARE EMERGING AREAS OF POTENTIALLY SIGNIFICANT STRENGTH FOR CANADA?

The following often have been identified as areas of research or technological application that are likely to be of increasing significance over the next 10-15 years. Please choose from the list below (augmented by any you may wish to add) the TOP FIVE areas where you believe Canada is best-placed to be among the global leaders in development and/or application.

- ❍ Clean fossil fuel technologies; CO2 sequestration; etc.
- ❍ Clean renewable energy wind, biofuels, etc.
- ❍ Energy recovery technologies e.g. oil sands; gas hydrates
- ❍ Fuel cells and the hydrogen economy
- ❍ Next generation nuclear technologies for medical, energy and materials science applications
- ❍ Improved diagnostic and surgical methods
- ❍ Genetically "customized" health care
- ❍ Drug delivery targeted to specific tumours or pathogens
- ❍ Tissue engineering (including stem cells, etc.)
- ❍ Rapid assays to detect specific biological substances (including pathogens)
- ❍ Advanced bio-based materials
- ❍ Genetically modified crops
- ❍ Filters and catalysts for water purification
- ❍ Sustainable development and the extractive industries
- ❍ Green manufacturing
- ❍ High performance computing
- ❍ Ubiquitous radio-frequency identification (RFID) tagging of products
- ❍ Public and personal security technologies
- ❍ Quantum cryptography for secure information transfer

Other? (Please list, but do not identify more than five items in total, including those you have checked from the list above)

- ❍ Don't Know/No response

QUESTION 4

HOW WOULD YOU SUM UP CANADA'S OVERALL S&T CAPABILITY?

Taking into account all aspects of S&T — knowledge generation and application; supporting infrastructure; and positioning for the future — what is your opinion of Canada's current overall strength in S&T relative to other advanced countries? Please also rate your opinion of the overall trend in Canada's relative strength over roughly the past five years - are we gaining ground, falling behind, or remaining stable?

Canada's Overall Strength Relative to Other Advanced Countries							**Recent Trend**		
VERY STRONG			ABOUT THE SAME			VERY WEAK	GAINING GROUND	STABLE	FALLING BEHIND
7	6	5	4	3	2	1	❍	❍	❍

QUESTION 5

CANADA'S S&T STRENGTHS, IN YOUR OWN WORDS

Please use this space, if you wish, to comment on any aspects of Canada's S&T capabilities — existing or prospective — and particularly on matters that may not have been reflected adequately in the questionnaire.

For example, you may wish to identify emerging areas of interdisciplinary work that are particularly important for Canada. Or, you may wish to comment on Canada's strengths (or weaknesses) in translating research into commercial application. Or, you may wish to comment on particular regional strengths and specific clusters of S&T capabilities.

(Your comments will not be attributed to you, but anonymous excerpts might be included in our report.)

❍ Comments
❍ No comments

QUESTION 6

Your affiliation(s)

(Please check as many boxes as apply. Click twice to erase if necessary)

Fellow of the Royal Society of Canada

- ❍ Academy of Arts and Humanities
- ❍ Academy of Social Sciences
- ❍ Academy of Science

- ❍ Fellow of the Canadian Academy of Engineering
- ❍ Fellow of the Canadian Academy of Health Sciences
- ❍ University or College Administrator (President, VP Research or equivalent, University-Industry Liaison)
- ❍ Canada Research Chair
- ❍ Networks of Centres of Excellence
- ❍ Canadian Institute for Advanced Research Program Member
- ❍ Other Faculty from a University or College

Senior Employee of a Business Corporation (including commercial Crown Corporations)

- ❍ Small business (under 20 full-time employees)
- ❍ Medium business (20-99 employees)
- ❍ Medium-Large business (100-500 employees)
- ❍ Large business (over 500 employees)

- ❍ Senior Representative of an Industry Association
- ❍ Recipient of technology development funding (e.g. Industry Research Chair; Collaborative Research Development Grant)
- ❍ Officer of IRAP or Technology Partnerships Canada
- ❍ Senior Executive in Federal Government or Government-Sponsored Entity (ADM, Chief Scientist, Director General, Foundation Executive)
- ❍ Representative of a Provincial Government (or Affiliated Entity)
- ❍ Other Federal Government (or Affiliate) Employee
- ❍ Current Member of a Federal or Provincial (S&T-Related) External Advisory Body or Board
- ❍ Senior Representative of a "Think Tank" (i.e. Policy-Advisory NGO)
- ❍ Member of the International Development Community (S&T-related)
- ❍ Member of another S&T-related Non-Governmental Organization
- ❍ Shad Valley Alumnus
- ❍ Other (Please specify)
- ❍ No response

QUESTION 7

Please indicate where you normally work.

- ❍ British Columbia
- ❍ Alberta
- ❍ Saskatchewan
- ❍ Manitoba
- ❍ Ontario
- ❍ Quebec
- ❍ Nova Scotia
- ❍ New Brunswick
- ❍ Prince Edward Island
- ❍ Newfoundland & Labrador
- ❍ Yukon
- ❍ North West Territories
- ❍ Nunavut
- ❍ Outside Canada (Please specify country)

____

- ❍ No response

QUESTION 8

Your Age?

(Please specify range)

- ❍ Under 35 years
- ❍ 35 44 years
- ❍ 45 54 years
- ❍ 55 years or older
- ❍ No response

Thank you for taking the time to complete this survey.

The Council's report to the Government of Canada will be made public on our website in early September.

Appendix 4: Survey Results on 197 Sub-Areas

	Sub-Areas[*]	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
1	Oilsands and Related*	316	6.41	97	1	77	2	Nat Res
2	Conventional Oil & Gas Exploration/Extraction*	305	5.66	84	1	43	3	Nat Res
3	Hydroelectric Power*	291	5.56	79	2	22	9	Nat Res
4	Resource Production in Cold Climates*	254	5.48	86	5	36	9	Nat Res
5	Geology	234	5.44	81	4	21	18	Nat Res
6	Mining Exploration*	249	5.35	77	3	24	8	Nat Res
7	Mineral Extraction & Primary Processing*	237	5.34	77	3	23	10	Nat Res
8	Aluminium Production*	120	5.34	76	3	34	12	Nat Res
9	Physical Geography, Remote Sensing	247	5.32	80	4	30	14	Nat Res/ Environ
10	Petroleum / Polymer Eng	244	5.24	78	7	46	9	Nat Res
11	Genetics (Medical)	381	5.24	75	6	42	10	Health & Rel
12	Geochem & Geochronology	170	5.23	74	5	21	16	Nat Res/ Environ
13	Mining & Mineral Processing	218	5.22	78	4	30	12	Nat Res
14	Offshore Oil and Gas*	287	5.21	74	6	35	8	Nat Res
15	Comms & Network Eng	233	5.20	76	7	27	19	ICT
16	New Media, Multimedia, Animation, Gaming*	169	5.19	77	10	59	8	ICT
17	Geophysics & Seismology	198	5.19	71	8	20	14	Nat Res
18	Genetics, Genomics & Proteomics	474	5.18	74	9	51	12	Health & Rel
19	Hydrology	208	5.17	75	4	25	14	Environ
20	Telecom Equipment*	313	5.17	75	9	25	32	ICT
21	Broadband Networks*	302	5.16	71	8	31	16	ICT
22	Oceanography	241	5.15	73	7	25	27	Environ
23	Cancer Research	441	5.14	73	6	44	9	Health & Rel
24	Pipelines*	260	5.12	68	4	22	4	Nat Res
25	Climate Science	265	5.11	72	7	26	19	Environ

[*] Sub-areas of technology application; others (without asterisk) are sub-areas of scientific research
[1] Mean = Weighted average of seven-point scale ratings
[2] Strong = Percentage of survey respondents rating the sub-area as "Strong" (rating 5, 6, 7)
[3] Weak = Percentage rating the sub-area as "Weak" (rating 1, 2, 3)
[4] Up = Percentage rating the sub-area as "Gaining Ground"
[5] Down = Percentage rating the sub-area as "Losing Ground"

	Sub-Areas[*]	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
26	Wireless Networks*	330	5.09	72	11	38	16	ICT
27	Cold Climate Construction*	217	5.08	75	11	28	11	
28	Optics, Lasers	188	5.05	68	11	38	13	ICT
29	Astronomy, Astrophysics, Cosmology	207	5.05	67	12	25	13	
30	Neurobiology / Neurosciences	331	5.02	67	11	39	14	Health & Rel
31	Computer Software Development & Theory	258	5.00	68	9	27	16	ICT
32	Telecom Services*	277	5.00	68	10	25	18	ICT
33	Aerospace Products and Parts*	184	4.98	66	11	22	20	
34	Electricity Distribution*	246	4.96	64	11	19	18	
35	Forestry Engineering	208	4.95	67	11	23	18	Nat Res
36	Genomic and Proteomic Technologies*	408	4.94	67	12	46	15	Health & Rel
37	Circulatory & Respiratory	337	4.93	63	6	27	10	Health & Rel
38	Infection & Immunity	384	4.91	65	10	43	13	Health & Rel
39	Artificial Intell, Robotics	262	4.91	64	15	31	18	ICT
40	Electronic & Photonic Eng	240	4.90	64	11	27	17	ICT
41	Meteorology	208	4.90	58	5	12	12	Environ
42	Visual & Creative Arts	126	4.89	67	16	49	12	
43	Neuroscience, Mental Health, Addiction	340	4.89	64	12	36	14	Health & Rel
44	Quantum Informatics	167	4.89	60	17	51	12	ICT
45	Electrical Engineering	231	4.89	58	9	17	20	
46	Satellite-based Systems and Services*	270	4.88	62	14	23	20	ICT
47	Fuel Cell & Hydrogen*	241	4.87	65	18	32	24	Environ
48	Geography; Urban & Environmental Planning	165	4.85	67	13	31	21	Environ
49	Computer Databases, Information Systems	234	4.85	63	12	27	13	ICT
50	Pulp & Paper*	129	4.85	61	12	10	36	Nat Res
51	Timber Harvesting Technols*	262	4.84	64	15	14	22	Nat Res
52	Library & Archive Science	107	4.83	60	12	34	14	
53	Software Development*	336	4.82	58	12	26	17	ICT
54	Communications, Media & Cultural Sciences	171	4.81	63	15	37	19	
55	Nuclear Power*	292	4.81	60	14	10	42	
56	Humanities "Computing"	100	4.81	59	10	39	7	

	Sub-Areas*	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
57	Soil Science	177	4.81	58	8	8	15	Nat Res/Envir
58	Building Construction*	150	4.80	63	7	22	10	
59	Food Safety Assurance Technologies*	157	4.80	63	11	36	17	
60	Organic Chemistry	150	4.79	59	10	16	17	
61	Language & Literature	134	4.78	60	14	22	18	
62	Aerospace Engineering	284	4.77	61	23	19	32	
63	Civil Engineering	233	4.77	57	7	17	16	
64	Hydrocarbon Refining*	232	4.77	53	9	18	11	Nat Res
65	Medical Imaging Technols*	401	4.76	60	17	38	17	Health & Rel
66	Other Non-conventional Hydrocarbons*	252	4.75	62	17	39	18	Nat Res
67	Environmental Engineering	239	4.75	59	14	27	25	Environ
68	ICT Systems Engineering*	233	4.72	55	10	21	14	ICT
69	Plant Biotechnologies*	316	4.71	59	13	27	13	
70	Cell Biology	380	4.71	55	11	22	14	Health & Rel
71	Nutrition, Metabolism & Diabetes	314	4.70	57	13	35	10	Health & Rel
72	Biomedical Engineering	225	4.69	62	15	39	14	Health & Rel
73	Polymer Chemistry	163	4.69	54	15	19	18	
74	Aquaculture*	166	4.67	60	16	30	24	
75	Agricultural Engineering	179	4.67	56	14	21	17	
76	e-Learning*	177	4.67	55	16	36	14	ICT
77	Materials Engineering & Sci	234	4.67	54	10	27	13	
78	Physical Chemistry	165	4.67	52	10	15	11	
79	e-Government*	175	4.66	57	18	37	15	ICT
80	Clean Water Technologies*	253	4.66	56	16	36	20	Environ
81	Motor Vehicle Parts/Products	181	4.65	59	16	23	24	
82	Nuclear Engineering	210	4.65	58	16	12	34	
83	Ecology & Evolutionary Biology	331	4.65	50	14	22	15	Environ
84	Advanced Industrial Materials*	159	4.64	59	16	41	18	
85	Forest Conservation*	268	4.64	58	19	24	34	Nat Res/Envir
86	Stem-cell Therapeutics*	406	4.64	56	20	46	20	Health & Rel
87	Biochemistry	389	4.64	48	10	10	13	

	Sub-Areas*	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
88	Robotics, Automation & AI*	290	4.63	57	19	29	22	ICT
89	Law & Criminology	142	4.63	53	14	23	11	
90	Inorganic Chemistry	147	4.63	48	10	13	13	
91	Population & Public Health	339	4.62	56	16	33	16	Health & Rel
92	Condensed Matter Physics	166	4.61	48	16	21	20	
93	Nanotechnology (Electronics, Photonics)*	181	4.60	57	24	49	19	ICT
94	Political Sci & Public Admin	168	4.59	52	13	20	15	
95	Data - Architecture, Processing Security*	251	4.59	49	15	25	12	ICT
96	Microbiology	342	4.58	49	13	19	13	Health & Rel
97	Aging	375	4.57	53	14	32	13	Health & Rel
98	Computer - Human Interfaces	221	4.57	53	18	24	14	ICT
99	Plant Biology	321	4.57	51	15	18	14	
100	Applied Math	207	4.56	51	14	24	11	
101	ICT-enabled Commercial Services*	155	4.56	51	15	33	11	ICT
102	Other Chemical Engineering	192	4.56	49	11	12	12	
103	Sawmills/Primary Processing*	220	4.56	49	16	11	26	Nat Res
104	Animal Biology	317	4.56	48	13	12	16	
105	Food Processing Technols*	144	4.56	48	15	20	16	
106	Business & Management Sci	170	4.55	52	19	30	17	
107	New Food Development & Food Biotechnologies*	164	4.54	56	20	40	20	
108	Nuclear Physics	169	4.54	54	20	13	31	
109	Clinical Research	357	4.54	47	19	25	26	Health & Rel
110	Nanomaterials*	192	4.53	57	24	52	19	
111	Economics	187	4.53	48	13	14	16	
112	Human Development, Child & Youth Health	317	4.53	47	14	25	14	Health & Rel
113	Gender & Health	307	4.53	46	14	33	12	Health & Rel
114	Environmental Monitoring & Systems*	239	4.52	50	21	28	19	Environ
115	Pure Math	190	4.52	47	18	20	17	
116	Systems Biology & Bioinformatics	373	4.51	54	21	40	23	Health & Rel
117	Demography	131	4.51	50	14	16	15	

	Sub-Areas*	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
118	Musculoskeletal Health & Arthritis	299	4.51	46	11	19	9	Health & Rel
119	Analytical Chemistry	149	4.51	46	12	10	14	
120	Catalytic Processes*	105	4.50	55	14	21	24	
121	Fish Harvesting & Processing*	153	4.50	52	20	14	31	Nat Res
122	Computer Engineering	253	4.50	51	19	14	29	ICT
123	Aboriginal Health	362	4.49	54	22	48	17	Health & Rel
124	Food Handling & Marketing*	131	4.49	44	15	18	15	
125	Education	172	4.48	53	19	21	32	
126	Health Services & Policy	353	4.48	51	21	30	22	Health & Rel
127	Infrastructure Construction *	140	4.48	49	17	19	19	
128	e-Commerce*	175	4.48	49	19	29	19	ICT
129	Polymer Synthesis, Plastics*	122	4.47	52	20	18	24	
130	Nanoscale Physical Science	200	4.47	51	23	48	20	
131	Elementary Particle Physics	158	4.44	48	23	19	21	
132	Social Psychology	136	4.44	46	17	21	13	
133	Kinesiology	242	4.44	40	13	16	9	Health & Rel
134	Microelectronics Components & Systems*	270	4.43	47	21	20	32	ICT
135	Veterinary Science	254	4.43	41	13	16	14	
136	Global Health	346	4.42	49	23	31	19	Health & Rel
137	Math Statistics	173	4.42	42	14	15	12	
138	Experimental Psychology	238	4.42	40	18	13	12	
139	Air Transport Technologies*	130	4.41	50	22	15	27	
140	Nanobiotech & Biomimetics*	64	4.41	50	27	47	23	Health & Rel
141	Bioinformatics*	335	4.41	49	21	36	18	Health & Rel
142	Nano and Regenerative Med	282	4.41	48	20	42	21	Health & Rel
143	History	124	4.41	45	18	16	17	
144	Metal Products*	136	4.41	43	18	15	27	Nat Res
145	Physiology	295	4.40	41	16	10	19	Health & Rel
146	Linguistics	131	4.39	49	21	25	16	
147	Space Science	223	4.37	50	30	19	29	
148	Architecture (Design)	105	4.37	45	18	31	13	
149	Animal Biotechnologies*	280	4.35	41	17	20	14	
150	Nanostructures & Fabrication*	176	4.34	51	28	47	18	

	Sub-Areas*	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
151	Industrial & Environ Biotech*	311	4.32	45	23	32	19	Environ
152	e-Health*	165	4.30	52	27	43	26	ICT/Health
153	Steel-making*	119	4.30	45	24	8	34	
154	Other Medical Devices*	146	4.30	42	21	21	22	Health & Rel
155	Anthropology	150	4.28	35	17	16	18	
156	Sociology	164	4.27	40	22	13	20	
157	Philosophy	105	4.26	42	27	12	24	
158	Agro-Chemical Technologies*	149	4.25	39	22	11	23	
159	Industrial Engineering	212	4.24	35	19	10	21	
160	Other Mechanical Eng	226	4.23	33	17	7	17	
161	"Green Building" Technologies*	238	4.22	46	32	35	24	Environ
162	Printing Technologies*	89	4.22	31	18	8	19	
163	Clean Air*	221	4.20	40	27	26	28	Environ
164	Nursing Science	263	4.19	32	23	22	20	Health & Rel
165	Pharmaceutical Development*	433	4.18	42	34	19	35	Health & Rel
166	Computer & Related Equipment*	287	4.18	37	29	14	31	ICT
167	Other Transportation Equipment*	125	4.17	30	22	9	22	
168	Automotive Engineering	255	4.15	41	32	12	30	
169	Nanoscale Biosciences	267	4.14	39	31	42	23	
170	Archaeology	91	4.14	36	27	14	18	
171	"Clean" Hydrocarbons*	231	4.13	44	36	33	34	Nat Res/Envir
172	Religious Studies	87	4.13	34	26	8	19	
173	Agricultural Machinery*	131	4.09	32	27	7	39	
174	Dental Science	243	4.09	26	19	6	17	Health & Rel
175	Smart Energy & Conservation*	250	4.08	38	33	29	30	Environ
176	Medical Nanotech*	152	4.07	44	32	44	29	Health & Rel
177	Recycling & Recovery*	249	4.06	39	35	25	29	Environ
178	Energy Cogeneration*	229	4.06	36	32	29	28	Environ
179	Computer Hardware	92	4.03	37	36	13	40	ICT
180	Plasma Physics	125	4.02	30	28	9	29	
181	Architectural Eng	160	4.01	29	26	8	21	
182	Biofuels*	259	4.00	39	37	36	25	Environ
183	Rail Transport Technologies*	148	3.99	41	40	17	33	
184	Solid Waste Management*	239	3.96	34	36	19	32	Environ

	Sub-Areas*	Numb. Resps.	Mean[1]	Percentage of Respondents				Cluster
				Strong[2]	Weak[3]	Up[4]	Down[5]	
185	Road Transport Technologies*	137	3.90	30	36	10	23	
186	Furniture & Related Products*	124	3.88	27	33	3	48	
187	Classics	103	3.86	27	38	10	36	
188	Machinery (Electric)*	124	3.84	21	31	6	30	
189	Machinery (Non-electric)*	119	3.81	19	32	5	23	
190	Microfabrication*	109	3.80	28	42	23	33	
191	Advanced Textiles*	95	3.76	27	43	15	40	
192	Multi-modal Transport*	101	3.76	25	35	9	26	
193	Wind Power Technologies*	274	3.62	28	55	38	34	Environ
194	Solar Power Technologies*	244	3.40	20	58	20	40	Environ
195	Marine Transport*	112	3.38	18	57	4	46	
196	Clothing*	118	3.34	15	58	4	60	
197	Shipbuilding*	145	3.06	12	63	2	72	

Appendix 5: Bibliometrics and Technometrics

- Appendix 5A: All Bibliometric Sub-Areas Classified by Quadrant
- Appendix 5B: Bibliometric Graphs — Detailed Perspectives
- Appendix 5C: Growth and Decline: Bibliometrics
- Appendix 5D: Growth and Decline: Technometrics

Appendix 5A

All Bibliometric Sub-Areas Classified by Quadrant

	Cluster**	Sub–area	SI	ARIF	Canada	World	Cda-Wld
		Alphabetical Order Within Quadrant			Growth of Publication Volume 2001-2004 vs 1997-2000		
		SI > 1, ARIF > 1					
Q1	O	Acoustics*	1.03	1.11	-15.3%	-7.0%	-8.2%
Q1	O	Animal Biology	1.70	1.07	-10.8%	-3.9%	-6.9%
Q1	O	Anthropology	1.16	1.04	14.8%	7.6%	7.1%
Q1	O	Biochemistry	1.06	1.03	-3.0%	-5.6%	2.6%
Q1	H	Circulatory & Respiratory Health	1.09	1.16	15.4%	-1.7%	17.1%
Q1	E	Climate Science & Meteorology	1.45	1.05	-9.4%	3.4%	-12.8%
Q1	H	Clinical Research (cross-cutting)	1.10	1.41	-1.7%	-10.4%	8.6%
Q1	I	Computer Sciences	1.24	1.01	18.5%	13.0%	5.5%
Q1	E	Ecology & Evolution Biology	1.47	1.13	25.2%	15.8%	9.4%
Q1	E	Environmental Science*	1.74	1.08	5.1%	11.8%	-6.7%
Q1	O	Ergonomics*	1.63	1.05	1.3%	-15.8%	17.2%
Q1	H	Fertility*	1.21	1.08	-12.6%	-14.1%	1.5%
Q1	N	Forestry Engineering	3.06	1.03	8.0%	6.7%	1.3%
Q1	O	General Engineering*	1.10	1.23	20.5%	10.4%	10.1%
Q1	H	Genetics	1.30	1.09	-8.7%	-7.5%	-1.2%
Q1	H	Genetics, Genomics, Proteomics	1.07	1.08	-4.6%	-2.4%	-2.3%
Q1	N/E	Geochemistry & Geochronology	1.46	1.03	10.7%	8.1%	2.6%
Q1	N	Geology	1.98	1.05	-4.0%	7.6%	-11.6%
Q1	H	Human Development & Youth Health	1.23	1.16	-11.4%	-6.2%	-5.3%
Q1	E	Hydrology	2.36	1.00	37.2%	45.0%	-7.8%
Q1	H	Kinesiology	2.05	1.02	25.4%	25.1%	0.3%
Q1	E	Marine Biology & Hydrobiology*	1.87	1.20	-15.9%	1.3%	-17.2%
Q1	O	Math Statistics	1.22	1.01	6.1%	3.1%	3.0%
Q1	H	Musculoskeletal & Arthritis	1.27	1.10	-7.0%	13.0%	-20.0%

** H=Health Related; I=ICT; E=Environment; N=Natural Resources; O=Other

	Cluster*	Sub–area	SI	ARIF	Canada	World	Cda-Wld
Q1	H	Neurobiology / Neurosciences	1.39	1.02	-4.0%	-1.0%	-3.0%
Q1	H	Nursing Science	1.33	1.13	0.2%	-7.6%	7.8%
Q1	H	Nutrition, Metabolism & Diabetes	1.08	1.13	11.4%	6.6%	4.8%
Q1	E	Oceanography	1.37	1.20	-0.6%	7.0%	-7.6%
Q1	O	Operations Research*	1.98	1.03	5.7%	19.3%	-13.6%
Q1	H	Orthopedics*	1.16	1.06	59.4%	24.3%	35.2%
Q1	H	Pharmacology*	1.08	1.07	-9.0%	-6.1%	-2.9%
Q1	N/E	Physical Geography, Remote Sensing	1.47	1.05	25.8%	17.7%	8.0%
Q1	H	Psychiatry*	1.78	1.05	-10.5%	-5.2%	-5.3%
Q1	O	Psychology*	1.33	1.23	-13.2%	-14.3%	1.1%
Q1	O	Psychology, Clinical*	1.52	1.09	-1.6%	-7.0%	5.4%
Q1	O	Psychology, Mathematical*	2.06	1.16	25.5%	13.5%	12.0%
Q1	O	Pure Math	1.02	1.01	6.1%	13.5%	-7.4%
Q1	H	Radiology & Nuclear Medicine*	1.07	1.01	-11.1%	-8.7%	-2.4%
Q1	H	Rehabilitation*	1.48	1.00	-15.4%	-9.1%	-6.3%
Q1	O	Social Issues*	1.33	1.07	5.5%	-9.0%	14.5%
Q1	O	Social Psychology	1.86	1.06	11.7%	-6.7%	18.4%
Q1	H	Social Sciences, Biomedical*	1.95	1.21	-12.6%	-5.2%	-7.4%
Q1	O	Social Sciences, Interdisciplinary*	1.41	1.09	-0.7%	-10.7%	9.9%
Q1	O	Social Work*	1.30	1.08	-12.4%	-15.0%	2.6%
Q1	N/E	Soil Science	1.70	1.05	-25.8%	-8.0%	-17.8%
Q1	O	Transport Studies*	1.62	1.03	-34.1%	-4.9%	-29.2%
Q1	O	Veterinary Science	1.15	1.01	-15.9%	-6.1%	-9.8%
Q1	O	Women's Studies*	1.56	1.00	-24.3%	-8.6%	-15.7%
		SI < 1, ARIF > 1					
Q2	O	Analytical Chemistry	0.66	1.23	-12.6%	-12.3%	-0.3%
Q2	O	Applied Chemistry*	0.84	1.19	-5.0%	4.0%	-9.0%
Q2	O	Applied Physics*	0.43	1.08	-7.0%	-2.8%	-4.2%
Q2	M	Astronomy, Astro Phys, Cosmology	0.99	1.14	22.3%	12.8%	9.5%
Q2	H	Biomedical Engineering	0.89	1.02	-1.7%	5.6%	-7.3%
Q2	H	Cancer Research	0.88	1.21	9.3%	4.0%	5.3%
Q2	O	Cell Biology	0.94	1.07	-11.4%	-5.7%	-5.7%
Q2	O	Chemical Physics*	0.93	1.03	-11.2%	-3.4%	-7.8%
Q2	O	Condensed Matter Physics	0.49	1.22	-1.0%	-5.1%	4.1%
Q2	H	Dental Science	0.63	1.07	-28.4%	3.0%	-31.4%
Q2	H	Dermatology & Venereal Disease*	0.46	1.18	-8.1%	-13.1%	4.9%
Q2	I	Electronic & Photonic Engineering	0.85	1.01	12.1%	1.7%	10.4%

	Cluster*	Sub–area	SI	ARIF	Canada	World	Cda-Wld
Q2	H	Gastroenterology*	0.72	1.41	-2.1%	-4.6%	2.5%
Q2	H	General Biomedical Research*	0.90	1.21	-6.6%	-14.3%	7.7%
Q2	O	General Chemistry*	0.75	1.25	-7.7%	4.1%	-11.8%
Q2	O	General Physics*	0.65	1.29	4.7%	-3.2%	7.9%
Q2	H	Infection & Immunity	0.89	1.12	-12.9%	-7.5%	-5.4%
Q2	O	Inorganic Chemistry	0.55	1.43	6.3%	4.7%	1.6%
Q2	O	Microbiology	0.96	1.01	2.7%	1.8%	0.9%
Q2	O	Microscopy*	0.91	1.04	-24.7%	-17.8%	-7.0%
Q2	O	Nanoscale Biosciences	0.72	1.00	41.1%	35.1%	6.0%
Q2	O	Nanoscale Physical Science	0.49	1.15	20.8%	26.2%	-5.4%
Q2	H	Neurosci, Mental Health, Addiction	0.99	1.02	-35.5%	-10.9%	-24.6%
Q2	O	Nuclear Engineering	0.56	1.25	-23.8%	4.5%	-28.3%
Q2	O	Nuclear Physics & Elem Particles	0.87	1.15	-1.3%	-4.0%	2.7%
Q2	H	Obstetrics & Gynecology*	0.76	1.25	1.8%	-15.0%	16.8%
Q2	I	Optics; Lasers	0.64	1.02	6.1%	-2.6%	8.7%
Q2	O	Organic Chemistry	0.62	1.18	-10.0%	0.3%	-10.3%
Q2	O	Other Mechanical Engineering	0.71	1.01	32.9%	16.8%	16.0%
Q2	H	Ortorhinolaryngology*	0.56	1.12	-13.3%	-22.3%	8.9%
Q2	H	Pathology*	0.82	1.26	-11.4%	-13.9%	2.5%
Q2	N	Petroleum Engineering / Polymer	0.76	1.09	2.4%	9.6%	-7.2%
Q2	H	Pharmacy*	0.37	1.23	25.6%	-9.7%	35.3%
Q2	O	Physical Chemistry	0.62	1.12	-9.3%	2.3%	-11.6%
Q2	O	Polymer Chemistry	0.69	1.19	6.5%	1.3%	5.2%
Q2	O	Psychology, Educational*	0.81	1.40	-12.9%	-8.6%	-4.3%
Q2	H	Tropical Medicine*	0.33	1.06	13.2%	-12.6%	25.7%
Q2	H	Urology*	0.83	1.10	9.5%	-4.5%	14.0%
		SI > 1, ARIF < 1					
Q3	H	Aging	1.42	0.93	6.4%	2.9%	3.5%
Q3	O	Agricultural Engineering	1.42	0.90	-11.0%	4.0%	-15.0%
Q3	O	Business & Management Science	1.34	0.95	-1.9%	-9.8%	7.9%
Q3	O	Civil Engineering	2.05	0.83	3.6%	32.4%	-28.8%
Q3	N/E	Earth & planetary Science*	1.82	0.89	-1.2%	7.2%	-8.4%
Q3	O	Economics	1.15	0.99	-5.4%	-5.8%	0.4%
Q3	O	Education	1.09	0.98	-27.5%	-16.3%	-11.1%
Q3	O	Electrical Engineering	1.25	0.78	-9.8%	11.6%	-21.4%
Q3	H	Embryology*	1.00	0.94	-8.2%	-8.3%	0.1%
Q3	O	Entomology*	1.53	0.98	-19.3%	1.4%	-20.7%

	Cluster*	Sub–area	SI	ARIF	Canada	World	Cda-Wld
Q3	O	Experimental Psychology*	1.99	0.94	-4.3%	-5.4%	1.1%
Q3	O	Family Studies*	1.14	0.70	-26.5%	-28.4%	1.9%
Q3	E	Geography; Urban & Enviro Planning	1.37	0.90	6.4%	-3.7%	10.1%
Q3	N	Geophysics & Seismology	1.31	0.96	-0.9%	9.8%	-10.8%
Q3	H	Health Services & Policy	1.61	0.76	19.0%	5.3%	13.7%
Q3	O	Industrial Engineering	1.44	0.99	24.8%	42.0%	-17.2%
Q3	O	Industrial Relations & Labour*	2.49	0.75	-1.1%	-12.6%	11.6%
Q3	O	Linguistics	1.56	0.83	1.6%	-6.5%	8.1%
Q3	N	Mining & Mineral Processing	2.48	0.97	1.3%	3.2%	-2.0%
Q3	O	Other Chemical Engineering	1.29	0.99	9.1%	18.2%	-9.1%
Q3	H	Physiology	1.65	0.98	-7.6%	-15.1%	7.5%
Q3	O	Plant Biology	1.16	0.95	-6.2%	-5.1%	-1.1%
Q3	O	Political Science & Public Admin	1.31	0.68	-2.6%	-8.3%	5.7%
Q3	H	Population & Public Health	1.53	0.92	-4.0%	-4.2%	0.1%
Q3	O	Psychology, Biological*	1.71	0.95	-27.6%	-7.5%	-20.0%
Q3	O	Sociology	1.04	0.86	-13.4%	-2.3%	-11.1%
		SI < 1, ARIF < 1					
Q4	A	Aerospace Engineering	0.70	0.98	-14.5%	-7.4%	-7.1%
Q4	O	Applied Math	0.99	0.95	11.2%	16.1%	-4.9%
Q4	M	Communications, Media & Culture	0.61	0.91	19.7%	-5.9%	25.5%
Q4	O	Demography	0.95	0.78	17.6%	-9.0%	26.6%
Q4	E	Environmental Engineering	0.94	0.98	4.3%	22.8%	-18.6%
Q4	O	Law & Criminology	0.76	0.90	3.5%	-2.0%	5.5%
Q4	O	Materials Engineering	0.61	0.91	10.4%	36.1%	-25.7%
Q4	N	Metals & Metallurgy*	0.98	0.77	-17.6%	5.7%	-23.3%
Q4	H	Nano and Regenerative Medicine	0.59	0.93	27.0%	42.2%	-15.2%
Q4	H	Ophthalmology*	0.80	0.95	20.6%	15.6%	5.0%
Q4	H	Parasitology*	0.83	0.99	-18.0%	-10.4%	-7.7%
Q4	O	Plasma Physics	0.60	0.99	26.5%	4.2%	22.3%
Q4	H	Surgery*	0.98	0.92	-3.7%	-0.6%	-3.1%

* Denotes sub-areas not separately identified in the survey.

Appendix 5B

Bibliometric Graphs — Detailed Perspectives

The following figures depict Canada's position relative to world science with respect to research intensity (SI on the x-axis) and research output quality (ARIF on the y-axis). The size of the circles on the chart is proportional to the number of Canadian papers published in the various fields over the eight years from 1997 through 2004. (Note that some fields, including health and related life sciences, have characteristically higher publishing volumes than others.) The following three figures depict the disaggregated data that underlie the macro picture in **Figure 5.16** (Chapter 5 of the report). The filled circles (blue) are sub-areas that correspond to the categories used in the Council's survey whereas the open circles (red) are other relevant categories drawn from the US National Science Foundation (NSF) categories.

Figure 5B.1

Detailed Perspective on Natural Sciences, Engineering, 1997–2004

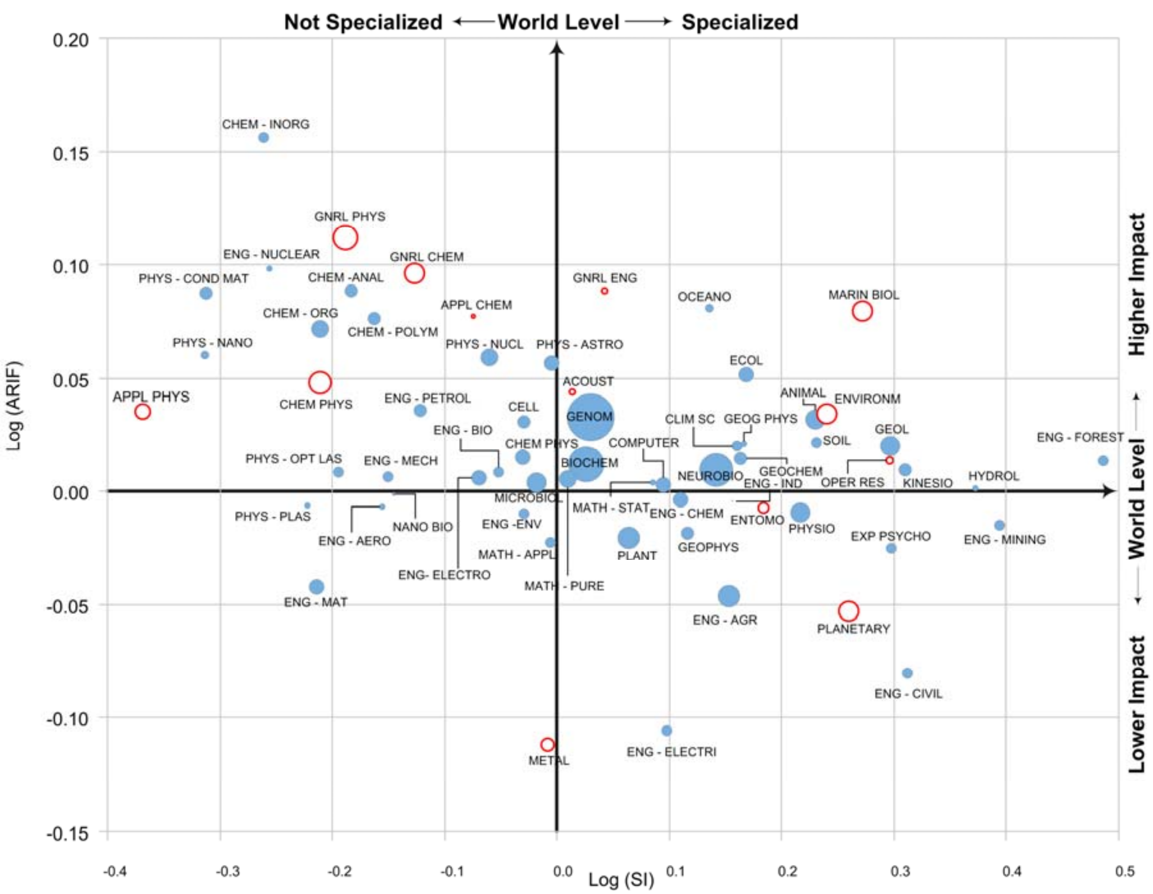


Figure 5B.2

Detailed Perspective on the Health Sciences, 1997–2004

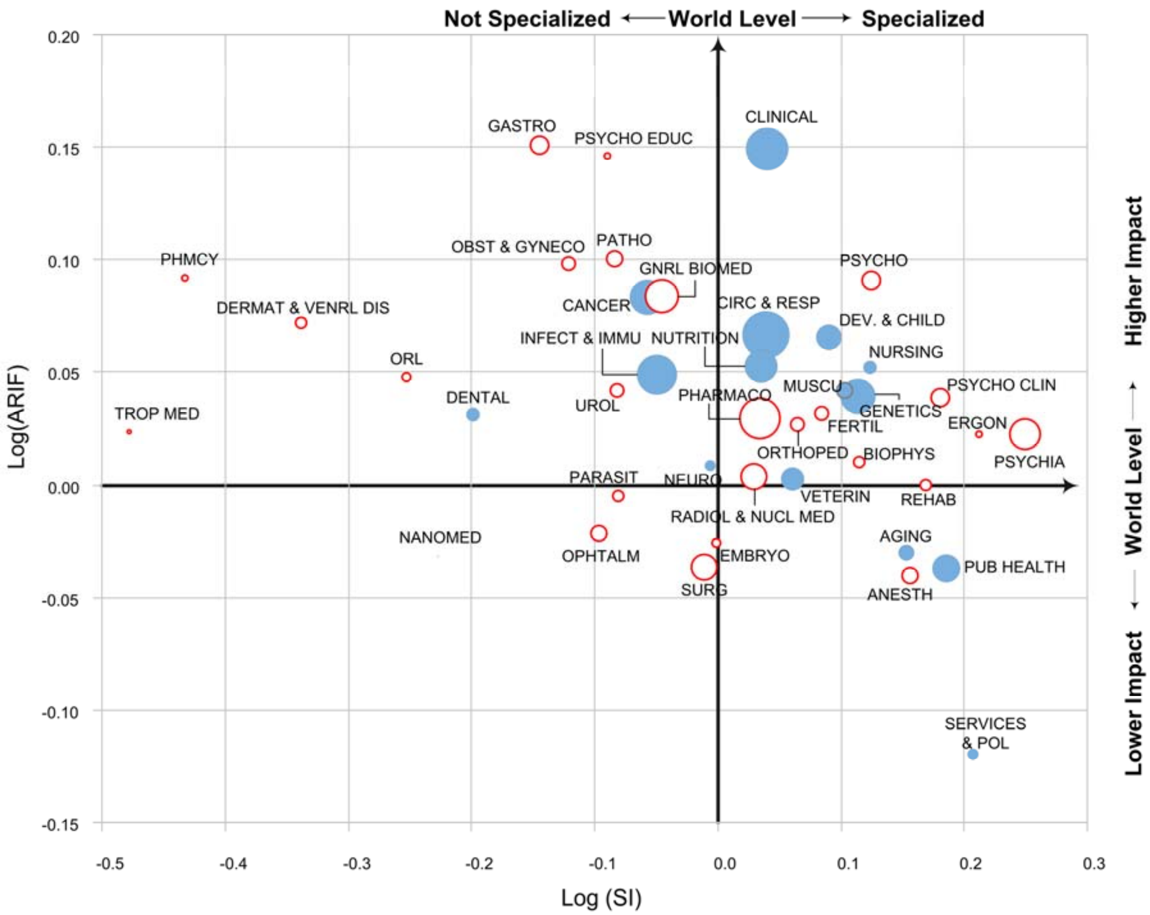
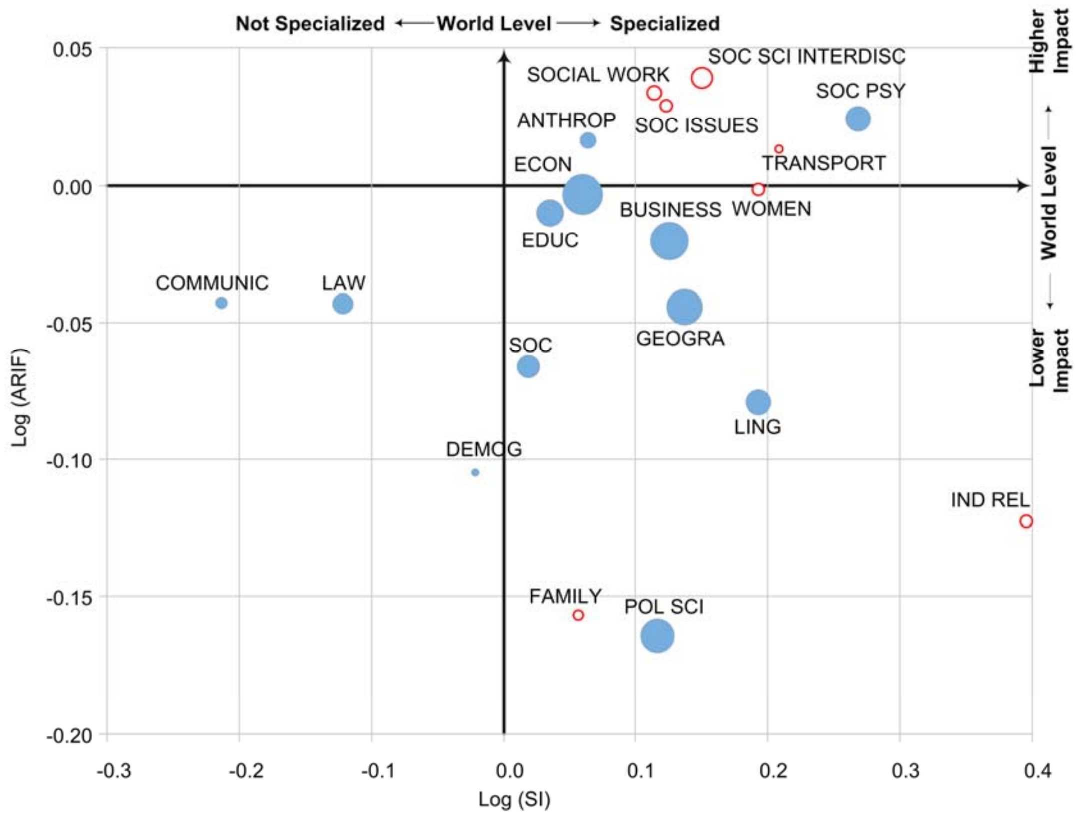


Figure 5B.3

Detailed Perspective on Canada's Position in the Social Sciences, 1997–2004



Appendix 5C

Growth and Decline: Bibliometrics

Growth in Canadian papers was calculated by subtracting the number of papers published between 1997 and 2000 from the number of papers published between 2001 and 2004 and dividing the results by the number of papers published between 1997 and 2000.[1]

Analysis of Bibliometric Growth Data

Figure 5C.1 maintains the sub-areas in their respective quality/intensity quadrants but includes growth ratings. Growth in publication volume was computed for the 2001–2004 period relative to 1997–2000. In this figure, the right side (green blocks) indicates sub-areas where Canada is "gaining ground" — i.e., those fields that are growing faster, or not declining as rapidly, in Canada as at the world level. Sub-areas on the left side (red blocks) are those for which Canada is losing share of world publication volume. In this figure, sub-areas in bold indicate where Canada's growth rate is positive, while sub-areas denoted by ‡ represent fields that have been growing at the world level. Note that Canada can be gaining ground in a field even if its publication volume is shrinking, provided the volume of global publication is shrinking even more rapidly — i.e., what matters is the *difference* between the growth percentage in Canada and in the world.

Figure 5C.2 complements **Figure 5C.1** by listing — together with numerical values — the top 30 sub-areas where (1) Canada is growing fastest, (2) the world is growing fastest, and (3) Canada's growth most exceeds world growth.

[1] The same was applied to growth in patents except that the difference was calculated for the periods 1995–1999 and 2000–2004. Data used for charts that show growth at the world and national levels were normalized for growth in the overall dataset and were *log transformed* to increase readability.

Figure 5C.1

Bibliometric Growth and Decline by Quadrants

	Canada Losing Share	Canada Gaining Share
High Quality and Intensity ARIF>1, SI>1	Genetics Genome, Proteome Rad & Nuclear Med Pharmacology Neurobiol/ Neurosci Human Dev & Youth Psychiatry Rehabilitation **Enviro Science‡** Animal Biology **Pure Math‡** Social Sci, Biomed Oceanography‡ **Hydrology‡** Acoustics Veterinary Science Geology‡ Climate & Meterology‡ **Operations Resrch‡** Women's Studies Marine Biol, Hydrobiol‡ Soil Science Musculo & Arthritis‡ Transport Studies	**Orthopedics‡** **Social Psychology** **Ergonomics** **Circ & Resp Health** **Social Issues** **Psychol, Math‡** **General Eng‡** Social Sci, Interdisc **Ecol & Evolution Bio‡** Clinical Research **Phys Geo, Rem Sens‡** **Nursing Science** **Anthropology‡** **Computer Sciences‡** Psychology, Clinical **Nutrit, Metabo, Diabt‡** **Math Statistics‡** **Geochem/Geochron‡** Social Work Biochemistry Fertility **Forestry Eng‡** Psychology **Kinesiology‡**
High Quality Low Intensity ARIF>1, SI<1	Analytical Chemistry Applied Physics Psychol, Educational Infection & Immunity **Nanoscale Phy Sci‡** Cell Biology Microscopy **Petrol/Polym Eng‡** Biomedical Eng‡ Chemical Physics Applied Chemistry‡ Organic Chemistry‡ Physical Chemistry‡ General Chemistry‡ Neuro Health, Addicti Nuclear Engineering‡ Dental Science‡	**Pharmacy** **Tropical Medicine** **Obstetrics & Gyn** **Other Mechanl Eng‡** **Urology** **Electron, Phot Eng‡** **Astro Phys, Cosmol‡** Otorhinolaryngology **Optics; Lasers** **General Physics** General Biomedical **Nano Biosciences‡** **Cancer Research‡** **Polymer Chemistry‡** **Dermatology** Condens Matt Physics Nucl Phys, Elem Part Pathology Gastroenterology **Inorganic Chem‡** **Microbiology‡**
Low Quality High Intensity ARIF<1, SI>1	Plant Biology **Mining & Mineral Processing‡** Earth & Planetary Science‡ **Other Chemical Eng‡** Geophysics & Seismology‡ Sociology Education Agricultural Engineering‡ **Industrial Engineering‡** Psychology, Biological Entomology‡ Electrical Engineering‡ **Civil Engineering‡**	**Health Services & Policy‡** Industrial Relations & Labour **Geog; Urban & Enviro Planning** **Linguistics** Business & Mgmt Science Physiology Political Science & Public Admin **Aging‡** Family Studies Experimental Psychology Economics Embryology Population & Public Health
Low Quality Low Intensity ARIF<1, SI<1	Surgery **Applied Math‡** Aerospace Engineering Parasitology **Nano and Regenerative Medicine‡** **Environmental Engineering‡** Metals & Metallurgy‡ **Materials Engineering‡**	**Demography** **Communications, Media & Culture** **Plasma Physics‡** **Law & Criminology** **Ophthalmology‡**

Figure 5C.2

Top 30 Sub-areas by Growth: Canada, World and Canada minus World Growth

Ordered by Canada Growth
Publication Volume Change (%):
2004-01 vs 1997-2000

	Sub - Area	**CDA**	WLD	C-W
1	Orthopedics*	**59**	24	35
2	Nanoscale Biosciences	**41**	35	6
3	Hydrology	**37**	45	-8
4	Other Mechanical Eng	**33**	17	16
5	Nano and Regen Med	**27**	42	-15
6	Plasma Physics	**27**	4	22
7	Physical Geog, Rem Sens	**26**	18	8
8	Pharmacy*	**26**	-10	35
9	Psychol, Mathematical*	**26**	14	12
10	Kinesiology	**25**	25	0
11	Ecology & Evol Biol	**25**	16	9
12	Industrial Engineering	**25**	42	-17
13	Astro Phys, Cosmol	**22**	13	10
14	Nanoscale Physical Sci	**21**	26	-5
15	Ophthalmology*	**21**	16	5
16	General Engineering*	**21**	10	10
17	Comms, Media, Culture	**20**	-6	26
18	Health Services & Policy	**19**	5	14
19	Computer Sciences	**19**	13	6
20	Demography	**18**	-9	27
21	Circ & Resp Health	**15**	-2	17
22	Anthropology	**15**	8	7
23	Tropical Medicine*	**13**	-13	26
24	Electron & Photon Eng	**12**	2	10
25	Social Psychology	**12**	-7	18
26	Nutrit, Metabol, Diabet	**11**	7	5
27	Applied Math	**11**	16	-5
28	Geochem & Geochron	**11**	8	3
29	Materials Engineering	**10**	36	-26
30	Urology*	**10**	-5	14

Ordered by World Growth
Publication Volume Change (%):
2004-01 vs 1997-2000

	Sub - Area	CDA	**WLD**	C-W
1	Hydrology	37	**45**	-8
2	Nano and Regen Med	27	**42**	-15
3	Industrial Engineering	25	**42**	-17
4	Materials Engineering	10	**36**	-26
5	Nanoscale Biosciences	41	**35**	6
6	Civil Engineering	4	**32**	-29
7	Nanoscale Physical Sci	21	**26**	-5
8	Kinesiology	25	**25**	0
9	Orthopedics*	59	**24**	35
10	Environmental Eng	4	**23**	-19
11	Operations Research*	6	**19**	-14
12	Other Chemical Eng	9	**18**	-9
13	Physical Geog, Rem Sens	26	**18**	8
14	Other Mechanical Eng	33	**17**	16
15	Applied Math	11	**16**	-5
16	Ecology & Evolution Biol	25	**16**	9
17	Ophthalmology*	21	**16**	5
18	Psychol, Mathematical*	26	**14**	12
19	Pure Math	6	**14**	-7
20	Musculoskel & Arthritis	-7	**13**	-20
21	Computer Sciences	19	**13**	6
22	Astro Phys, Cosmol	22	**13**	10
23	Environmental Science*	5	**12**	-7
24	Electrical Engineering	-10	**12**	-21
25	General Engineering*	21	**10**	10
26	Geophys & Seismology	-1	**10**	-11
27	Petroleum Eng / Polymer	2	**10**	-7
28	Geochem & Geochron	11	**8**	3
29	Anthropology	15	**8**	7
30	Geology	-4	**8**	-12

Ordered by Canada-World Growth
Publication Volume Change (%):
2004-01 vs 1997-2000

	Sub - Area	CDA	WLD	**C-W**
1	Pharmacy*	26	-10	**35**
2	Orthopedics*	59	24	**35**
3	Demography	18	-9	**27**
4	Tropical Medicine*	13	-13	**26**
5	Comms, Media & Culture	20	-6	**26**
6	Plasma Physics	27	4	**22**
7	Social Psychology	12	-7	**18**
8	Ergonomics*	1	-16	**17**
9	Circ & Resp Health	15	-2	**17**
10	Obstetrics & Gyn*	2	-15	**17**
11	Other Mechanical Eng	33	17	**16**
12	Social Issues*	6	-9	**15**
13	Urology*	10	-5	**14**
14	Health Services & Policy	19	5	**14**
15	Psychol, Mathematical*	26	14	**12**
16	Industrial Rel & Labour*	-1	-13	**12**
17	Electron & Photon Eng	12	2	**10**
18	General Engineering*	21	10	**10**
19	Geog; Urb & Enviro Plan	6	-4	**10**
20	Social Sci, Interdisci*	-1	-11	**10**
21	Astro Phys, Cosmol	22	13	**10**
22	Ecology & Evolution Biol	25	16	**9**
23	Otorhinolaryngology*	-13	-22	**9**
24	Optics; Lasers	6	-3	**9**
25	Clinical Research	-2	-10	**9**
26	Linguistics	2	-7	**8**
27	Phys Geog, Remote Sens	26	18	**8**
28	General Physics*	5	-3	**8**
29	Bus & Mngmt Sci	-2	-10	**8**
30	Nursing Science	0	-8	**8**

Note: Differences between Canada and the World may be affected by rounding

Canada Losing Share

Sub-areas in the left side of **Figure 5C.1** (red blocks) are losing share in Canada. Despite the positive growth rates of several of these fields (bolded) such as environmental science, pure and applied mathematics, and materials engineering, Canada has not kept pace with the world growth rate (‡) of these fields. There are also many sub-areas on the left side of the table where Canada has experienced an absolute decline in publication volume but where the world is growing — e.g., climate science and meteorology, metals and metallurgy and nuclear engineering. In the latter field, Canada is losing share rapidly. When combined with a relatively poor patenting performance (noted in the following section), it would appear that nuclear power R&D in Canada is out of synch with increasing demand for nuclear energy at the world level.

There are also some areas where publishing volume is not growing either in the world or in Canada, and where Canada is slightly losing share — e.g., genetics, pharmacology and infectious and immunological diseases, all fields where Canada produces high-quality scientific publications. Canada is also losing share in both genomics and neurobiology. This is perhaps puzzling and could be perceived as a cause for concern considering that Canadian research is currently strong in these areas as measured by both SI and ARIF. It is important to examine these data in context. Deeper analysis shows that there are countries — particularly in Asia — that are rapidly catching up in fields such as genomics. The fact that Canada is losing share is, in some cases, the inevitable consequence of the rapid gains being made by other countries such as China.

It is important to note that scientific fields neither grow regularly nor grow indefinitely. There are instances after major breakthroughs (e.g., genome sequencing) when a torrent of new results pours out. Eventually, scientists have to work much harder to extend the frontier. This is likely what happened in genomics, which has led some to talk of post-genomics or, perhaps more precisely, of "post-sequencing" genomics. There are also fields that reach a point where there has been so much activity that continued growth cannot be sustained at peak level. But there is not necessarily a link between scientific maturity and technological maturity. Because of the complex web of interactions between science and technology, it is often necessary to pursue scientific activities in a field to answer questions raised by technological applications.

Canada Gaining Share

Sub-areas on the right hand side of **Figure 5C.1** (green blocks) show where Canada is gaining share of global publication volume — e.g., cancer research, nanoscale biology, mechanical engineering, ecology and plasma physics. Areas in which Canada is growing but the world is not, include tropical medicine; optical and laser physics; communications, media and culture; demography; and social psychology.

The committee acknowledges that all these data are complex and difficult to interpret. No overall patterns are evident. It should also be noted that the growth figures apply only to publication volume and say nothing as to whether quality (ARIF) or specialization (SI) is increasing or decreasing. We must be content simply to present the figures and leave it to the various expert communities to provide further interpretation.

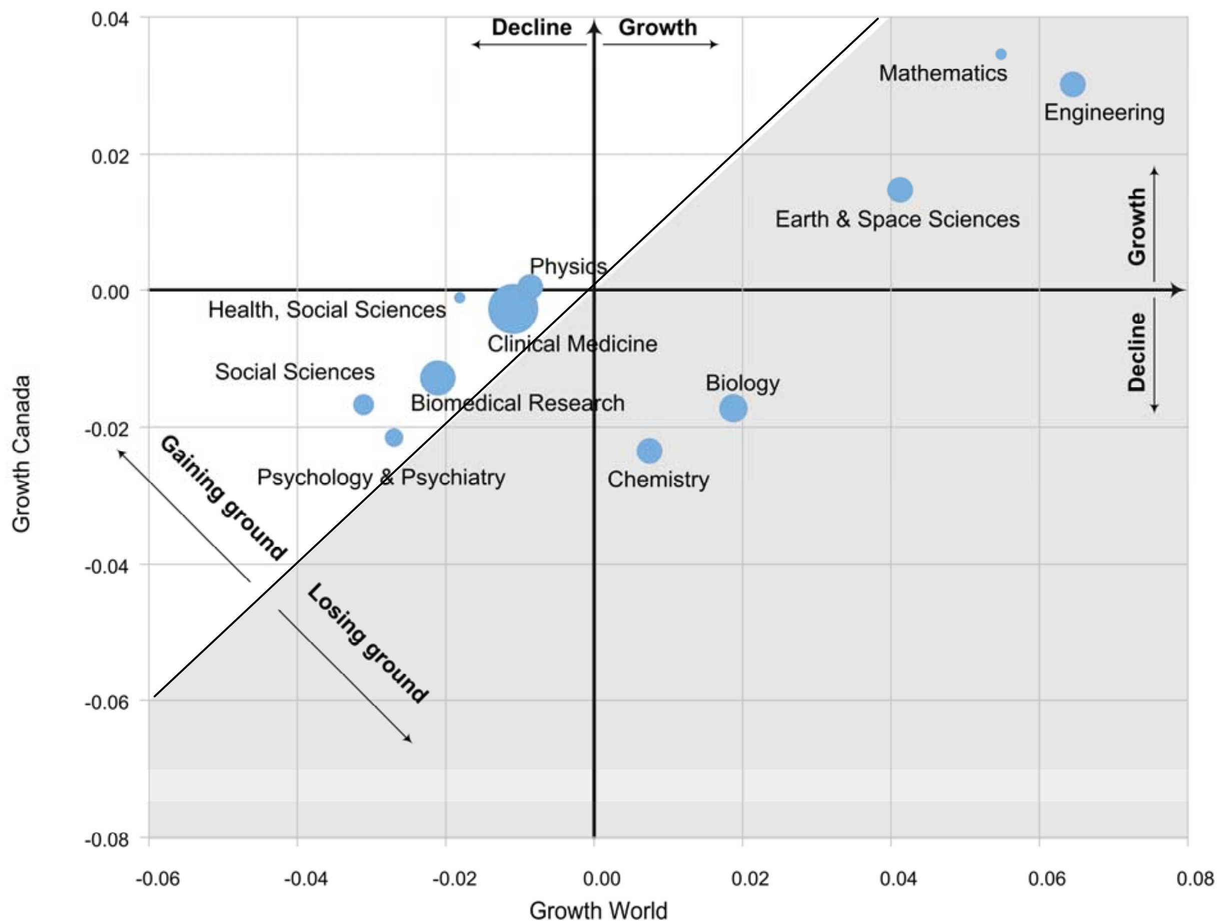
Growth and Decline Graphs

The graphics in this section are much clearer in colour and may be difficult to read if printed in black and white.

Figure 5C.3 compares growth of the major areas of research in Canada (on the y-axis) with growth of the same areas at the world level (on the x-axis). Growth in publication volume is computed for the 2001–2004 period relative to 1997–2000. In this graph, the circles above the 45° line through the origin (sloping to the northeast) are domains where Canada is "gaining ground" — i.e., those fields are growing faster, or are not declining as rapidly, in Canada as at the world level.

Figure 5C.3

Dynamics of Science, Engineering, Health and Social Sciences in Canada and the World: Change in Publication Volume – 2000–2004 vs. 1997–2000



In the macro-level figure above (**Figure 5C.3**), it is evident that Canada is losing ground — i.e., its *share* of world publications is declining — in all the fields that are growing at the world level (engineering, mathematics, earth and space sciences, biology and chemistry). Canadian researchers, on the whole, are gaining ground only in fields that are declining at the world level — i.e., social sciences, psychology and psychiatry, biomedical research, clinical medicine, health-related social sciences and physics. It is also noteworthy that Canadian scientific publication *volume* is declining (or stable) in all of the major categories except mathematics, engineering, and earth and space sciences.

The following figures provide detailed perspectives on the dynamics of natural science and engineering (**Figure 5C.4**), the health sciences (**Figure 5C.5**) and the social sciences (**Figure 5C.6**).

Figure 5C.4

Dynamics of Natural Sciences and Engineering in Canada and the World: Change in Publication Volume – 2001–2004 vs. 1997–2000

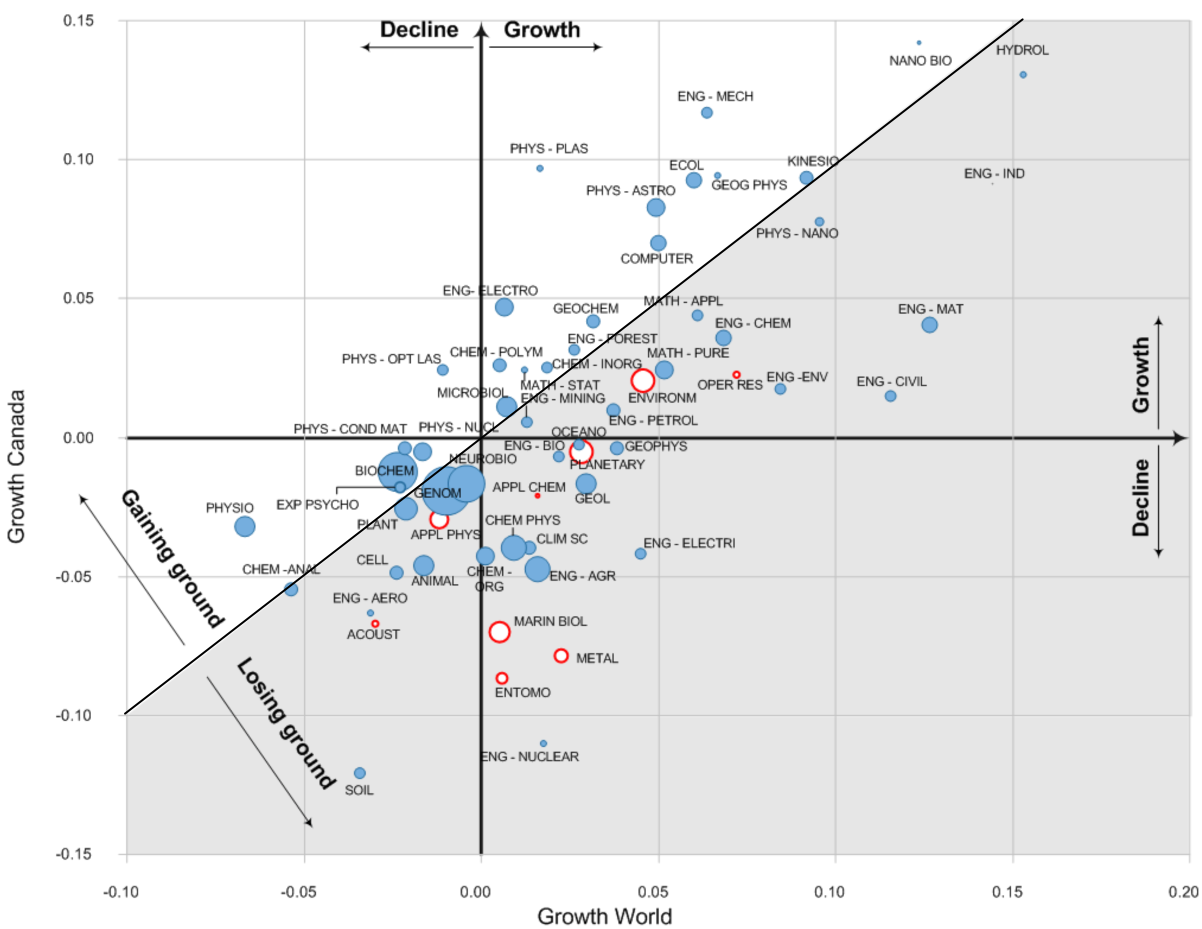


Figure 5C.5

Dynamics of Health Sciences in Canada and the World: Change in Publication Volume – 2001–2004 vs. 1997–2000

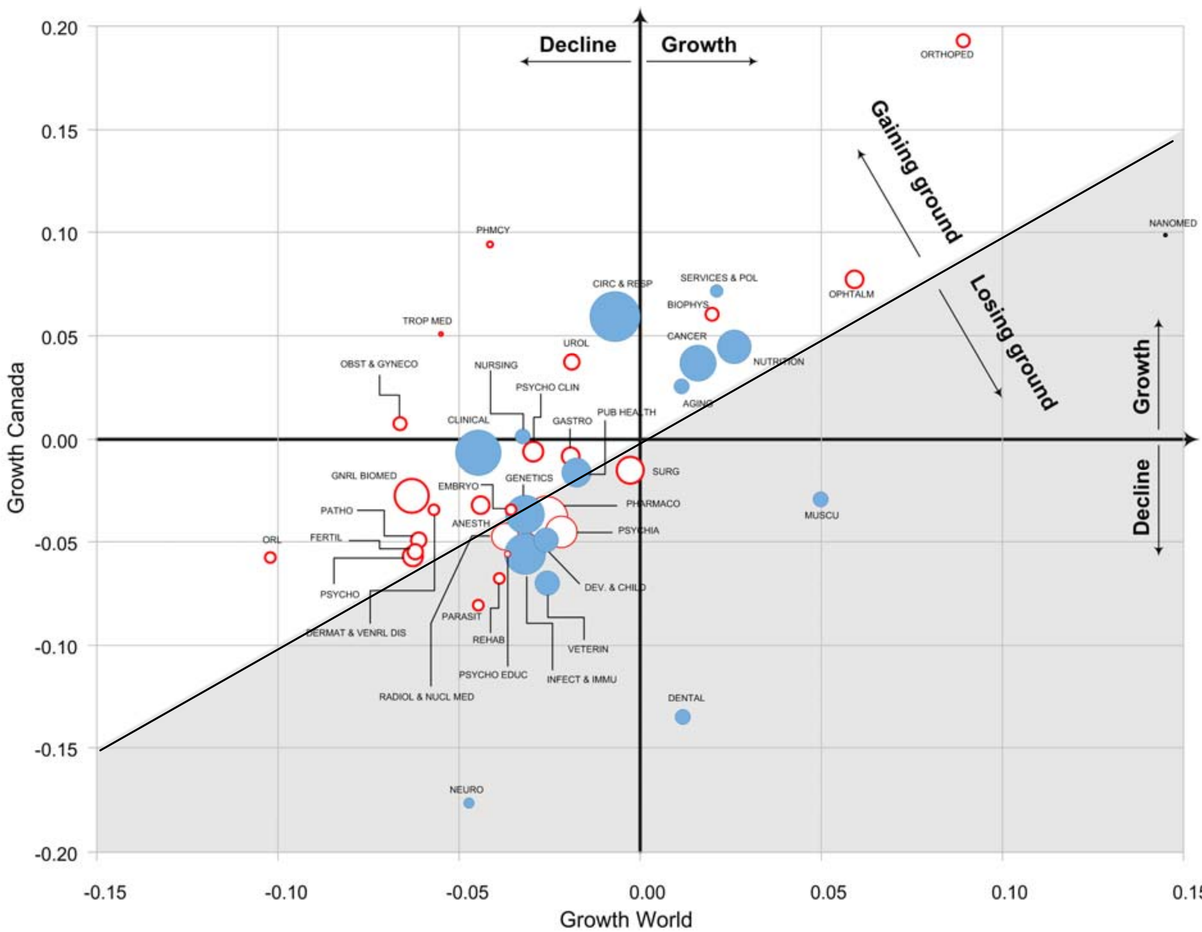
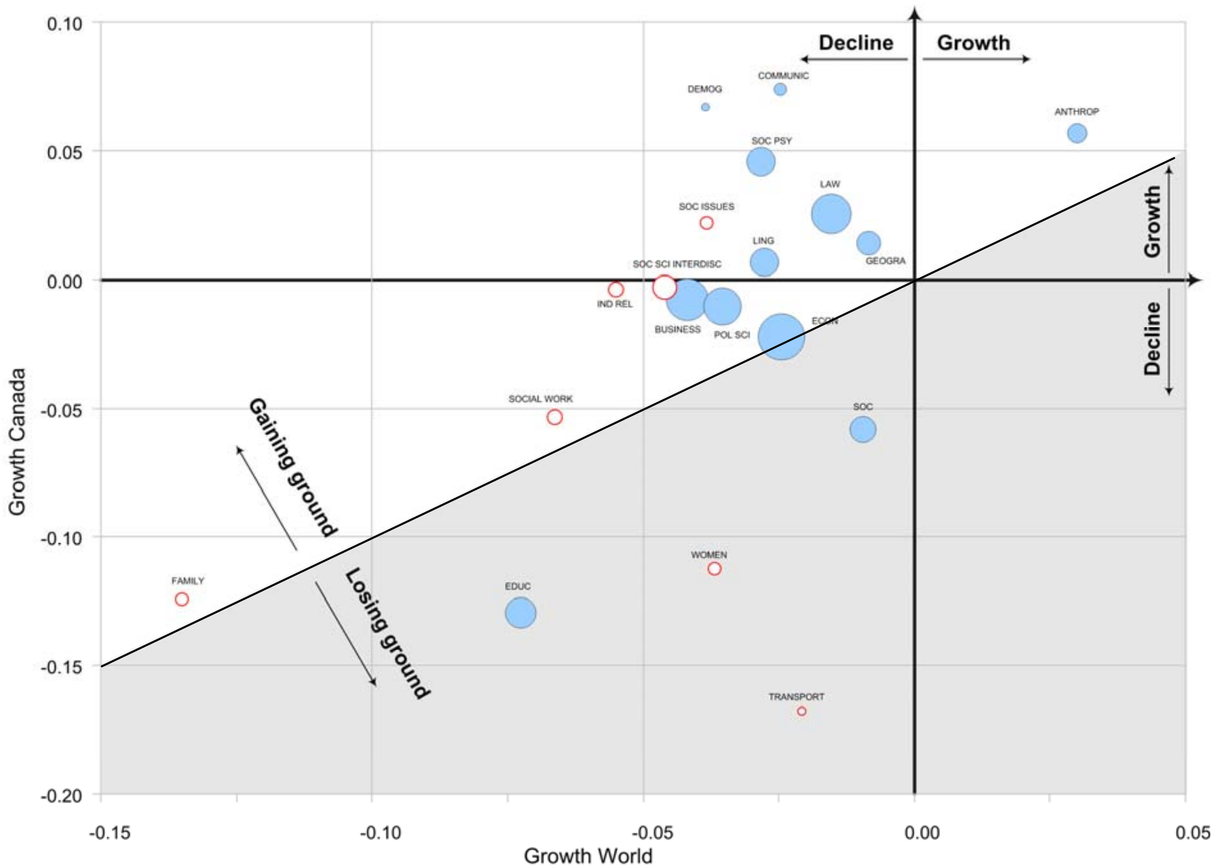


Figure 5C.6

Dynamics of Social Sciences in Canada and the World: Change in Publication Volume – 2001–2004 vs. 1997–2000



Appendix 5D

Growth and Decline: Technometrics

Figures 5D.1 and **5D.2** show that Canada is gaining ground relative to world patent growth — particularly in ICT (e.g., telecom, optics/photonics, and computers) and in health and biotech. The latter areas have exhibited some decline in global patent activity in the past five years.

Figure 5D.1

Areas of World Patent Growth: 2000-2004 vs. 1995-1999

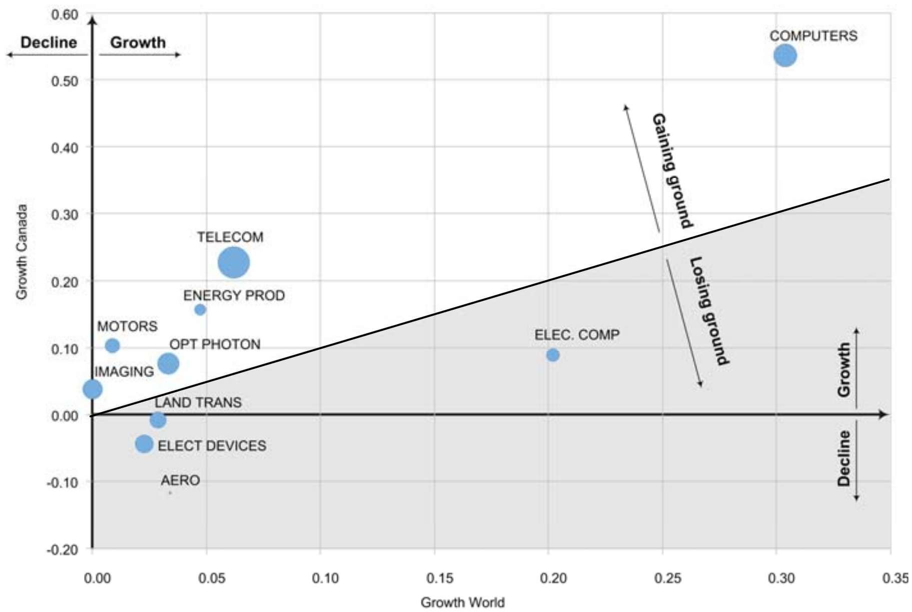
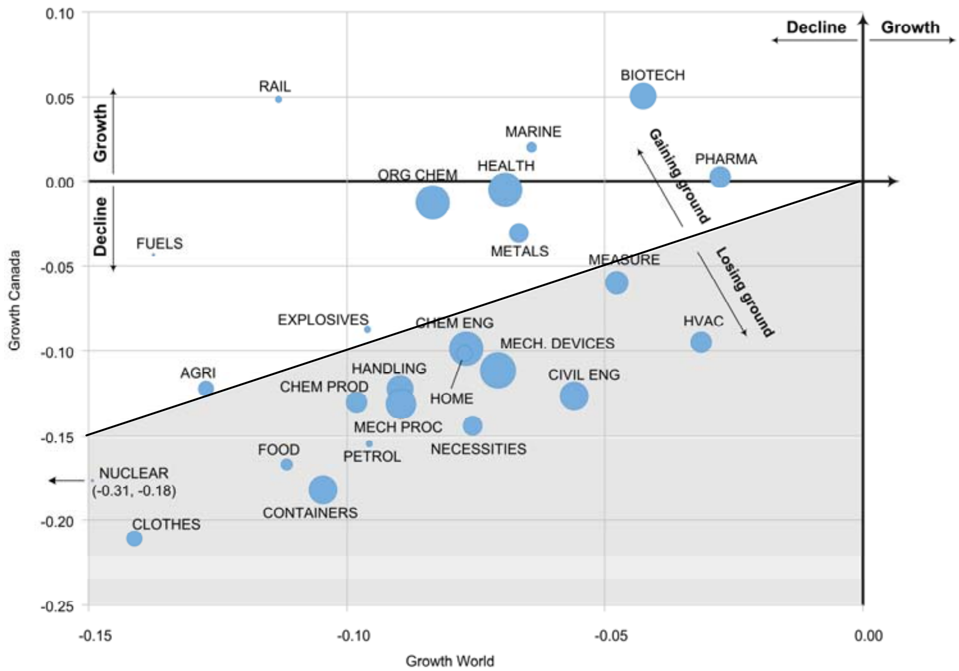


Figure 5D.2

Areas of World Patent Decline: 2000-04 vs. 1995-99



Appendix 6: Survey Results and Bibliometric Results Compared

- Appendix 6A: The 78 Comparable Sub-Areas
- Appendix 6B: 78 Sub-Areas in Order of Survey Mean, of SI, and of ARIF
- Appendix 6C: Survey Results Compared with SI and ARIF
- Appendix 6D: Bibliometric Results by Quadrant (SI and ARIF combined) and Survey Results by Decile
- Appendix 6E: Analysis of Bibliometric Growth and Survey "Net Trend"

Appendix 6A

The 78 Comparable Sub-Areas (Listed in alphabetical order)

		Survey Results[1]		Bibliometric Results [2]				
	Sub-area	Mean	U-D	SI	ARIF	Canada Growth	World Growth	C-W Growth
1	Aerospace Eng	4.77	-14	0.70	0.98	-14%	-7%	-7%
2	Aging	4.57	19	1.42	0.93	6%	3%	4%
3	Agricultural Eng	4.67	4	1.42	0.90	-11%	4%	-15%
4	Analytical Chemistry	4.51	-4	0.66	1.23	-13%	-12%	0%
5	Animal Biology	4.56	-4	1.70	1.07	-11%	-4%	-7%
6	Anthropology	4.28	-2	1.16	1.04	15%	8%	7%
7	Astro Phys, Cosmol	5.05	12	0.99	1.14	22%	13%	9%
8	Biochemistry	4.64	-3	1.06	1.03	-3%	-6%	3%
9	Biomedical Engineering	4.69	25	0.89	1.02	-2%	6%	-7%
10	Bus & Mngmt Sci	4.55	13	1.34	0.95	-2%	-10%	8%
11	Cancer Research	5.14	36	0.88	1.21	9%	4%	5%
12	Cell Biology	4.71	8	0.94	1.07	-11%	-6%	-6%
13	Circulatory & Respiratory Health	4.93	17	1.09	1.16	15%	-2%	17%
14	Civil Engineering	4.77	1	2.05	0.83	4%	32%	-29%
15	Climate Sci & Meteorology	5.02	4	1.45	1.05	-9%	3%	-13%
16	Clinical Research (cross-cutting)	4.54	0	1.10	1.41	-2%	-10%	9%
17	Communications, Media & Culture	4.81	18	0.61	0.91	20%	-6%	26%
18	Computer Sciences	4.77	9	1.24	1.01	18%	13%	6%
19	Condensed Matter Physics	4.61	2	0.49	1.22	-1%	-5%	4%
20	Demography	4.51	1	0.95	0.78	18%	-9%	27%
21	Dental Science	4.09	-11	0.63	1.07	-28%	3%	-31%
22	Ecology & Evolution Biology	4.65	7	1.47	1.13	25%	16%	9%
23	Economics	4.53	-1	1.15	0.99	-5%	-6%	0%
24	Education	4.48	-11	1.09	0.98	-27%	-16%	-11%
25	Electrical Engineering	4.89	-3	1.25	0.78	-10%	12%	-21%
26	Electronic & Photonic Eng	4.90	10	0.85	1.01	12%	2%	10%
27	Environmental Eng	4.75	2	0.94	0.98	4%	23%	-19%
28	Experimental Psychology	4.42	1	1.99	0.94	-4%	-5%	1%

		Survey Results[1]		Bibliometric Results [2]				
	Sub-area	Mean	U-D	SI	ARIF	Canada Growth	World Growth	C-W Growth
29	Forestry Engineering	4.95	5	3.06	1.03	8%	7%	1%
30	Genetics	5.24	32	1.30	1.09	-9%	-7%	-1%
31	Genetics, Genomics, Proteomics	5.18	39	1.07	1.08	-5%	-2%	-2%
32	Geochem & Geochronology	5.23	6	1.46	1.03	11%	8%	3%
33	Geog; Urban & Enviro Planning	4.85	11	1.37	0.90	6%	-4%	10%
34	Geology	5.44	4	1.98	1.05	-4%	8%	-12%
35	Geophysics & Seismology	5.19	7	1.31	0.96	-1%	10%	-11%
36	Health Services & Policy	4.48	8	1.61	0.76	19%	5%	14%
37	Human Dev't & Youth Health	4.53	11	1.23	1.16	-11%	-6%	-5%
38	Hydrology	5.17	11	2.36	1.00	37%	45%	-8%
39	Industrial Engineering	4.24	-11	1.44	0.99	25%	42%	-17%
40	Infection & Immunity	4.91	31	0.89	1.12	-13%	-7%	-5%
41	Inorganic Chemistry	4.63	0	0.55	1.43	6%	5%	2%
42	Kinesiology	4.44	7	2.05	1.02	25%	25%	0%
43	Law & Criminology	4.63	12	0.76	0.90	3%	-2%	5%
44	Linguistics	4.39	9	1.56	0.83	2%	-7%	8%
45	Materials Engineering	4.67	14	0.61	0.91	10%	36%	-26%
46	Math Applied	4.56	13	0.99	0.95	11%	16%	-5%
47	Math Statistics	4.42	2	1.22	1.01	6%	3%	3%
48	Mental Health, Addiction	4.89	22	0.99	1.02	-36%	-11%	-25%
49	Microbiology	4.58	6	0.96	1.01	3%	2%	1%
50	Mining & Mineral Processing	5.22	18	2.48	0.97	1%	3%	-2%
51	Musculoskeletal & Arthritis	4.51	9	1.27	1.10	-7%	13%	-20%
52	Nano and Regenerative Medicine	4.41	21	0.59	0.93	27%	42%	-15%
53	Nanoscale Biosciences	4.14	20	0.72	1.00	41%	35%	6%
54	Nanoscale Physical Science	4.47	28	0.49	1.15	21%	26%	-5%
55	Neurobiology / Neurosciences	5.02	26	1.39	1.02	-4%	-1%	-3%
56	Nuclear Engineering	4.65	-22	0.56	1.25	-24%	4%	-28%
57	Nuclear Phys & Elem Particles	4.49	-10	0.87	1.15	-1%	-4%	3%
58	Nursing Science	4.19	3	1.33	1.13	0%	-8%	8%
59	Nutrition, Metabolism, Diabetes	4.70	24	1.08	1.13	11%	7%	5%
60	Oceanography	5.15	-2	1.37	1.20	-1%	7%	-8%
61	Optics; Lasers	5.05	25	0.64	1.02	6%	-3%	9%
62	Organic Chemistry	4.79	-2	0.62	1.18	-10%	0%	-10%
63	Other Chemical Eng	4.56	1	1.29	0.99	9%	18%	-9%
64	Other Mechanical Eng	4.23	-10	0.71	1.01	33%	17%	16%
65	Petroleum Eng / Polymer	5.24	37	0.76	1.09	2%	10%	-7%
66	Physical Chemistry	4.67	4	0.62	1.12	-9%	2%	-12%
67	Physical Geog, Remote Sensing	5.32	16	1.47	1.05	26%	18%	8%
68	Physiology	4.40	-10	1.65	0.98	-8%	-15%	8%
69	Plant Biology	4.57	4	1.16	0.95	-6%	-5%	-1%
70	Plasma Physics	4.02	-20	0.60	0.99	27%	4%	22%
71	Pol Sci & Public Admin	4.59	4	1.31	0.68	-3%	-8%	6%
72	Polymer Chemistry	4.69	1	0.69	1.19	6%	1%	5%
73	Population & Public Health	4.62	17	1.53	0.92	-4%	-4%	0%

		Survey Results[1]		Bibliometric Results [2]				
	Sub-area	Mean	U-D	SI	ARIF	Canada Growth	World Growth	C-W Growth
74	Pure Math	4.52	3	1.02	1.01	6%	13%	-7%
75	Social Psychology	4.44	8	1.86	1.06	12%	-7%	18%
76	Sociology	4.27	-7	1.04	0.86	-13%	-2%	-11%
77	Soil Science	4.81	-7	1.70	1.05	-26%	-8%	-18%
78	Veterinary Science	4.43	2	1.15	1.01	-16%	-6%	-10%

1. "U-D" is the percentage of survey respondents who believe Canada is gaining ground (Up) minus the percentage of those who see Canada losing ground (Down).
2. The "Growth" figures are the percentage changes in publication volume: 2001-04 vs. 1997-2000. "C-W" is the difference between the growth rates of Canada and the world (and may be effected by rounding).

Appendix 6B

78 Sub-Areas in Decreasing Order of Survey Mean, of SI, and of ARIF (The second columns are decile indicators)

Sub-area	Mean	
Geology	5.44	D1
Physical Geog, Remote Sens	5.32	D1
Genetics	5.24	D1
Petroleum Eng / Polymer	5.24	D1
Geochem & Geochronology	5.23	D1
Mining & Mineral Processing	5.22	D1
Geophysics & Seismology	5.19	D1
Genetics, Genomics, Proteom	5.18	D2
Hydrology	5.17	D2
Oceanography	5.15	D2
Cancer Research	5.14	D2
Astro Phys, Cosmol	5.05	D2
Optics; Lasers	5.05	D2
Neurobiology / Neurosciences	5.02	D2
Climate Sci & Meterology	5.02	D2
Forestry Eng	4.95	D3
Circ & Respiratory Health	4.93	D3
Infection & Immunity	4.91	D3
Electronic & Photonic Eng	4.90	D3
Electrical Engineering	4.89	D3
Mental Health, Addiction	4.89	D3
Geog; Urban & Enviro Plan	4.85	D3
Comms, Media & Culture	4.81	D3
Soil Science	4.81	D4
Organic Chemistry	4.79	D4

Sub-area	SI	
Forestry Eng	3.06	D1
Mining & Mineral Process	2.48	D1
Hydrology	2.36	D1
Civil Engineering	2.05	D1
Kinesiology	2.05	D1
Experimental Psychology	1.99	D1
Geology	1.98	D1
Social Psychology	1.86	D2
Soil Science	1.70	D2
Animal Biology	1.70	D2
Physiology	1.65	D2
Health Services & Policy	1.61	D2
Linguistics	1.56	D2
Populat & Public Health	1.53	D2
Ecology & Evolution Biol	1.47	D2
Physical Geog, Rem Sens	1.47	D3
Geochem & Geochronol	1.46	D3
Climate Sci & Meterology	1.45	D3
Industrial Engineering	1.44	D3
Agricultural Eng	1.42	D3
Aging	1.42	D3
Neurobiology / Neurosci	1.39	D3
Geog; Urban & Envir Plan	1.37	D3
Oceanography	1.37	D4
Bus & Mngmt Sci	1.34	D4

Sub-area	ARIF	
Inorganic Chemistry	1.43	D1
Clinical Research	1.41	D1
Nuclear Engineering	1.25	D1
Analytical Chemistry	1.23	D1
Condensed Matter Physics	1.22	D1
Cancer Research	1.21	D1
Oceanography	1.20	D1
Polymer Chemistry	1.19	D2
Organic Chemistry	1.18	D2
Circ & Respiratory Health	1.16	D2
Human Dev&Youth Health	1.16	D2
Nanoscale Physical Science	1.15	D2
Nuclear Phys & Elem Part	1.15	D2
Astro Phys, Cosmol	1.14	D2
Nutrition, Metabol, Diabet	1.13	D2
Nursing Science	1.13	D3
Ecology & Evolution Biol	1.13	D3
Infection & Immunity	1.12	D3
Physical Chemistry	1.12	D3
Musculoskeletal & Arthritis	1.10	D3
Genetics	1.09	D3
Petroleum Eng / Polymer	1.09	D3
Genetics, Genom, Proteom	1.08	D3
Animal Biology	1.07	D4
Dental Science	1.07	D4

Sub-area	Mean	
Computer Sciences	4.77	D4
Aerospace Eng	4.77	D4
Civil Engineering	4.77	D4
Environmental Eng	4.75	D4
Cell Biology	4.71	D4
Nutrition, Metabolism, Diabet	4.70	D4
Polymer Chemistry	4.69	D5
Biomedical Engineering	4.69	D5
Physical Chemistry	4.67	D5
Agricultural Eng	4.67	D5
Materials Engineering	4.67	D5
Ecology & Evolution Biology	4.65	D5
Nuclear Engineering	4.65	D5
Biochemistry	4.64	D5
Law & Criminology	4.63	D6
Inorganic Chemistry	4.63	D6
Population & Public Health	4.62	D6
Condensed Matter Physics	4.61	D6
Pol Sci & Public Admin	4.59	D6
Microbiology	4.58	D6
Aging	4.57	D6
Plant Biology	4.57	D6
Math Applied	4.56	D7
Animal Biology	4.56	D7
Other Chemical Eng	4.56	D7
Bus & Mngmt Sci	4.55	D7
Clinical Research (cross-cutt)	4.54	D7
Economics	4.53	D7
Human Dev't & Youth Health	4.53	D7

Sub-area	SI	
Nursing Science	1.33	D4
Pol Sci & Public Admin	1.31	D4
Geophysics & Seismology	1.31	D4
Genetics	1.30	D4
Other Chemical Eng	1.29	D4
Musculoskeletal & Arthrit	1.27	D4
Electrical Engineering	1.25	D5
Computer Sciences	1.24	D5
Human Dev&Youth Healt	1.23	D5
Math Statistics	1.22	D5
Anthropology	1.16	D5
Plant Biology	1.16	D5
Veterinary Science	1.15	D5
Economics	1.15	D5
Clinical Research	1.10	D6
Circ & Respiratory Health	1.09	D6
Education	1.09	D6
Nutrition, Metabol, Diab	1.08	D6
Genetics, Genom, Proteom	1.07	D6
Biochemistry	1.06	D6
Sociology	1.04	D6
Pure Math	1.02	D6
Astro Phys, Cosmol	0.99	D7
Math Applied	0.99	D7
Mental Health, Addiction	0.99	D7
Microbiology	0.96	D7
Demography	0.95	D7
Environmental Eng	0.94	D7
Cell Biology	0.94	D7

Sub-area	ARIF	
Cell Biology	1.07	D4
Social Psychology	1.06	D4
Soil Science	1.05	D4
Physical Geog, Rem Sens	1.05	D4
Climate Sci & Meterology	1.05	D4
Geology	1.05	D4
Anthropology	1.04	D5
Geochem & Geochronol	1.03	D5
Forestry Eng	1.03	D5
Biochemistry	1.03	D5
Neurobiol / Neurosciences	1.02	D5
Kinesiology	1.02	D5
Optics; Lasers	1.02	D5
Mental Health, Addiction	1.02	D5
Biomedical Engineering	1.02	D6
Other Mechanical Eng	1.01	D6
Electronic & Photonic Eng	1.01	D6
Pure Math	1.01	D6
Math Statistics	1.01	D6
Microbiology	1.01	D6
Computer Sciences	1.01	D6
Veterinary Science	1.01	D6
Hydrology	1.00	D7
Nanoscale Biosciences	1.00	D7
Economics	0.99	D7
Other Chemical Eng	0.99	D7
Industrial Engineering	0.99	D7
Plasma Physics	0.99	D7
Aerospace Eng	0.98	D7

Sub-area	Mean	
Pure Math	4.52	D7
Demography	4.51	D8
Analytical Chemistry	4.51	D8
Musculoskeletal & Arthritis	4.51	D8
Nuclear Phys & Elem Part	4.49	D8
Health Services & Policy	4.48	D8
Education	4.48	D8
Nanoscale Physical Science	4.47	D8
Social Psychology	4.44	D9
Kinesiology	4.44	D8
Veterinary Science	4.43	D9
Math Statistics	4.42	D9
Experimental Psychology	4.42	D9
Nano and Regen Medicine	4.41	D9
Physiology	4.40	D9
Linguistics	4.39	D9
Anthropology	4.28	D9
Sociology	4.27	D10
Industrial Engineering	4.24	D10
Other Mechanical Eng	4.23	D10
Nursing Science	4.19	D10
Nanoscale Biosciences	4.14	D10
Dental Science	4.09	D10
Plasma Physics	4.02	D10

Sub-area	SI	
Infection & Immunity	0.89	D7
Biomedical Engineering	0.89	D8
Cancer Research	0.88	D8
Nuclear Phys & Elem Part	0.87	D8
Electronic & Photonic Eng	0.85	D8
Law & Criminology	0.76	D8
Petroleum Eng / Polymer	0.76	D8
Nanoscale Biosciences	0.72	D8
Other Mechanical Eng	0.71	D8
Aerospace Eng	0.70	D9
Polymer Chemistry	0.69	D9
Analytical Chemistry	0.66	D9
Optics; Lasers	0.64	D9
Dental Science	0.63	D9
Physical Chemistry	0.62	D9
Organic Chemistry	0.62	D9
Comms, Media & Culture	0.61	D9
Materials Engineering	0.61	D10
Plasma Physics	0.60	D10
Nano and Regen Med	0.59	D10
Nuclear Engineering	0.56	D10
Inorganic Chemistry	0.55	D10
Condensed Matter Physics	0.49	D10
Nanoscale Physical Sci	0.49	D10

Sub-area	ARIF	
Physiology	0.98	D7
Environmental Eng	0.98	D8
Education	0.98	D8
Mining & Mineral Process	0.97	D8
Geophysics & Seismology	0.96	D8
Bus & Mngmt Sci	0.95	D8
Plant Biology	0.95	D8
Math Applied	0.95	D8
Experimental Psychology	0.94	D8
Aging	0.93	D9
Nano and Regen Med	0.93	D9
Population & Public Health	0.92	D9
Materials Engineering	0.91	D9
Comms, Media & Culture	0.91	D9
Law & Criminology	0.90	D9
Geog; Urban & Enviro Plan	0.90	D9
Agricultural Eng	0.90	D9
Sociology	0.86	D10
Linguistics	0.83	D10
Civil Engineering	0.83	D10
Demography	0.78	D10
Electrical Engineering	0.78	D10
Health Services & Policy	0.76	D10
Pol Sci & Public Admin	0.68	D10

Appendix 6C

Survey Results Compared with SI and ARIF

These are the raw data used to construct **Figure 5.21** in the main report.

	Decile	
Sub-area (by SI)	**Mean**	**SI**
Box 1:SI (1,2,3) Mean (8,9,10)		
Experimental Psychology	D9	D1
Kinesiology	D8	D1
Health Services & Policy	D8	D2
Linguistics	D9	D2
Physiology	D9	D2
Social Psychology	D9	D2
Industrial Engineering	D10	D3
Box 2: SI (1,2,3) Mean (1,2,3)		
Forestry Eng	D3	D1
Geology	D1	D1
Hydrology	D2	D1
Mining & Mineral Processing	D1	D1
Climate Sci & Meteorology	D2	D3
Geochem & Geochronology	D1	D3
Geog; Urban & Enviro Planning	D3	D3
Neurobiology / Neurosciences	D2	D3
Physical Geog, Remote Sensing	D1	D3
Box 3: SI (8,9,10) Mean (8,9,10)		
Nanoscale Biosciences	D10	D8
Nuclear Phys & Elem Part	D8	D8
Other Mechanical Eng	D10	D8
Analytical Chemistry	D8	D9
Dental Science	D10	D9
Nano and Regenerative Medicine	D9	D10
Nanoscale Physical Science	D8	D10
Plasma Physics	D10	D10
Box 4: SI (8,9,10) Mean (1,2,3)		
Cancer Research	D2	D8
Electronic & Photonic Eng	D3	D8

	Decile	
Sub-area (by ARIF)	**Mean**	**ARIF**
Box 1: ARIF (1,2,3) Mean (8,9,10)		
Analytical Chemistry	D8	D1
Nanoscale Physical Science	D8	D2
Nuclear Phys & Elem Particles	D8	D2
Nursing Science	D10	D3
Musculoskeletal Health & Arthritis	D8	D3
Box 2: ARIF (1,2,3) Mean (1,2,3)		
Cancer Research	D2	D1
Oceanography	D2	D1
Circulatory & Respiratory Health	D3	D2
Astro Phys, Cosmol	D2	D2
Infection & Immunity	D3	D3
Genetics, Genomics & Proteomics	D2	D3
Genetics	D1	D3
Petroleum Eng / Polymer	D1	D3
Box 3: ARIF (8,9,10) Mean (8,9,10)		
Experimental Psychology	D9	D8
Education	D8	D8
Nano and Regenerative Medicine	D9	D9
Sociology	D10	D10
Linguistics	D9	D10
Demography	D8	D10
Health Services & Policy	D8	D10
Box 4: ARIF (8,9,10) Mean (1,2,3)		
Geophysics & Seismology	D1	D8
Mining & Mineral Processing	D1	D8
Comm, Media & Cultural Sci	D3	D9
Geog; Urban & Enviro Planning	D3	D9
Electrical Engineering	D3	D10

Sub-area (by SI)	Decile Mean	Decile SI
Petroleum Eng / Polymer	D1	D8
Comms, Media & Culture	D3	D9
Optics; Lasers	D2	D9
Box 5: SI (4,5,6,7) Mean (4,5,6,7)		
Bus & Mngmt Sci	D7	D4
Other Chemical Eng	D7	D4
Pol Sci & Public Admin	D6	D4
Computer Sciences	D4	D5
Economics	D7	D5
Human Dev't & Youth Health	D7	D5
Plant Biology	D6	D5
Biochemistry	D5	D6
Clinical Research (cross-cutting)	D7	D6
Nutrition, Metabolism, Diabetes	D4	D6
Pure Math	D7	D6
Applied Math	D7	D7
Cell Biology	D4	D7
Environmental Eng	D4	D7
Microbiology	D6	D7
Box 6: SI (1,2,3) Mean (4,5,6,7)		
Civil Engineering	D4	D1
Animal Biology	D7	D2
Ecology & Evolution Biology	D5	D2
Population & Public Health	D6	D2
Soil Science	D4	D2
Aging	D6	D3
Agricultural Eng	D5	D3
Box 7: SI (8,9,10) Mean (4,5,6,7)		
Biomedical Engineering	D5	D8
Law & Criminology	D6	D8
Aerospace Eng	D4	D9
Organic Chemistry	D4	D9
Physical Chemistry	D5	D9
Polymer Chemistry	D5	D9
Condensed Matter Physics	D6	D10

Sub-area (by ARIF)	Decile Mean	Decile ARIF
Box 5: ARIF (4,5,6,7) Mean (4,5,6,7)		
Animal Biology	D7	D4
Cell Biology	D4	D4
Soil Science	D4	D4
Biochemistry	D5	D5
Pure Math	D7	D6
Microbiology	D6	D6
Biomedical Engineering	D5	D6
Computer Sciences	D4	D6
Economics	D7	D7
Other Chemical Eng	D7	D7
Aerospace Eng	D4	D7
Box 6: ARIF (1,2,3) Mean (4,5,6,7)		
Clinical Research	D7	D1
Condensed Matter Physics	D6	D1
Inorganic Chemistry	D6	D1
Nuclear Engineering	D5	D1
Human Dev't & Youth Health	D7	D2
Polymer Chemistry	D5	D2
Nutrition, Metabolism & Diabetes	D4	D2
Organic Chemistry	D4	D2
Ecology & Evolution Biol.	D5	D3
Physical Chemistry	D5	D3
Box 7: ARIF (8,9,10) Mean (4,5,6,7)		
Applied Math	D7	D8
Bus & Mngmnt Science	D7	D8
Plant Biology	D6	D8
Environmental Eng	D4	D8
Aging	D6	D9
Law & Criminology	D6	D9
Population & Public Health	D6	D9
Agricultural Eng	D5	D9
Materials Engineering	D5	D9
Pol Sci & Public Admin	D6	D10
Civil Engineering	D4	D10

	Decile	
Sub-area (by SI)	**Mean**	**SI**
Inorganic Chemistry	D6	D10
Materials Engineering	D5	D10
Nuclear Engineering	D5	D10
Box 8: SI (4,5,6,7) Mean (8,9,10)		
Musculoskeletal & Arthritis	D8	D4
Nursing Science	D10	D4
Anthropology	D9	D5
Math Statistics	D9	D5
Veterinary Science	D9	D5
Education	D8	D6
Sociology	D10	D6
Demography	D8	D7
Box 9: SI (4,5,6,7) Mean (1,2,3)		
Genetics	D1	D4
Geophysics & Seismology	D1	D4
Oceanography	D2	D4
Electrical Engineering	D3	D5
Circulatory & Respiratory Health	D3	D6
Genetics, Genomics, Proteomics	D2	D6
Astro Phys, Cosmol	D2	D7
Infection & Immunity	D3	D7
Mental Health, Addiction	D3	D7

	Decile	
Sub-area (by ARIF)	**Mean**	**ARIF**
Box 8: ARIF (4,5,6,7) Mean (8,9,10)		
Dental Science	D10	D4
Social Psychology	D9	D4
Anthropology	D9	D5
Kinesiology	D8	D5
Other Mechanical Eng	D10	D6
Math Statistics	D9	D6
Veterinary Science	D9	D6
Industrial Engineering	D10	D7
Nanoscale Biosciences	D10	D7
Plasma Physics	D10	D7
Physiology	D9	D7
Box 9: ARIF (4,5,6,7) Mean (1,2,3)		
Climate Sci & Meteorology	D2	D4
Geology	D1	D4
Physical Geog, Remote Sensing	D1	D4
Forestry Eng	D3	D5
Mental Health, Addiction	D3	D5
Neurobiology / Neurosciences	D2	D5
Optics; Lasers	D2	D5
Geochem & Geochronology	D1	D5
Electronic & Photonic Eng	D3	D6
Hydrology	D2	D7

Appendix 6D

Analysis of Bibliometric Results by Quadrant (SI and ARIF combined) and Survey Results by Decile

We are able to make a further rough comparison in those cases (1) where *both* bibliometric parameters are strong — i.e., SI and ARIF are both above the world average; and (2) where both indicators are below the world average. In these two situations, the bibliometric evidence is fairly unequivocal and we can ask whether the survey strength ratings are consistent with the bibliometric evidence.

We identify a rough concordance in the top panel of **Figure 6D.1**, which includes those sub-areas (1) that are in the top half of the survey strength ratings; and (2) where both the SI and ARIF exceed the world average. There are several such concordances and they fall largely into the four main clusters of strength identified in **Chapter** 5. (Although there is only one representative of the ICT cluster in the top panel, it should be noted that the five sub-areas of computer science that were included in the survey were collapsed to one macro-category to facilitate the bibliometric comparison.)

The bottom panel of **Figure 6D.1** represents the case where there is clear divergence between the survey and bibliometric evidence. In the bottom left panel are areas of unequivocal bibliometric strength (i.e., both SI and ARIF above the world average) but where the survey strength rating is in the bottom 30 percent of the 78 sub-areas — e.g., clinical research, nursing science, anthropology. The bottom right panel is the opposite case, where the survey results were considerably stronger than bibliometrics — e.g., survey ratings of sub-areas of environmental, aerospace and materials engineering were in the top half, whereas both SI and ARIF measures were below the world average. The details of concordance are tabulated in **Figure 6D.2**.

Figure 6D.1

Analysis of Bibliometric Results by Quadrant (SI and ARIF combined) and Survey Results by Decile

Strong Bibliometric Results (SI and ARIF combined) and Strong Survey Results

Environment
Hydrology
Oceanography
Climate Sci & Meteorology
Ecology & Evolution Biology

Natural Resources / Environment
Physical Geog, Remote Sensing
Geochem & Geochronology
Soil Science

Natural Resources
Geology
Forestry Eng

Health
Genetics
Neurobiology / Neurosciences
Genetics, Genomics, Proteomics
Circulatory & Respiratory Health

ICT
Computer Sciences (Combined)

Other
Biochemistry

Strong Bibliometric Results (SI and ARIF combined) and Weak Survey Results

Health
Clinical Research (cross-cutting)
Human Dev't & Youth Health
Kinesiology
Musculoskeletal & Arthritis
Nursing Science

Other
Animal Biology
Veterinary Science
Pure Math
Math Statistics
Anthropology
Social Psychology

Weak Bibliometric Results (SI and ARIF combined) and Strong Survey Results

Environment
Environmental Eng

Other
Aerospace Eng
Communications, Media & Culture
Materials Engineering

Figure 6D.2

Bibliometric Results by Quadrant (SI and ARIF combined) and Survey Results by Decile

	Alphabetical Order Within Quadrant	SI	ARIF	Mean	Mean Decile
	SI and ARIF > 1 (Quadrant 1)				
O	Animal Biology	1.70	1.07	4.56	D7
O	Anthropology	1.16	1.04	4.28	D9
O	Biochemistry	1.06	1.03	4.64	D5
H	Circulatory & Respiratory Health	1.09	1.16	4.93	D3
E	Climate Sci & Meteorology	1.45	1.05	5.02	D2
H	Clinical Research (cross-cutting)	1.10	1.41	4.54	D7
I	Computer Sciences	1.24	1.01	4.77	D4
E	Ecology & Evolution Biology	1.47	1.13	4.65	D5
N	Forestry Eng	3.06	1.03	4.95	D3
H	Genetics	1.30	1.09	5.24	D1
H	Genetics, Genomics, Proteomics	1.07	1.08	5.18	D2
N/E	Geochem & Geochronology	1.46	1.03	5.23	D1
N	Geology	1.98	1.05	5.44	D1
H	Human Dev't & Youth Health	1.23	1.16	4.53	D7
E	Hydrology	2.36	1.00	5.17	D2
H	Kinesiology	2.05	1.02	4.44	D8
O	Math Statistics	1.22	1.01	4.42	D9
H	Musculoskeletal & Arthritis	1.27	1.10	4.51	D8
H	Neurobiology / Neurosciences	1.39	1.02	5.02	D2
H	Nursing Science	1.33	1.13	4.19	D10
H	Nutrition, Metabolism & Diabetes	1.08	1.13	4.70	D4
E	Oceanography	1.37	1.20	5.15	D2
N/E	Physical Geog, Remote Sensing	1.47	1.05	5.32	D1
O	Pure Math	1.02	1.01	4.52	D7
O	Social Psychology	1.86	1.06	4.44	D9
N/E	Soil Science	1.70	1.05	4.81	D4
O	Veterinary Science	1.15	1.01	4.43	D9
	SI < 1 and ARIF >1 (Quadrant II)				
O	Analytical Chemistry	0.66	1.23	4.51	D8
O	Astronomy, Astro Phys, Comology	0.99	1.14	5.05	D2

	Alphabetical Order Within Quadrant	SI	ARIF	Mean	Mean Decile
H	Biomedical Engineering	0.89	1.02	4.69	D5
H	Cancer Research	0.88	1.21	5.14	D2
O	Cell Biology	0.94	1.07	4.71	D4
O	Condensed Matter Physics	0.49	1.22	4.61	D6
H	Dental Science	0.63	1.07	4.09	D10
I	Electronic & Photonic Eng	0.85	1.01	4.90	D3
H	Infection & Immunity	0.89	1.12	4.91	D3
O	Inorganic Chemistry	0.55	1.43	4.63	D6
H	Mental Health, Addiction	0.99	1.02	4.89	D3
O	Microbiology	0.96	1.01	4.58	D6
O	Nanoscale Biosciences	0.72	1.00	4.14	D10
O	Nanoscale Physical Science	0.49	1.15	4.47	D8
O	Nuclear Engineering	0.56	1.25	4.65	D5
O	Nuclear Phys & Elem Particles	0.87	1.15	4.49	D8
I	Optics; Lasers	0.64	1.02	5.05	D2
O	Organic Chemistry	0.62	1.18	4.79	D4
O	Other Mechanical Eng	0.71	1.01	4.23	D10
N	Petroleum Eng / Polymer	0.76	1.09	5.24	D1
O	Physical Chemistry	0.62	1.12	4.67	D5
O	Polymer Chemistry	0.69	1.19	4.69	D5

	Alphabetical Order Within Quadrant	SI	ARIF	Mean	Mean Decile
	SI and ARIF < 1 (Quadrant IV)				
O	Aerospace Eng	0.70	0.98	4.77	D4
M	Communications, Media & Culture	0.61	0.91	4.81	D3
O	Demography	0.95	0.78	4.51	D8
E	Environmental Eng	0.94	0.98	4.75	D4
O	Law & Criminology	0.76	0.90	4.63	D6
O	Materials Engineering	0.61	0.91	4.67	D5
O	Math Applied	0.99	0.95	4.56	D7
H	Nano and Regenerative Medicine	0.59	0.93	4.41	D9
O	Plasma Physics	0.60	0.99	4.02	D10
	SI > 1 and ARIF <1 (Quadrant III)				
H	Aging	1.42	0.93	4.57	D6
O	Agricultural Eng	1.42	0.90	4.67	D5
O	Bus & Mngmt Sci	1.34	0.95	4.55	D7
O	Civil Engineering	2.05	0.83	4.77	D4
O	Economics	1.15	0.99	4.53	D7
O	Education	1.09	0.98	4.48	D8
O	Electrical Engineering	1.25	0.78	4.89	D3
O	Experimental Psychology	1.99	0.94	4.42	D9
E	Geog; Urban & Enviro Planning	1.37	0.90	4.85	D3
N	Geophysics & Seismology	1.31	0.96	5.19	D1
H	Health Services & Policy	1.61	0.76	4.48	D8
O	Industrial Engineering	1.44	0.99	4.24	D10
S	Linguistics	1.56	0.83	4.39	D9
N	Mining & Mineral Processing	2.48	0.97	5.22	D1
O	Other Chemical Eng	1.29	0.99	4.56	D7
H	Physiology	1.65	0.98	4.40	D9
O	Plant Biology	1.16	0.95	4.57	D6
O	Pol Sci & Public Admin	1.31	0.68	4.59	D6
H	Population & Public Health	1.53	0.92	4.62	D6
O	Sociology	1.04	0.86	4.27	D10

Appendix 6E

Analysis of Bibliometric Growth Data and Survey "Net Trend"

We have also compared the growth of the 78 sub-areas as estimated from bibliometric databases and by survey respondents. Here too the comparison is complex and somewhat indirect.

Survey respondents were asked whether they believed a specific sub-area was gaining or losing ground in Canada relative to other economically advanced countries. They were not asked to estimate the rate of growth or decline. The trend metric in the survey was simply the difference between the percentage of respondents rating "up" and those rating "down". Bibliometrics enables a precise growth percentage to be calculated for the *volume* of publications in a field — both in Canada and in the world. The difference between those two growth rates tells whether we are gaining or losing publication "market share" globally, and how rapidly.

Although the growth parameters in the survey and the bibliometric analysis are conceptually quite different we can make a rough comparison by looking at the top, bottom and middle of the growth ranges, as indicated by both survey and bibliometrics. The results are summarized in **Figure 6E.1**. The back-up detail is outlined in **Figure 6E.2**.

Sub-areas in the main diagonal boxes are judged to be in reasonable concordance in terms of the survey net trend and the bibliometric growth measure. (The latter measures the extent to which Canadian research publication volume is growing faster - or declining less rapidly - than the world, or vice versa.) Consider, for example, an area like Physical Geography & Remote Sensing in the top right cell of **Figure 6E.1**. Canadian publication volume grew by 26 percent in 2001–2004 relative to 1997–2000. Publications in the world grew by 18 percent, so Canada gained share of world publication in the field. Meanwhile 30 percent of survey respondents believed the field has been gaining ground and only 14 percent believed it was losing ground. So the net upward trend of 16 percent from the survey is broadly consistent with the bibliometric result – though we would re-emphasize that the bibliometric growth parameters are conceptually and qualitatively very different from the "Up minus Down" net trend indicator from the survey. The bibliometric indicator measures an actual *volume* change, while the survey indicator is a percentage of the number of respondents (expressing a view as to the direction of change). The other cells in the matrix can be interpreted analogously. For example, those in the upper left and lower right identify areas for which the growth trends as perceived by survey respondents, and as measured by publication volume, are at opposite ends of the spectrum.

Figure 6E.1

Survey and Bibliometrics Compared - Growth

Within blocks, sub-areas in decreasing order of growth difference: Canada – World

Survey Net Trend: Up-Down %	Lowest 30%	Middle 40%	Highest 30%
Hightest 30%	C-W (Weak) U-D (Strong) Nano & Regen Medicine Mental Health, Addiction Materials Engineering	C-W (Mid) U-D (Strong) Cancer Research Nutrit, Metabo, Diabetes Aging Population & Public Health Genomics, Proteomics Genetics Neurobiol/Neurosciences Mining & Mineral Process Math Applied Petroleum Eng / Polymer Infection & Immunity Nanoscale Physical Sci Biomedical Engineering	C-W (Strong) U-D (Strong) Comms, Media & Culture Circ & Resp Health Optics; Lasers Phys Geog, Remote Sens Astro Phys, Cosmol Nanoscale Biosciences Bus & Mngmt Sci
Middle 40%	C-W (Weak) U-D (Mid) Hydrology Geophysics & Seismology Veterinary Science Other Chemical Eng Geology Climate Sci & Meterology Physical Chemistry Agricultural Eng Environmental Eng Musculoskeletal & Arthritis Civil Engineering	C-W (Mid) U-D (Mid) Geochem & Geochron Condensed Matter Phys Math Statistics Polymer Chemistry Kinesiology Microbiology Forestry Eng Human Dev, Youth Health Plant Biology Pure Math Cell Biology	C-W (Strong) U-D (Mid) Health Services & Policy Social Psychology Geog; Urbn & Enviro Plan Electronic & Photonic Eng Linguistics Ecol & Evolution Biology Law & Criminology Computer Sciences Pol Sci & Public Admin Nursing Science
Lowest 30%	C-W (Weak) U-D (Weak) Oceanography Organic Chemistry Sociology Education Soil Science Industrial Engineering Electrical Engineering Dental Science Nuclear Engineering	C-W (Mid) U-D (Weak) Nuclear Phys & Elem Part Experimental Psychology Inorganic Chemistry Economics Biochemistry Analytical Chemistry Animal Biology Aerospace Eng	C-W (Strong) U-D (Weak) Demography Other Mechanical Eng Plasma Physics Clinical Research Anthropology Physiology

Growth Rate Difference: Canada minus World (C - W)

Figure 6E.2

Survey Growth Results as Compared to Bibliometric Growth

Sub-area (by Growth)	Decile U-D	Decile C-W
Box 1: C-W (1,2,3) U-D (8,9,10)		
Demography	D8	D1
Other Mechanical Eng	D10	D1
Plasma Physics	D10	D1
Clinical Research (cross-cutting)	D8	D2
Anthropology	D8	D3
Physiology	D9	D3
Box 2: C-W (1,2,3) U-D (1,2,3)		
Comms, Media & Culture	D3	D1
Circulatory & Respiratory Health	D3	D1
Optics; Lasers	D2	D2
Physical Geog, Remote Sensing	D3	D2
Astro Phys, Cosmol	D3	D2
Nanoscale Biosciences	D2	D3
Bus & Mngmt Sci	D3	D3
Box 3: C-W (8,9,10) U-D (8,9,10)		
Oceanography	D8	D8
Organic Chemistry	D8	D8
Sociology	D9	D8
Education	D10	D8
Soil Science	D9	D9
Industrial Engineering	D10	D9
Electrical Engineering	D9	D10
Dental Science	D10	D10
Nuclear Engineering	D10	D10
Box 4: C-W (8,9,10) U-D (1,2,3)		
Nano and Regenerative Medicine	D2	D9
Mental Health, Addiction	D2	D10
Materials Engineering	D3	D10
Box 5: C-W (4,5,6,7) U-D (4,5,6,7)		
Geochem & Geochronology	D5	D4
Condensed Matter Physics	D7	D4
Math Statistics	D7	D4
Polymer Chemistry	D7	D4
Kinesiology	D5	D5
Microbiology	D5	D5
Forestry Eng	D6	D5
Human Dev't & Youth Health	D4	D6
Plant Biology	D6	D6
Pure Math	D6	D7
Cell Biology	D5	D7

Sub-area (by Growth)	Decile U-D	Decile C-W
Box 6: C-W (1,2,3) U-D (4,5,6,7)		
Health Services & Policy	D5	D1
Social Psychology	D5	D1
Geog; Urban & Enviro Planning	D4	D2
Electronic & Photonic Eng	D4	D2
Linguistics	D4	D2
Ecology & Evolution Biology	D5	D2
Law & Criminology	D4	D3
Computer Sciences	D4	D3
Pol Sci & Public Admin	D6	D3
Nursing Science	D7	D3
Box 7: C-W (8,9,10) U-D (4,5,6,7)		
Hydrology	D4	D8
Geophysics & Seismology	D5	D8
Veterinary Science	D7	D8
Other Chemical Eng	D7	D8
Geology	D6	D9
Climate Sci & Meterology	D6	D9
Physical Chemistry	D6	D9
Agricultural Eng	D6	D9
Environmental Eng	D7	D9
Musculoskeletal & Arthritis	D4	D10
Civil Engineering	D7	D10
Box 8: C-W (4,5,6,7) U-D (8,9,10)		
Nuclear Phys & Elem Part	D9	D4
Experimental Psychology	D8	D5
Inorganic Chemistry	D8	D5
Economics	D8	D5
Biochemistry	D9	D5
Analytical Chemistry	D9	D6
Animal Biology	D9	D7
Aerospace Eng	D10	D7
Box 9: C-W (4,5,6,7) U-D (1,2,3)		
Cancer Research	D1	D4
Nutrition, Metabolism, Diabetes	D2	D4
Aging	D2	D4
Population & Public Health	D3	D5
Proteomics	D1	D6
Genetics	D1	D6
Neurobiology / Neurosciences	D1	D6
Mining & Mineral Processing	D2	D6
Math Applied	D3	D6
Petroleum Eng / Polymer	D1	D7
Infection & Immunity	D1	D7
Nanoscale Physical Science	D1	D7
Biomedical Engineering	D2	D7
Nanoscale Physical Science	D1	D7
Biomedical Engineering	D2	D7