External scanning of manufacturing technology: patenting and publishing activity, Canada-US and international R and D trends, and technology roadmaps

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External Scanning of Manufacturing Technology : Patenting and Publishing Activity, Canada-US and International R&D Trends, and Technology Roadmaps

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External Scanning of Manufacturing Technology:

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London, Ontario

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Background and Contents

NRC-IMTI is currently engaged in the development of its strategic plan; a variety of data gathering activities have been undertaken in support of this planning effort. This document contains executive summaries of external scanning and analysis of the following:

- Patenting Activities Worldwide in Manufacturing
- Trends in Manufacturing Related Publishing Worldwide
- Manufacturing R&D Trends in Canada and the U.S.
- R&D Trends in Manufacturing Worldwide
- Manufacturing Technology Roadmaps

CONTENTS

Patenting Activities Worldwide in Manufacturing

Objective:
To collect data and analyze trends on international patenting activity in advanced manufacturing for the past three years.

Methodology:
A patent search was performed using the CISTI's FOCUST database service. Results were obtained for the last three years for the regions of the U.S., Europe, and Japan. The scanning was expanded with the Canadian Patents Database maintained by the Canadian Intellectual Property Office (CIPO), and with the international database maintained under the Patent Cooperation Treaty (PCT).

Findings:
For all technologies over the three years, the Japan patent office had about 157K patents, the European patent office 33K applications, the PCT Office 21K applications and Canada 4.6K applications. The United States had 104K issued patents. It is important to note that these numbers represent the filing location and not the source of the IP activity.

Each industry sector uses a range of methods for protecting intellectual property to varying degrees. For example, only 42% of wood product manufacturers protect their IP (33% in the form of patents; 47% in trademarks, 9% copyrights, 53% confidentiality agreements; 29 % trade secrets). On the other hand, 93% of communications equipment manufacturers protect their IP (53% in the form of patents; 50% in trademarks, 27% copyrights, 90% confidentiality agreements; 43% trade secrets).

Almost 95% of the patenting activity in advanced manufacturing took place in only seven areas, as listed in Figure 1.

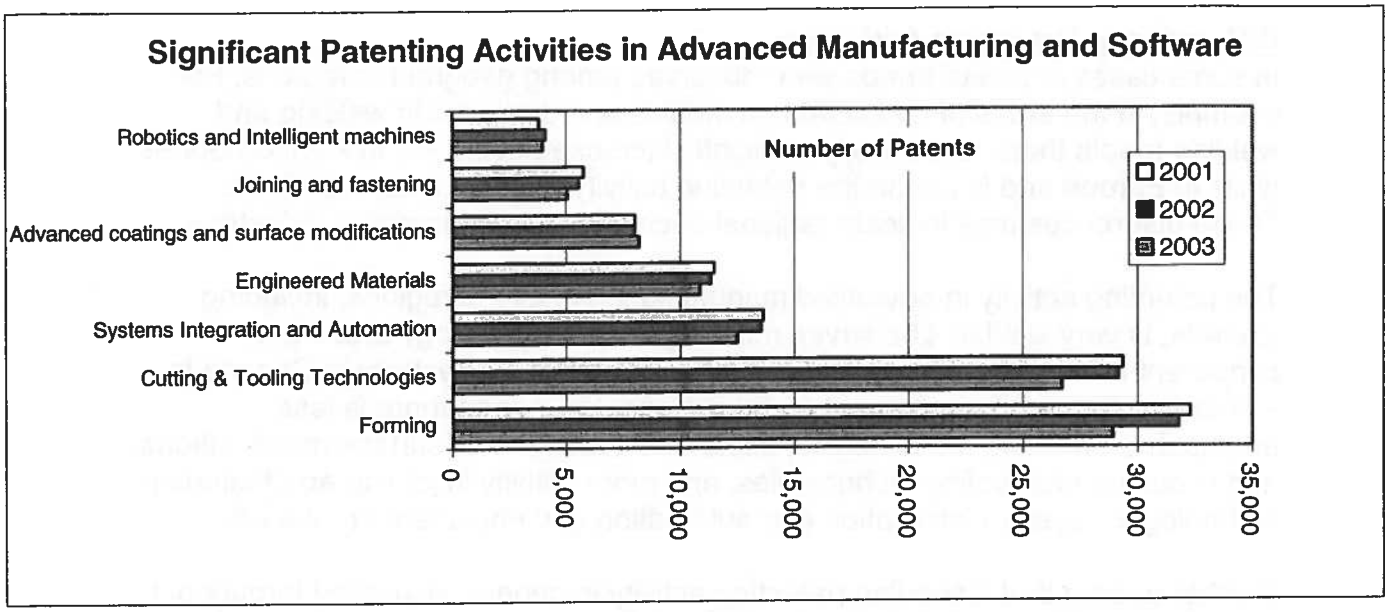

Figure 1. Areas of significant Patenting Activities

<u>Growth in Patenting Activities:</u>
According to the data collected, in the areas of "Supply Chain Management", "Production Process Management", "Production Monitoring and Supervisory Control", "Robotics and Intelligent Machines", "Laser-based Manufacturing", "MEMS Manufacturing", "High Performance Machining", "Advanced Coatings & Surface Modification", "Assembly & Testing", and "Remote Monitoring and Controls" growth was observed.

The observations are based on the total patenting activity; however, there are regional differences. Activities in "Production Monitoring and Supervisory Control" and "Laser-based Manufacturing" are on the increase in the U.S. and decreasing in Europe, and in Japan the data is up-and-down. In "Robotics and Intelligent Machines" the increase is mostly attributable to the U.S.; the activities in the other regions are more or less steady. The increase in "Advanced Coatings & Surface Modification" exists only in the U.S., and is declining in the other regions.

<u>Decline in Patenting Activities:</u>
In the areas of "Joining and Fastening Technologies", "Forming Technologies", "Systems Integration and Automation", "Cutting & Tooling Technologies", and "Engineered Materials" a decline in patenting activity was observed. Several of these technologies appear to be relatively mature, which could explain the drop in patenting activity. However, the high rate of patenting activity indicates that there are many unexplored areas and opportunities for R&D. The high productivity, flexibility, applicability and the wide acceptance of these technologies and processes are the main reasons behind the large investment worldwide.

Difference in Patenting Activities:
In some cases opposite trends were observed among geographic regions. For example, in the areas of CAD/CAM, in moulds and dies, and in welding and welding robots there was steady or slightly increased activity in the United States while in Europe and in Japan the patenting activity in these areas declined. These differences may indicate regional desires to sustain targeted industries.

The patenting activity in advanced manufacturing in all the regions, including Canada, is very similar. The seven most significant technology areas are consistent in all regions. Despite the similarities, patenting activity in Canada is somewhat different from the rest of the regions. In Canada there is less emphasis on forming technologies, advanced coatings and surface modifications, and in cutting and tooling technologies, and more activity in joining and fastening technologies, system integration and automation and engineered materials.

It would appear that Canadian patenting activity in general increased throughout the 1990s. Unfortunately it remains at a fairly low per capita rate and is low in absolute numbers compared with other G7 countries, due to Canadian market size and dynamic.

References:

1. Lee, Po-Chih and Steven Tzeferakos, Innovation Performance in Canadian Manufacturing Industries, Industry Canada, November 2001, http://strategis.ic.gc.ca/epic/internet/inmib-dgif.nsf/vwapj/innovationeng.pdf/$FILE/innovationeng.pdf

2. Collaborating for Innovation, the Conference Board of Canada's 2nd Annual Innovation Report, The Conference Board, Ottawa, 2000

3. Jayson Myers, Canada's Excellence Gap: Benchmarking the Performance of Canadian Industry against the G7, Canadian Manufacturers & Exporters, [2003], http://www.cme-mec.ca/national/documents/Excellence_Gap.pdf

Trends in Manufacturing Related Publishing Worldwide

Objective:
To scan and analyze publication activity in manufacturing technologies worldwide (including the USA and Canada).

Methodology:
Data was collected from EI Compendex and INSPEC databases and classified into the following five areas covering the manufacturing product life cycle:

- Business Relations
- Design and Simulation
- Production Technologies
- Use and Maintenance Technologies.
- Reuse and Recycling

A search for recent (within the last 5 years) manufacturing related conference and journal publications in Compendex results in over 33,000 matching results when the term "manufacturing" is used and over 69,000 matching results when the term "production" is used and an additional 20,000 when "fabrication" is used. To capture the recent trends in completed research, journal papers published within 2003 and 2004, and conference papers published from 2001 to 2004 were considered. To focus on the relevant sectors, the terms "automotive", "automobile", "aerospace", "electronics", "medical device", "machinery" and "equipment" were used to narrow the search.

Following a worldwide analysis, the search was focused on research activities in Canada and the United States. For this study, 796 relevant publications were retained for the analysis.

Worldwide Findings:
Based on the survey, the following trends were noticed:
1. In the "Business Relations" area, only "life cycle and knowledge management" shows relatively large number of publications (about 1,000 paper/year), while in other areas there is much less publishing activity:

- Life cycle and knowledge management
- Supply chain management
- e-Commerce

2. Within the "Design and Simulation" area, "modeling and simulation" dominates the publication activity (approximately 3,000-4,000 papers/year), while other areas are relatively inactive.

- Modeling and simulation
- Production process simulation
- Human factors
- Production scheduling and planning
- Production process management
- Concurrent engineering
- Production monitoring and supervisory control

3. Within the "Production" area, "advanced coatings/surface modifications" shows a lot of publishing activity (approximately 20,000 papers/year), and several other areas are covered by more than 1,000 papers/year as well.

- Advanced coatings & surface modifications
- Joining and fastening technologies
- Systems integration and automation
- Laser-based manufacturing
- Engineered materials
- MEMS manufacturing
- Cutting and tooling technologies
- Freeform manufacturing
- Assembly and testing
- Robotics and Intelligent machines
- Reconfigurable & flexible manufacturing
- Forming technologies

4. In the "Use and Maintenance" area, only "equipment monitoring" shows significant publishing activity (about 2,000 papers/year).

- Equipment monitoring
- Remote monitoring and control
- Repair and maintenance
- Fault and in-line analysis
- Reduce, reuse and recycle

<u>Canada and U.S. Findings:</u>
The total number of publications in Canada is low in absolute numbers. Areas where zero publications were found does not indicate that no research is being carried out, rather that within the context of the technology areas, they were not explicitly self-identified through key words. The skewness of the distribution appears higher in the U.S. than in Canada. **Figure 2 shows the top ten technologies areas published by Canadian and U.S. authors.**

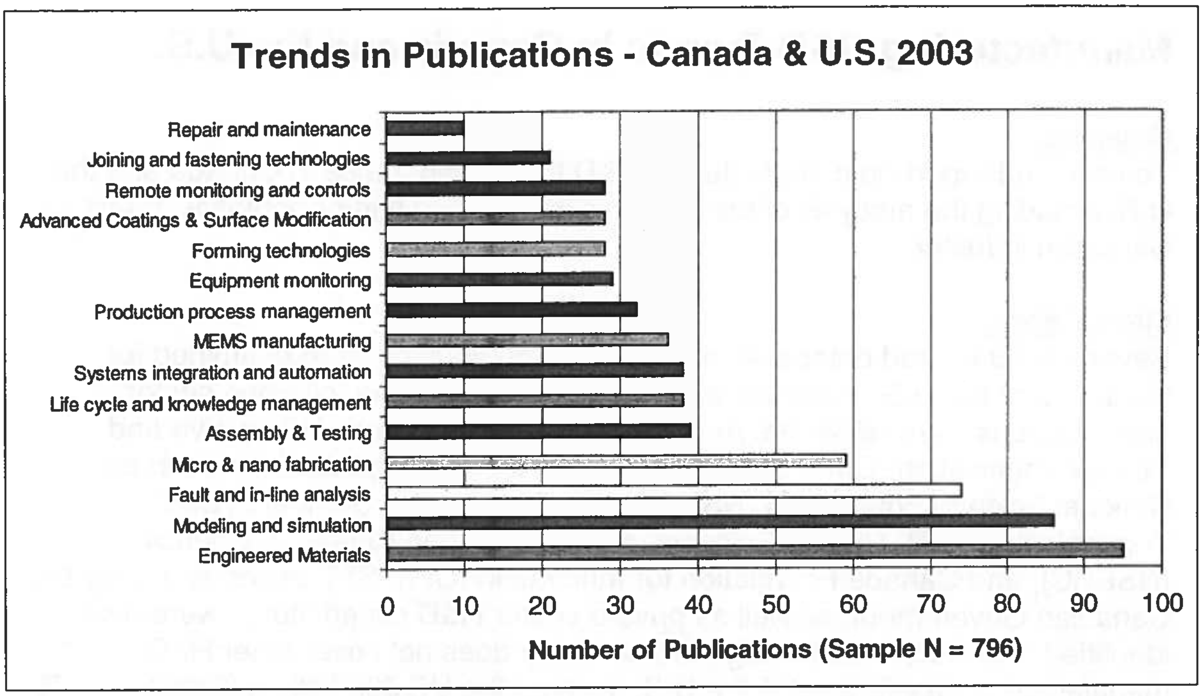

Figure 2, Top 10 Technologies by Number of Publications

Manufacturing R&D Trends in Canada and the U.S.

Objective:
To scan and report on manufacturing R&D topics and trends in Canada and the U.S. including the analysis of the strategic importance and/or potential impact on Canadian industry.

Methodology:
Several R&D related databases and information sources were examined for Canada and the U.S. Activities and projects related to the following sector classifications were reviewed: Aerospace, Medical devices, Automotive and Telecommunication. Other sources consulted include organizations such as National Science Foundation (NSF), National Institute of Standards and Technology (NIST), Natural Sciences and Engineering Research Council (NSERC), and Canada Foundation for Innovation (CFI). S&T expenditures by the Canadian Government, as well as private sector R&D expenditures were also identified. It is worth mentioning that this study does not cover other R&D manufacturing investments in the U.S. such as the US $38 Million (2003) Manufacturing Extension Program (MEP) and roughly US $25 Million funding to Engineering Research Centers (ERCs).

Findings:
Note throughout this section, technologies are listed in relation to the value of investment, largest-to-smallest.

Canada - NSERC Discovery, Strategic and Collaborative Projects
The data on recently funded university research by NSERC indicated that the following are the top ten manufacturing technologies areas funded through various NSERC programs:

1. Forming technologies
2. Engineered materials
3. Micro & nano fabrication
4. Production scheduling, planning and process management
5. Robotics and Intelligent machines
6. Supply chain management
7. Modeling and simulation
8. Virtual manufacturing
9. Intelligent product and process advisors
10. Concurrent engineering
11. Advanced Coatings & Surface Modification
12. Reconfigurable & flexible manufacturing

Note: the top four technology areas represent 74% of NSERC funding in manufacturing.

Canada - CFI Investments in Manufacturing R&D Infrastructure

Over 3000 infrastructure projects have been funded since the establishment of the Canada Foundation for Innovation. There were 85 projects to support manufacturing R&D since 1998, representing an investment in R&D infrastructure of over 44 million dollars. The top ten manufacturing technology areas funded are:

1. Forming technologies
2. Virtual manufacturing
3. MEMS manufacturing
4. Micro & nano fabrication
5. Advanced Coatings & Surface Modification
6. Engineered Materials
7. Joining and fastening technologies
8. Modeling and simulation
9. Production scheduling and planning
10. Robotics and Intelligent machines

Note: the top four technology areas represent 68 % of CFI funding in manufacturing infrastructure.

Canada – Federal R&D Spending

The total S&T expenditure by the government of Canada in 2003 was $ 8.5 billion. Figure 3 shows the distribution of funding across federal government departments. Roughly half of the research funded was performed by universities or outsourced to the private sector.

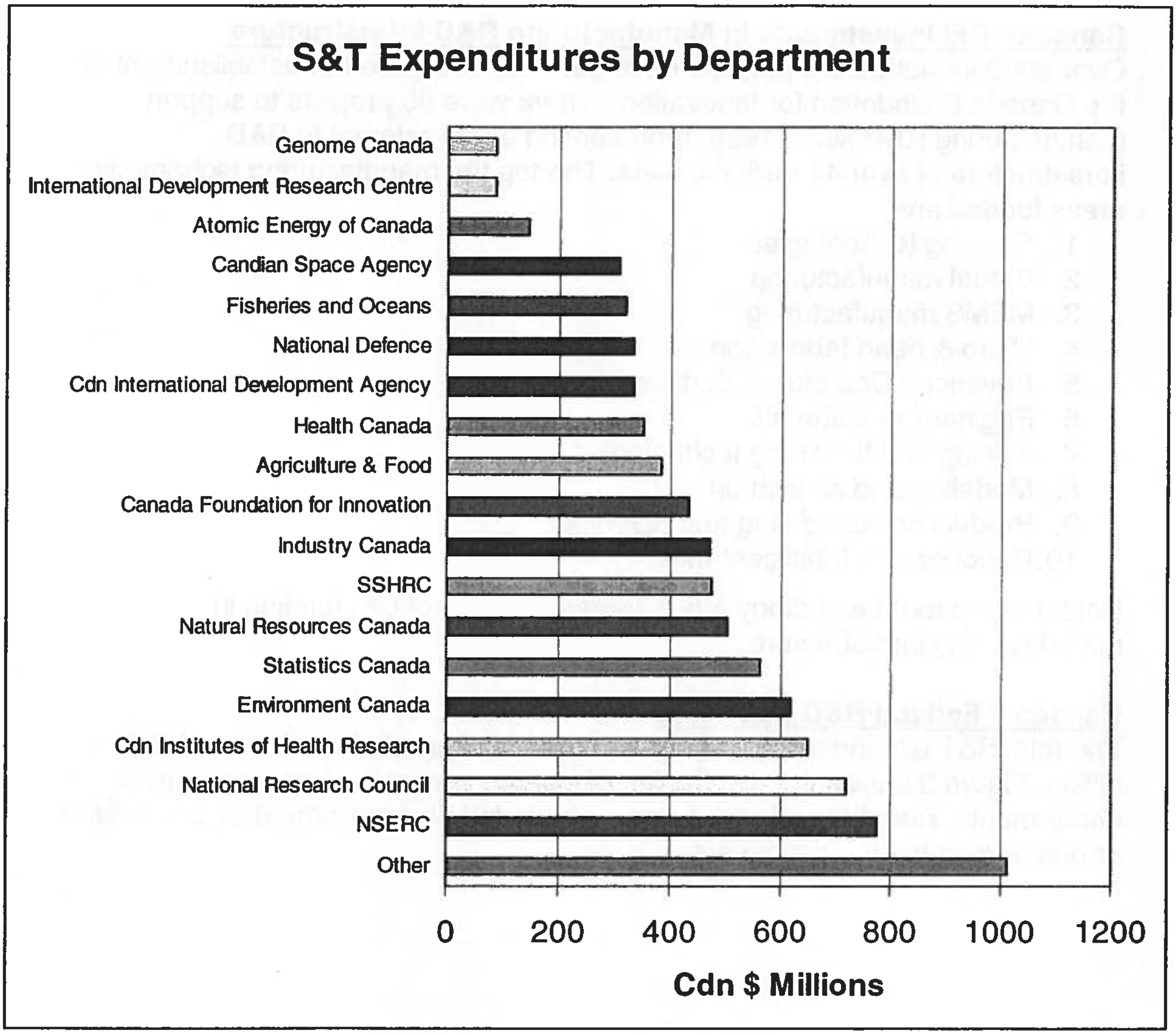

Figure 3, Canada Federal S&T Spending by Department

Canada – Top R&D Spenders

The top industrial R&D spending industries in Canada, as shown in Figure 4, represent CAD $ 10.9 Billion in 2003. Figure 5, charts Canada's top R&D spenders by industry sector.

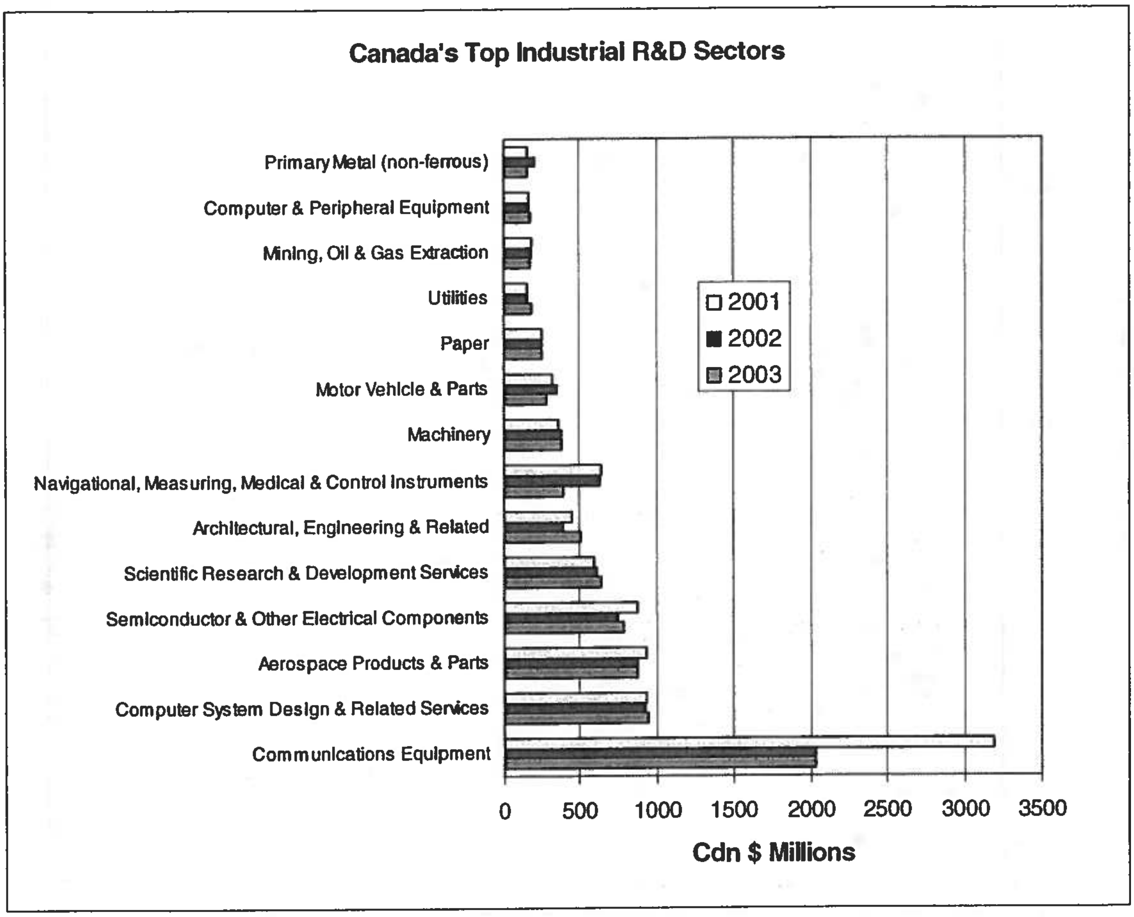

Figure 4, Canada Industrial R&D Spending by Sector

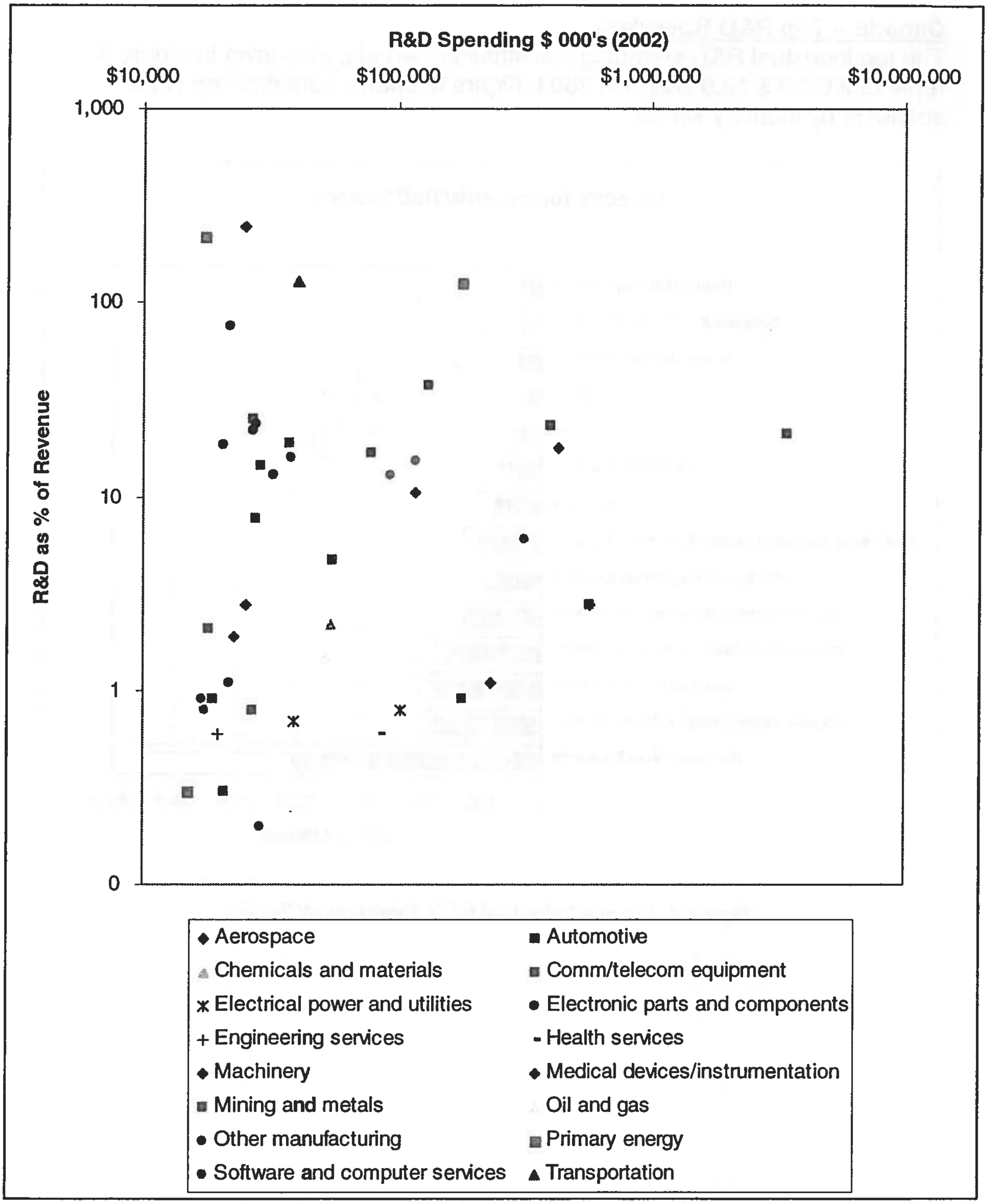

Figure 5, Canada Top R&D Spenders – Value and Ratio

USA - NSF Funding

Of the 183 currently active R&D projects retrieved from the NSF database, the National Science Foundation has invested over $37 million on manufacturing related R&D, of which the top 10 technologies represent roughly 56%. The following are the top ten projects funded in the manufacturing technologies:

1. Supply chain management
2. Production scheduling and planning
3. MEMS manufacturing
4. Production process management
5. Production monitoring and supervisory control
6. Extended enterprise
7. Micro & nano fabrication
8. Virtual manufacturing
9. Reconfigurable & flexible manufacturing
10. Cutting & Tooling Technologies

USA - NIST Advanced Technology Partnership (ATP) Projects

The following areas represent the large multi-partner, collaborative projects (by value) that were funded by NIST in the Advanced Technology Program:

1. Engineered Materials
2. Virtual Manufacturing
3. Micro and Nanofabrication
4. Forming Technologies
5. MEMS Manufacturing
6. Assembly and testing
7. Intelligent Product and Process Advisor
8. Fault and in-line analysis
9. Cutting and Tooling Technologies
10. Joining and Fastening Technologies
11. System Integration and Automation
12. Robotics and Intelligent Machines

Note: the total value of currently active manufacturing related projects under NIST ATP is US$ 147 Million.

R&D Trends in Manufacturing Worldwide

Objective:
To scan and analyze R&D trends in manufacturing technologies and industry sectors in different countries worldwide (Canada and U.S. excluded).

Methodology:
The scanning activity dealt with websites, publication records of research in academic organizations, government institutions, and funding bodies in Australia, China, the European Union, India, Japan, South Korea, Singapore and Taiwan. Information was collected on research in manufacturing technologies in general, but of primary interest were projects and initiatives supporting the automotive, aerospace, machinery, medical devices, and electronics industry.

Findings
The USA, European Union and Japan continue to be global leaders in manufacturing R&D worldwide. Over the last few decades China has become an equal partner in terms of its capability to produce various goods, and is rapidly catching up in terms of innovative R&D as well. As Figure 6 shows, these countries have the highest gross R&D expenditure (data for China not shown but is estimated at US$ 60 Billion in 2001).

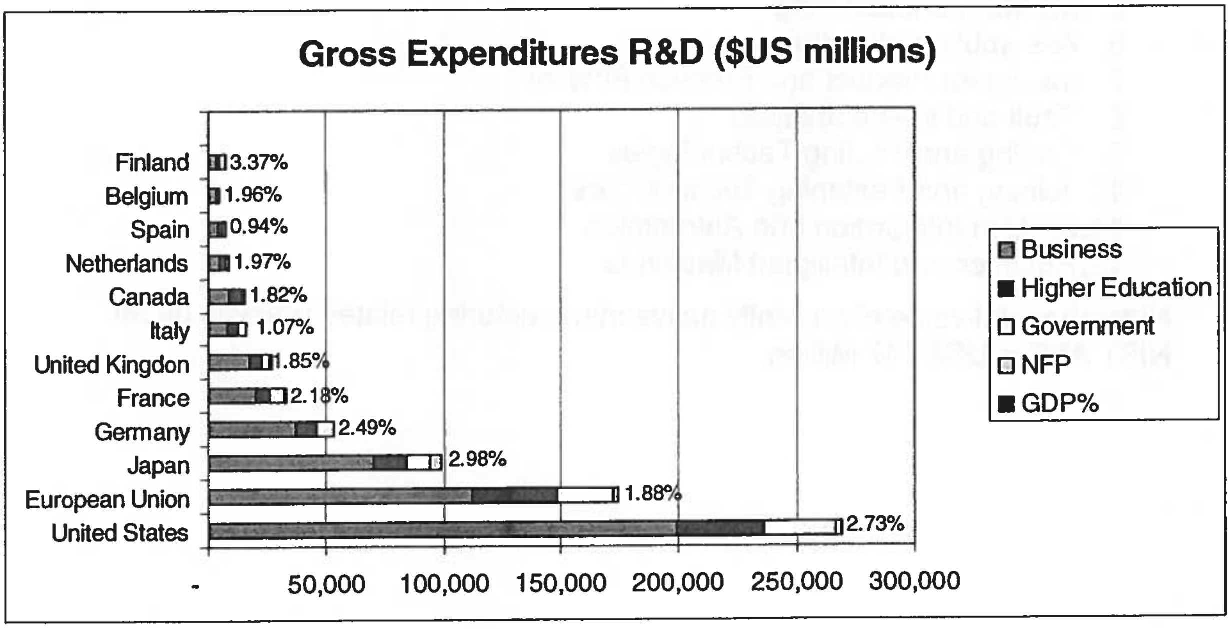

Figure 6, Gross Expenditures R&D (US$ millions) 2003; Source: OECD

Other countries scanned in this task (Australia, India, South Korea, Singapore and Taiwan) are also very active and successful in some focused areas, but their R&D initiatives are generally smaller in scale.

Figure 7 shows the percentage distribution of government versus higher education spending on R&D.

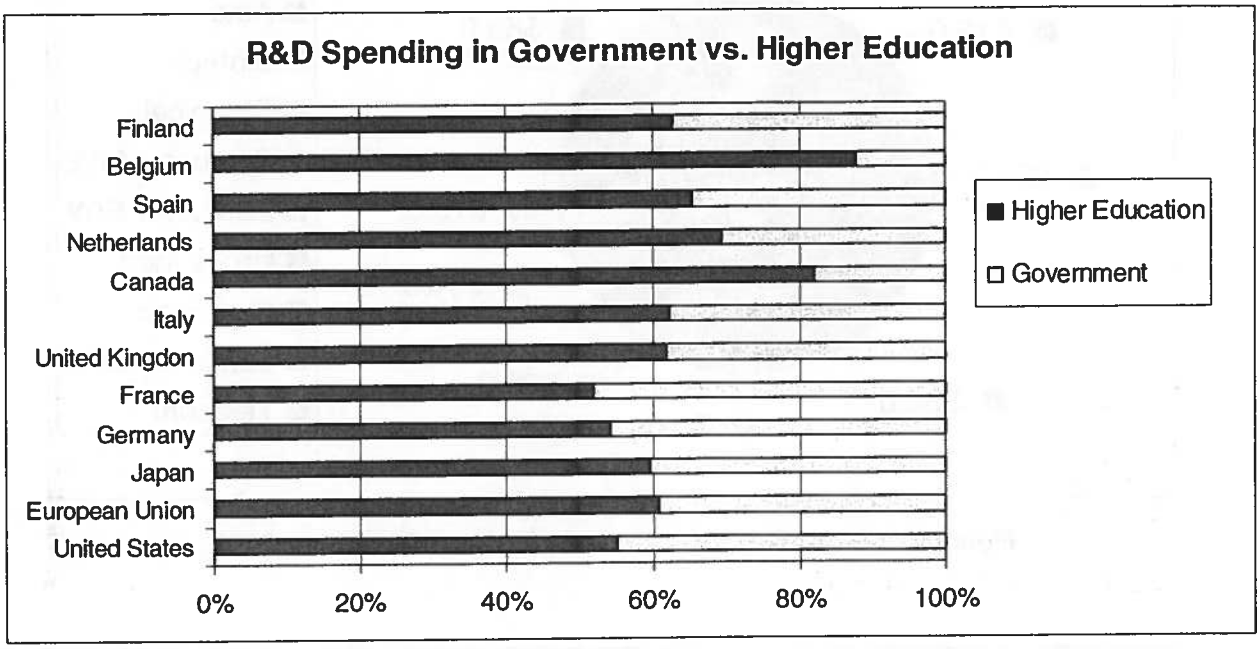

Figure 7, Distribution of Government versus Higher Education Spending on R&D

Figure 8 depicts how the expenditures of the top 150 R&D spenders worldwide are distributed by major industry sector.

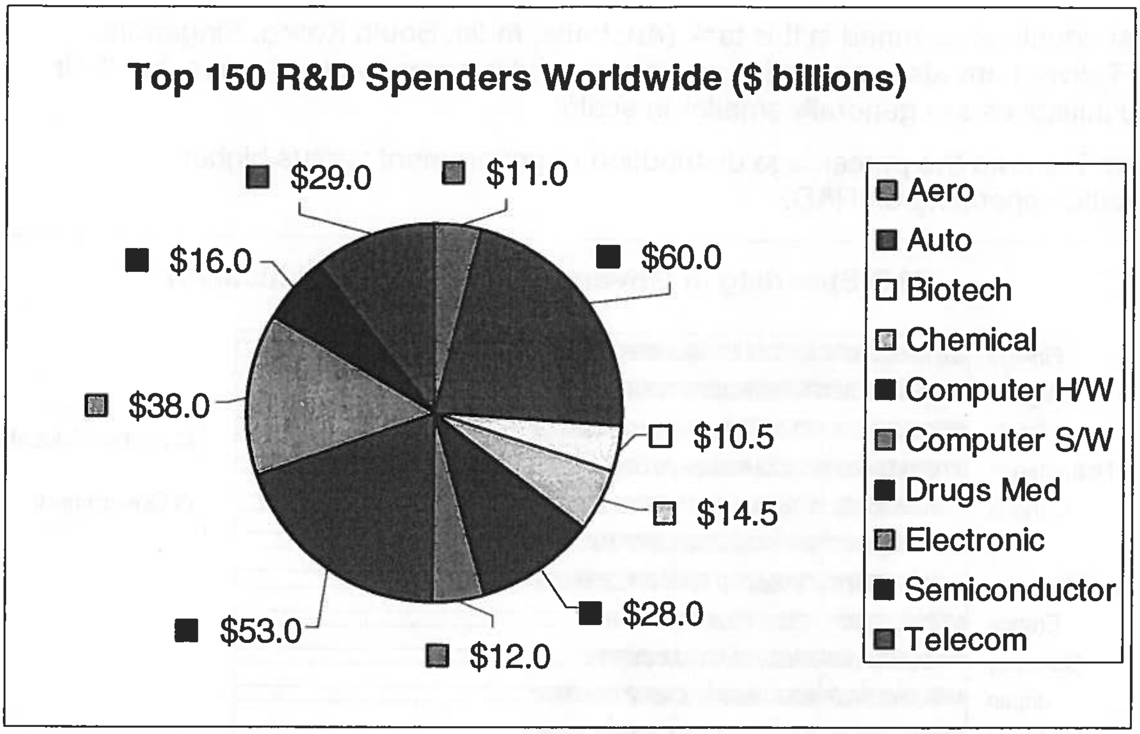

Figure 8, Top 150 R&D Spenders Worldwide (US$ billions) 2003

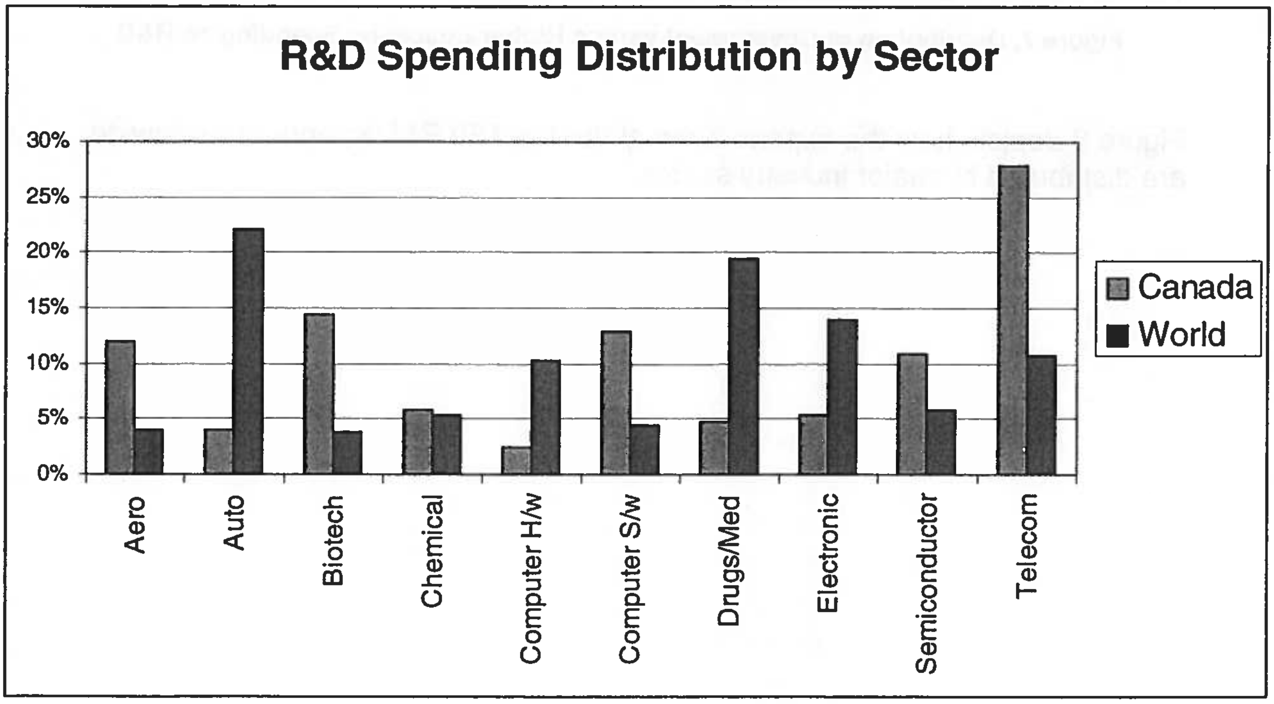

Figure 9, R&D Spending Distribution by Sector – Canada and Worldwide

The following is a summary of findings for the European Union, Japan and China. South Korea, Singapore and Taiwan have similar but smaller-scale R&D initiatives, especially in information technologies, nanotechnology and biotechnology.

As can be seen in the following sections, new production processes, nano-science (nanotechnology and nanomaterials) and its applications, are heavily emphasized in all major regions. Convergence of sciences and technologies (for example: medical, physical and engineering sciences) is also noticed in most regions, with application areas including transportation, health care, environmental care, food industry, and others.

European Union:

Manufacturing plays a major role in the European Union economy and a competitive manufacturing sector is of vital importance to the EU, representing 22% of GNP. There are approximately 2.5 million manufacturers in the EU, with about 31.5 million employees (compared to 21 million in the U.S.). The European Commission aims to make Europe "the most competitive and dynamic knowledge-based economy in the world" by 2010. Both national and EU-wide strategies to achieve this goal are now being implemented.

The European Union established a 4-year (2002-2006) program known as the Sixth Framework Programme (FP6) for funding research in Europe. FP6 focuses on seven "Thematic Areas" for the advancement of knowledge and technological progress. The areas and the budget breakdown among them are shown in Figure 10.

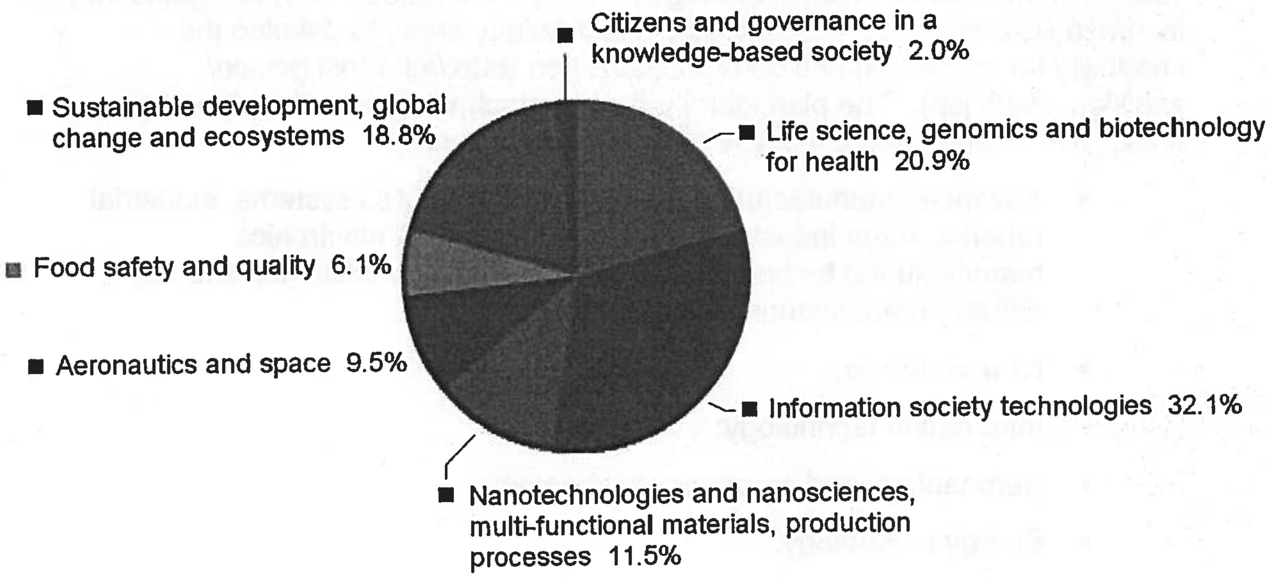

Figure 10, Budget breakdown (€11.3 billion) among FP6 priority areas

(Source: http://europa.eu.int/comm/research/rtdinfo/pdf/rtdspecial-fp6_en.pdf)

Japan:
Lacking natural resources, Japan views advanced manufacturing technologies as a lifeline for its economy. Japan wants to extend its current technological lead by further advancing its key manufacturing technologies through massive R&D performed by the private sector and collaboration among government, academics, and the private sector.

Monbusho (Japanese Ministry of Education, Culture, Sports, Science and Technology) identified the following manufacturing-related priority areas for R&D in the second 5-year Science and Technology Plan (2001-2005). They are (http://www8.cao.go.jp/cstp/english/s&tmain-e.html):

- Manufacturing technology - high precision machining, fine parts processing, micro machines, environmentally friendly manufacturing, quality assurance and safety, IT or bio-based manufacturing, medical/health care apparatus;
- Environmental sciences – production systems to reduce waste and support recycling;
- Nanotechnology and materials – nano-information devices, medical micro-robotics
- Energy – fuel cells and solar power generation, energy saving technologies

China:
China is emerging as one of the largest and most important manufacturing powers in the world. In addition to an increased manufacturing capability, China has intensified its investment in manufacturing R&D. China's overall R&D expenditures almost doubled from 1998 to 2001. China established its 10th 5-year Plan on Science and Technology Development (2000-2005) to significantly increase R&D expenditures in strategic technology areas to develop the capability for innovation and commercialization (http://gh.most.gov.cn/zcq/kjgh_swgh.jsp). The plan identified seven technologies as key funding areas, five of which are directly related to manufacturing:

- Advanced manufacturing and automation – CNC systems, industrial robotics, large industry systems, automotive & electronics manufacturing technologies and systems, high efficiency and fast delivery manufacturing systems
- New materials;
- Information technology;
- Aeronautical and aerospace technology;
- Energy technology.

Manufacturing Technology Roadmaps

Objective:
To identify a list of innovative manufacturing technologies that will produce major economic and social impacts on Canadian industries based on a review of technology roadmaps, considering the crosscutting manufacturing needs of many application sectors.

Methodology:
- Review dominant 'Manufacturing Technology Roadmaps', vision & white papers
- Review pertinent government & industry association surveys

Manufacturing industry typically assesses the impacts of future technologies by performing a technology road mapping exercise. It is a technique that is used extensively within industry to support strategic and long-range planning. It provides a structured means for exploring and communicating the relationships between evolving and developing markets, products and technologies over time. Such road mapping efforts will help manufacturing organizations to identify, select and develop technology options to satisfy future products, services and/or operational needs. The roadmap review reported in this study is conducted based on the assumption that most 'manufacturing' starts from customer requirements and business relations, and finishes at the recycling and/or disposal level. The crosscutting industry needs of many manufacturing sectors (see Figure 8 below) were considered prior to reviewing the many roadmap documents (complete listings given at end) that were compiled across the globe during the past several years.

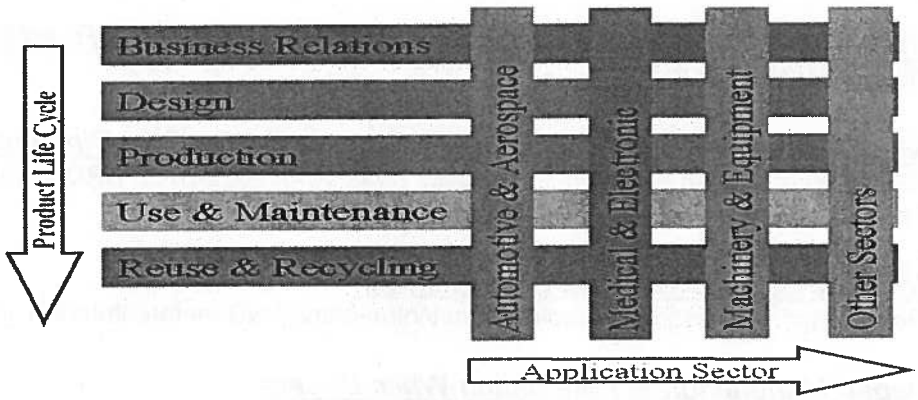

Figure 8, Manufacturing Technology Domains – Industries & Product-Life Cycle Stages

An elaborate literature search was performed on available roadmaps, surveys and vision and white papers relevant to the manufacturing domain. During the course of the study it became apparent that some roadmaps are sector specific (aerospace, electronic, etc.), while others are more generic; applicable to several manufacturing technologies. Some covered only narrow domains within the broad manufacturing discipline, whereas others covered the entire spectrum of manufacturing activities. The outcome of this review - the technologies that are expected to produce relatively large impacts on Canadian manufacturing industries - are compiled and presented below.

Findings:
The following table lists the 16 technologies considered most important in the roadmaps that we have studied. They are expected to yield high impacts, based on a combination of quantitative data (IMTI-USA roadmaps & SRI Consulting Business) and the views of the research team.

Figure 9, Innovative Technologies with Highest Perceived Impact

Extended Enterprise	Micro & nano fabrication
Life cycle and knowledge management	Robotics and Intelligent machines
Intelligent Product and Process Advisors	MEMS* manufacturing
Concurrent Engineering	Reconfigurable & Flexible manufacturing
Modeling and Simulation	Systems Integration and Automation
Virtual Manufacturing	Engineered Materials
Production Process Simulation	Advance coatings and Surface modifications
Production Monitoring & Supervisory Control	Reduce, reuse and recycle

* MEMS = micro-electro-mechanical systems

Roadmaps Considered:

1. *Integrated manufacturing Technology Initiative (IMTI) USA Road Maps*
   Refer: http://www.imti21.org/

2. *MTG Strategic Planning Exercise findings on Technology Directions:*
   Refer: Manufacturing Innovation: An Impact Strategy for 2000-2005" NRC Manufacturing Technology Group – report dated June 12, 2000

3. *Industry Canada Technology Roadmaps:*
   Refer: http://strategis.ic.gc.ca/epic/internet/intrm-crt.nsf/vwGeneratedInterE/h_rm00051e.html

4. *Japan Manufacturing Foundation White Papers:*
   Refer: http://www.meti.go.jp/report/whitepaper/index.html

5. *SRI Consulting Business Intelligence Technology Maps*
   Refer: http://www.sric-bi.com/Explorer/KMT/VptsPDF/KMT.2002-all.pdf

6. *Medical Devices:* Refer: Biomedical MEMS: Clinical applications of silicon technology, Published by QinetiQ and Institute of Physics Publishing. 2003

7. *2003 National Electronics Manufacturing Initiative Research Priorities* Refer: ftp://nemi.org/webdownload/newsroom/NEMI_2003%20Research%20Priorities.pdf

8. *International Technology Roadmap For Semiconductors:* Refer: http://public.itrs.net

9. *Robotics & Intelligent Machines (RIM)– U.S. Department of Energy Road Mapping* Refer: http://www.sandia.gov/isrc/RIMfinal.pdf

10. *ManuFuture 2003 – European Manufacturing of the Future* Refer: http://europa.eu.int/comm/research/industrial_technologies/pdf/policy_manufuture.pdf

11. *IMS- Intelligent Manufacturing Systems: Technology Maps* Refer: ftp://ftp.cordis.lu/pub/ims/docs/ims_technologymap_en.doc

12. *NCMS – Annual Conference – Manufacturing Technologies Roadmaps:* Refer: http://techcon.ncms.org/98con/presentations/Burleson-Mfg%20Controls.pdf

13. Automotive Remanufacturing Industry: Roadmap Workshop Report Refer: http://www.apra.org/Promoting_Industry/Roadmap/roadmap.asp

14. *Precarn Incorporated – Survey* Refer: http://www.precarn.ca/intelligentsystems/file_2003_07_30_IS_Sector_Profile__CE_.PDF

15. *MONET Automotive Roadmap in Model-based & Qualitative Reasoning:* Refer: http://monet.aber.ac.uk:8080/monet/summer_school_2003/summer_school.html