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MEASURING THE CONTRIBUTION OF MODERN BIOTECHNOLOGY TO THE CANADIAN ECONOMY

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Measuring the Contribution of Modern Biotechnology to the Canadian Economy

Abstract

The role of modern biotechnology in agriculture, medicine, and industry has increased dramatically since the 1970s. Despite its growing importance, few efforts have been made so far to estimate the economic contribution of modern biotechnology to the Canadian economy. This report provides an overview of biotechnology activities in Canada, and, using an income-based approach, estimates that biotechnology activities accounted for approximately $15 billion in 2005, equivalent to 1.19 per cent of Canada's GDP in that year. The report also forecasts that the role of biotechnology in the economy will increase substantially in the next twenty years, representing between 2.6 per cent and 6.0 per cent of Canada's GDP in 2030.

Measuring the Contribution of Modern Biotechnology to the Canadian Economy

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Measuring the Contribution of Modern Biotechnology to the Canadian Economy

Executive Summary

Traditional biotechnologies such as fermentation have been used for thousands of years to produce goods such as bread, beer, and cheese. The benefits (economic and otherwise) of these applications have long been understood and incorporated by modern society. Starting in the early 1970s, however, the advent of recombinant DNA technology marked the beginning of modern biotechnology, which created new, previously unforeseen, economic possibilities based on the use of cellular, molecular, and genetic processes in the production of goods and services. Modern biotechnology has applications in three broad areas: agriculture and related activities, medicine and healthcare, and industry, environment and energy. The main objectives of this report are to estimate the economic contribution of modern biotechnology to Canada's GDP for 2005, and to forecast its potential contribution to the economy in 2030.

Overview of Biotechnology Activities in Canada

In Canada, the main source of biotechnology data was Statistics Canada's Biotechnology Use and Development Survey (BUDS). This survey was conducted biannually from 1999 to 2005, after which it was terminated due to lack of funding. Its focus was on innovative biotech firms, i.e. firms that were developing at least one new biotech product or process. Below, we highlight some of the key results of the 2005 BUDS.

- In 2005, Canada had 532 innovative biotech firms (or biotech R&D firms), up from 358 in 1999, an increase of almost 50 per cent. Medical biotech firms represented 58.3 per cent of total biotech firms, followed by agricultural biotech firms (20.1 per cent), and industrial biotech firms (18.6 per cent). Three quarters of innovative biotech firms had less than 50 employees and were located in Quebec, Ontario, or British Columbia.

- Whether we look at employment, R&D expenditures, or revenues, medical biotech firms accounted for the bulk of biotech activities in Canada throughout the 1999-2005 period.

- In 2005, 13,433 employees worked in innovative biotech firms, up from 7,749 in 1999, an increase of 73.4 per cent. Medical biotech firms were responsible for 80.9 per cent of total biotech employment. They were followed by agricultural biotech firms (9.8 per cent), and industrial biotech firms (8.6 per cent).

- Private biotech R&D expenditures in current dollars grew at an average annual rate of 12.7 per cent during the 1999-2005 period, from $831 million in 1999 to $1,704 million in 2005. Medical biotech R&D represented 87.3 per cent of total biotech R&D in 2005, while agricultural biotech R&D and industrial biotech R&D accounted for 9.2 per cent and 2.8 per cent, respectively.

- Nominal biotech revenues increased at an average annual growth rate of 13.7 per cent during the 1999-2005 period, from $1.95 billion in 1999 to $4.20 billion in 2005. Medical biotech was responsible for 70.6 per cent of total biotech revenues, followed by agricultural biotech (24.6 per cent) and industrial biotech (4.3 per cent).

BUDS data refer only to private biotech activities. The public sector, however, plays an important role in both funding and performing biotech R&D. According to Statistics Canada's *Biotechnology Scientific Activities in the Federal Government Departments and Agencies* report, the federal government funded $937 million in biotech R&D (and related scientific activities) in 2008, up from $319 million in 1999, which implies an average annual growth rate of 11.4 per cent. The main performer of federal biotech R&D was the higher education sector, responsible for 58.7 per cent of federal biotech expenditures in 2008, followed by the federal government itself (intramural expenditures), responsible for performing 29.0 per cent of federal biotech-related expenditures. The role of the higher education sector has increased significantly over time. In 1998, the sector was responsible for performing 49.0 per cent of federal biotech expenditures, 11.0 percentage points less than it performed in 2008. On the other hand, the federal government's role declined sharply, from performing 44.7 of federal biotech science and technology expenditures to performing the aforementioned 29.0 per cent, a 15.0 percentage point drop.

Framework for Measuring the GDP of Biotechnology Activities

The biotech value chain of production starts with firms selling intermediate and capital goods to *biotech producers*, which are establishments that produce biotech-based goods and services (e.g. pharmaceutical companies, breeders, enzyme manufacturers, etc.). The links between biotech producers and their suppliers are called *backward linkages*. Biotech producers can then sell the goods they produced to *biotech users* (e.g. farmers that use GM seeds to produce GM crops), which are firms that use biotech-based goods/services as intermediate inputs in their own production processes. Next, biotech users sell their goods to wholesalers, retailers, and other firms in the economy, developing *forward linkages*. Throughout this entire process, employees are paid wages and employers make profits. They spend most of their income buying goods and services offered by the rest of the economy, which in turn creates additional economic activity. This represents the *income multiplier effect*. All of the elements described above play a role in increasing the economy's output. However, technological innovations such as the ones generated by biotechnology activities can create new goods and services (as well as new ways to produce conventional goods and services) by displacing economic activity. In other words, goods and services that were previously useful become obsolete, and the firms producing them close down. This is the *displacement effect*.

This report does not attempt to measure the entire biotech value added chain of production. The estimates and forecasts discussed here refer only to biotech producers and biotech users. The rationale for this choice is the fact that these two groups constitute the actual core of biotechnology activity, i.e. they are the ones responsible for the production of biotech-based goods and services. The focus on biotech producers and users allows us to understand the relevance of biotech-based products and services in the economy, and allows us to compare the "biotech sector" with other sectors in the economy. Thus, this report will not provide estimates of backward linkages, forward linkages, the income multiplier effect, nor the displacement effect associated with biotechnology activity in Canada. In this sense, the reader should be aware that whenever the expression "total biotech contribution" is used here, it refers specifically to the sum of the direct economic contribution of biotech producers and biotech users.

Ideally, we would like to measure the economic contribution of biotechnology in terms of value added (GDP at basic prices), because it avoids the double-counting of output. However, due to the cross-sectoral/cross-industrial nature of biotech activities (i.e. there is no "biotech sector" or "biotech industry" in the North American Industry Classification System), there are no readily available value added data. The available data (revenues of biotech firms, public sector R&D expenditures, etc.) are converted to value added through a series of data adjustments:

- We use value added-gross output (VA-GO) ratios to convert revenue data for private sector biotech producers to GDP. In the case of public sector biotech producers, value added is estimated based on the labour compensation paid to biotech researchers.

- For biotech users, we calculate biotech GDP by multiplying an industry's GDP by an estimated *biotech adoption rate* that ranges from 0.0 to 1.0. In this context, biotech adoption rates refer to the share of firms in a particular industry that use biotech products and/or techniques as intermediate inputs in their own production process.

Another issue that arises when measuring the value added of biotech firms is that the extent to which these firms use biotechnology varies widely. In some firms, biotech plays a supporting role and accounts for only a small part of the total value added, while in others it is a core technology that accounts for most of the value added generated in the activity. However, as Zika *et al.* (2007) argue, the relative contribution of biotech to the value added of a specific activity is very hard to quantify, because it is not usually observable. This report adopts Zika *et* *al*. (2007) stance, attributing 100 per cent of a product's value added at the firm level to modern biotechnology whenever it played a role in this product's production process.

Biotech GDP in 2005

According to the CSLS estimates, the value added of biotech activities reached $15,300 million current dollars in 2005, up from $8,336 million in 1999 (Table 17). This represents an average annual growth rate of 10.7 per cent during the 1999-2005 period, considerably more than the growth experienced by the total economy (5.9 per cent per year), which explains why biotechnology's share of total economy GDP increased from 0.92 per cent to 1.19 per cent.

In 2005, biotech producers were estimated to have been responsible for approximately one fourth of the total value added of biotechnology activities, $3,501 million. In the private sector, the most important biotech producers were firms developing applications in medicine and healthcare ($1,661 million), followed by firms involved in agriculture and related activities ($572 million). In the public sector, biotech R&D performed by the higher education sector accounted for $917 million in value added, while government biotech R&D was responsible for $244 million.

Biotech users were responsible for three fourths of the total value added of biotech in 2005, $11,799 million. Industrial biotech applications, such as the use of enzymes in food and beverages processing, represented most of the biotech users total value added ($6,312 million). Medical biotech users generated a total value added of $3,335 million, while GM crops and other uses of biotech in agriculture were responsible for a total value added of $2,152 million.

Comparing the value added contribution of biotechnology activities to that of two-digit NAICS sectors in Canada in 2005, we can see that biotechnology represents a fairly small part of the Canadian economy (1.19 per cent of total economy GDP), close in size to arts, entertainment and recreation (0.91 per cent), as well as to agriculture, forestry, fishing and hunting (1.84 per cent), but well below sectors such as finance, insurance, real estate and renting and leasing (FIRE) (18.35 per cent), manufacturing (14.45 per cent), or mining and oil and gas extraction (8.64 per cent).

Looking at growth rates, however, we have a very different picture. The nominal GDP of biotech activities grew at an average annual rate of 10.7 per cent from 1999 to 2005, faster than any two-digit NAICS sector in the Canadian economy with the exception of mining and oil and gas extraction, which grew 20.5 per cent per year. Sectors such as administrative and support, waste management and remediation services (ASWMRS), and construction grew at fast rates (9.1 and 8.6 per cent per year, respectively), but still slightly slower than the growth rate observed in biotech.

Projecting Biotech GDP to 2030

Using the assumptions described in the methodology section, the CSLS forecasts that nominal biotech GDP will grow at an average annual rate of 9.4 per cent per year during the 2005-2030 period, with the value added associated with biotech users growing faster than that of biotech producers (9.5 per cent versus 8.8 per cent, respectively), and nominal GDP growth for the total economy averaging 4.2 per cent per year. In this baseline scenario, nominal biotech GDP will reach approximately $144 billion in 2030, equivalent to 3.99 per cent of forecasted total economy nominal GDP in Canada.

The OECD calculates that, at most, biotech would be responsible for 5.6 per cent of EU-25 GDP and 5.8 per cent of U.S. GDP in 2030. However, their actual estimate for the OECD countries is significantly below the upper bound, 2.7 per cent of GDP. Our estimate, despite being higher than that of the OECD by approximately 1.3 percentage points shares an important characteristic with the OECD estimate. Namely, industrial biotech accounts for the lion's share of biotech GDP in both estimates. The differences between the CSLS and the OECD forecast are driven partly by the fact that Canada and the aggregate of OECD countries have different industry compositions, and partly by the use of different methodologies and forecasting assumptions.

Measuring the Contribution of Modern Biotechnology to the Canadian Economy[1]

I. Introduction

The beginning of modern biotechnology in the 1970s created new economic possibilities based on the use of cellular, molecular, and genetic processes in the production of goods and services. Since then, modern biotechnology has had relevant applications in three main areas: agriculture and related activities; medicine and healthcare; and industry, energy and environment. Despite its growing importance, few efforts have been made so far to estimate the economic contribution of modern biotechnology to the Canadian economy.

The use and development of biotechnology affects the economy through multiple channels: it creates jobs, generates value added, improves the efficiency of production processes, reduces environmental damage, enhances human health, etc. This report does not attempt to measure all of the effects of biotechnology on Canadian society. Rather, it focuses on the value added generated by biotechnology. Using an income-based approach, this report estimates the current contribution of biotechnology to GDP in Canada, as well as projects its potential contribution to 2030.

The report is organized as follows. Section two defines modern biotechnology and describes the main data sources used in the report. Section three provides an overview of the biotechnology landscape in Canada, while section four discusses the literature on measuring the economic contribution of biotechnology. Section five details the framework and assumptions used by the CSLS to estimate (and forecast) the contribution of biotech to the Canadian economy. Section six shows the results of our estimations, and section seven concludes.

[1] This report was written by Ricardo de Avillez, under the supervision of Andrew Sharpe, and with the assistance of Crystal St. Denis. The author would like to thank Genome Canada's President and CEO Pierre Meulien, Executive Vice-President Cindy Bell, and the entire Executive Committee for their comments during the presentation at Genome Canada's headquarters on August 11, 2011. Special thanks go to Fred Gault and Someshwar Rao for their comments, corrections, and suggestions to earlier versions of this report. The CSLS would like to thank Genome Canada for the financial support. For comments, the author can be contacted at ricardo.avillez@csls.ca.

II. Definitions and Data Sources

In this section, we define modern biotechnology, listing its platform technologies, as well as its applications in agriculture and related activities, medicine and healthcare, and industry, energy and environment. Next, the main data sources used throughout the report are discussed.

A. Definitions

Biotechnology can be defined broadly as "the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD, 2009a, p. 9).[2] This single definition encompasses both *traditional biotechnology applications* – such as fermentation, and plant and animal hybridization – and *modern applications* – such as genetic modification and RNA interference.

Traditional biotechnologies such as fermentation have been used for thousands of years to produce goods such as bread, beer, and cheese. The benefits (economic and otherwise) of these applications have long been understood and incorporated by modern society. Starting in the early 1970s, however, the advent of recombinant DNA technology marked the beginning of modern biotechnology, which created a new set of (previously unforeseen) economic possibilities based on the use of cellular, molecular, and genetic processes in the production of goods and services (Zika *et al.*, 2007, p. 5).

Exhibit 1: List of Biotech-Related Scientific Disciplines and Techniques

DNA/RNA	Genomics, pharmacogenomics, gene probes, genetic engineering (also known as genetic modification), DNA/RNA sequencing/synthesis/amplification, gene expression profiling, and use of antisense technology.
Proteins and other molecules	Sequencing/synthesis/engineering of proteins and peptides (including large molecule hormones); improved delivery methods for large molecule drugs; proteomics, protein isolation and purification, signalling, identification of cell receptors.
Cell and tissue culture and engineering	Cell/tissue culture, tissue engineering (including tissue scaffolds and biomedical engineering), cellular fusion, vaccine/immune stimulants, embryo manipulation.
Process biotechnology techniques	Fermentation using bioreactors, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation, biofiltration and bioremediation.
Gene and RNA vectors	Gene therapy, viral vectors.
Bioinformatics	Construction of databases on genomes, protein sequences; modelling complex biological processes, including systems biology.
Nanobiotechnology	Applies the tools and processes of nano/microfabrication to build devices for studying biosystems and applications in drug delivery, diagnostics etc.

Source: OECD (2005).

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[2] Statistics Canada defines biotechnology as the "application of science and engineering in the direct or indirect use of living organisms or parts of organisms in their natural or modified forms in an *innovative manner* in the production of goods and services or to improve existing processes" (Traoré, 2004, p. 8). Although this definition is quite similar to the OECD's, it emphasizes innovative processes or products, while the OECD definition makes no such distinction.

The main objectives of this report are to estimate the current contribution of *modern biotechnology* to the Canadian economy, and to project its possible role to 2030. Since the single definition of biotechnology provided previously leaves room for possible misunderstandings, the OECD also has a list-based definition, which breaks down modern biotechnology techniques into seven main categories: DNA/RNA; proteins and other molecules; cell and tissue culture and engineering; process biotechnology techniques; gene and RNA vectors; bioinformatics; and nanobiotechnology.[3] Exhibit 1 shows the techniques included in each category.

Genomics (the study of the genomes of organisms), proteomics (the study of the structure of proteins), and metabolics (the examination of how cells function) form the core knowledge base used in modern biotechnology. Biotech R&D and applications share not only a common knowledge base, but can also (potentially) use the same set of tools and techniques, which comprise biotech's *platform technologies*. Examples of such technologies include:

- DNA sequencing "identifies the order of nucleotides (the base sequence) in a DNA molecule" (OECD, 2009, p.53), allowing for mutations and errors in the genetic coding of individuals to be identified easily;

- Genetic modification (GM) imparts a certain trait to an organism by inserting genes from a second organism into its DNA;

- DNA synthesis is "the assembly of a known sequence of DNA using synthetic chemicals"(OECD, 2009, p. 102); and

- RNA interference (RNAi) can deactivate targeted genes by "saturating cells with small, targeted segments of double-stranded RNA" (OECD, 2009, p. 52).

Modern biotechnology has applications in three broad domains: 1) agriculture and related activities; 2) medicine and healthcare; and 3) industry, energy and environment.[4]

Agricultural biotechnology is currently used as a means of developing new varieties of plants and animals (examples include herbicide tolerant plants, and crops with increased yield), diagnostic tools (which detect diseases by identifying the presence of certain genes or proteins),

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[3] Statistics Canada's list definition is practically the same as the OECD's, except for small differences such as calling the "Gene and RNA vectors" category by another name ("Sub-Cellular Organisms"), and including bioinformatics, nanobiotechnologies, and environmental biotechnology in the "Other" (biotechnologies) category. This similarity is not surprising, given that Statistics Canada led the development of the OECD biotech programme. Statistics Canada's list definition can be found at: http://www.statcan.gc.ca/imdb-bmdi/instrument/4226_Q1_V5-eng.pdf.

[4] A detailed list of biotech applications in those three domains is given in BIO (2008).

and treatments for veterinary illnesses. Exhibit 2 details the main applications of biotechnology in agriculture and related activities.

Exhibit 2: Biotechnology Applications in Agriculture and Related Activities

	Processes and Techniques	Products
Crop Production	- Plant cells and tissues are used in ***in vitro* propagation (micropropagation)**.[5] - **Marker assisted selection (MAS)** uses "biological or chemical markers to identify traits" (OECD, 2009, p. 55), and can reduce the time necessary to create new varieties of plants based on conventional breeding techniques.	- Development of **new crop varieties** through genetic modification (GM). Most approved GM crops are either herbicide tolerant or pest resistant (in 2007, 35 per cent of the 85 approved GM crops in the United States were herbicide tolerant, 34 per cent pest resistant, and 7 per cent had both traits). Although more than a dozen plant species have received regulatory approval, the majority of GM crops (by hectare planted) are different varieties of canola, corn, soybeans, and cotton (OECD, 2009, pp.55-57). - **Biotech based plant diagnostic tests** help detect diseases by identifying the presence of certain genes or proteins. E.g. Enzime-linked immunosorbent assay (ELISA) tests are used to detect the presence of specific antibodies or antigens in a sample; polymerase chain reaction (PCR) tests identify genetic variations in a DNA sequence.
Livestock Production	- The use of **marker assisted selection (MAS)** in animal breeding allows for faster and more accurate breeding efforts. So far, this is the largest commercial application of animal breeding. E.g. MAS is used by pig breeders to detect genetic problems. - **Embrio transfer (ET)** techniques are the main propagation techniques used in livestock breeding. Currently, it is used mainly in cattle, and its use is limited due to high costs (Zika *et al.*, 2007, p. 64). **Somatic nuclear transfer cloning** is also an important animal propagation technique, but it is still too expensive to be used in basic animal breeding (OECD, 2009, p. 61).	- **Animal diagnostics and therapeutics** help detect and treat animal diseases. According to the OECD (2009), the 160 veterinary kits available in 2007 used 69 different methods, 60 per cent of which were based in biotechnology (pp. 61-62). So far, only a small number of biopharmaceuticals and biovaccines have been approved for animal use.
Aquaculture	- **Ploidy induction** is used in aquaculture to increase the sets of chromosomes in a fish from two to three. This condition, known as triploidy, can lead to fish that grow faster and have, in general, higher carcass yield, survival rates, and flesh quality. - **Sex manipulation** using hormonal treatments can create monosex fish populations, which lead to "faster growth, reduced aggression and delayed maturation" (Zika *et al.*, 2007, p. 54). - **DNA fingerprinting** is used to identify stocks of migrating fish and can be used to "manage wild stocks and close fisheries when stocks become endangered" (OECD, 2009, p. 62).	- Development of **new varieties of fish** through genetic modification (generally aiming at faster growth rates). Although there are commercialized varieties of GM fish used as pets, no GM fish varieties have been approved as food yet. - **Diagnostics and vaccines** help detect and treat diseases that afflict fish**.**
Forestry	- **Tree Propagation** applications with the objective of generating "identical seedlings of genetically superior trees" (OECD, 2009, p. 59) are still at an early stage	- Applications in developing **new tree varieties** are at a research stage. E.g. Trees with modified lignin to reduce paper production costs, faster-growing trees for timber and biofuel production.

Source: Zika *et al.* (2007), and OECD (2009).

[5] "Propagation techniques are used to increase the number of individuals with favourable genetic characteristics at a faster pace and in a cost-effective manner, and as such support breeding efforts." (Zika *et al.*, 2007, p. 53).

In medicine and healthcare, biotechnology is used to develop preventatives (e.g. prophylactic vaccines), therapeutic techniques (which include experimental treatments such as cell and tissue engineering, as well as biopharmaceuticals and small-molecule therapeutics), and diagnostic methods (Exhibit 3).

Exhibit 3: Biotechnology Applications in Medicine and Healthcare

	Processes and Techniques	Products
Preventatives		- **Prophylactic vaccines** based on biotechnology can be used to accurately produce pathogens' proteins in order to cause an immune reaction (Zika *et al.*, 2007, p. 31). E.g. There are already marketed recombinant vaccines for cholera and hepatitis B.
Diagnostics	- ***In vivo* (invasive) diagnostic methods**, which are used primarily to detect cancer. - ***In vitro* diagnostic methods** allow for early detection and diagnosis of illnesses, and enable specialists to determine the likelihood an individual will develop a particular disease or condition. **Nanomedicine** can be used to improve the efficiency of in vitro diagnostic tools.	
Therapeutics	- **Pharmacogenetics research** (the study of the interaction between genes and drugs) is used to identify how a patient's genetics affects treatments, helping to determine appropriate dosages, as well as identifying patients' "susceptibility to adverse drug reactions"(OECD, 2009, p. 69). - There are several emerging **biotechnology based therapeutic methods**, which we describe below. It is important to keep in mind that most of those methods are at an early stage of development (even though some of their applications are already marketed). - **Gene therapy** treatments work through the introduction of a gene into a cell (e.g. replacing a "defective gene by (...) a functional one") (Zika *et al.*, 2007, p. 43). - **Cell-based therapies** are a novel therapeutic approach, and include autologous skin replacements, cartilage and bone products. (Zika *et al.*, 2007, p.41). - **Stem-cell**[6] **applications** range from bone marrow transplants to gene therapy and cell-based therapies. There is ongoing research on stem-cell based treatments for Alzheimer's, Parkinson's, and many other diseases. - **Antisense and RNA interference** are currently used in the treatment for HIV/AIDS patients. (Zika *et al.*, 2007, p.44)	- **Biopharmaceuticals** such as insulin, monoclonal antibodies, interferons, etc. (Zika *et al.*, 2007, p. 22). When coupled with **nanoparticles**, the effectiveness of biopharmaceuticals can be significantly increased whilst reducing the damage inflicted on surrounding cells. In 2009, the Canadian biopharmaceuticals sector generated $21.5 billion, while global biopharmaceutical sales were estimated to be more than US$800 billion. - **Small molecule drugs** are developed using organic compounds with low molecular weight (normally less than 500 daltons). According to the OECD (2009), 86 per cent of all new chemical entities approved since 1999 are small molecule drugs (p. 66). Biotechnology can be applied to "develop, produce, test and manage the use of small molecule drugs" (OECD, 2009, p. 66). Among its many uses, small molecule drugs are used in the treatment of HIV/AIDS, alcohol dependence, type II diabetes, and hypertension. - Biobased **therapeutic vaccines** treat "an already existing condition" (Zika, p.44). The first biotech based therapeutic cancer vaccine was approved by the FDA in April 2010. It uses recombinant DNA protein and treats prostate cancer.

Source: Zika *et al.* (2007), and OECD (2009).

[6] Stem cells are "non-specialized cells that have the capacity for self-renewal and the ability to differentiate under certain physiologic or experimental conditions, into various types of specialized cells" (Zika *et al.*, 2007, p. 42).

Finally, biotechnology has several industrial, environmental and energy-related applications. It is used to produce goods such as fuels (e.g. bioethanol and biodiesel), bulk chemicals (e.g. citric acid), specialty chemicals (such as enzymes, amino acids, vitamins, antibiotic derivatives), and biopolymers. Moreover, biotechnology processes are proving to be an alternative to traditional chemical processes used in the production of foodstuffs, pulp and paper, detergents, textiles, and chemicals (Exhibit 4).

BOX 1: The Three Waves of Biotechnology

The history of biotechnology is frequently divided into three waves. Despite having started at different points in time, each of the three waves now overlaps and impacts one another.

The first wave, the green wave, relates to agricultural biotechnology. Biotechnology has long been used to improve breeding and propagation techniques. More recently, genetic modification has allowed for the alteration of genes in order to obtain a desirable outcome. Crops can now be genetically modified so that they become herbicide tolerant, pest resistant or express a certain agronomic trait.

The second wave, the red wave, pertains to pharmaceuticals and medical biotechnology. Biotechnology has been used in the development of novel therapeutic techniques, diagnostic methods, and vaccines. Pharmaceuticals produced through the use of biotechnology include both small molecule and large molecule drugs. A wide range of experimental therapies are based on biotechnology, including cell-based therapies, genetic therapies, and antisense and RNA interference therapies. Prophylactic and therapeutic vaccines, as well as *in vivo* and *in vitro* diagnostics also make up part of the red wave of biotechnology.

The more recent wave, the white wave, marks the beginning of industrial biotechnology. The study of genomics has opened a wide range of possibilities related to the use of biotechnology in industrial production: from the use of enzymes in food manufacturing, to the production of chemicals and bioplastics; the development of biofuels, such as bioethanol and biodiesel; biomining techniques that allow for metals to be extracted with a much higher degree of success than previous methods allowed for; improved bioremediation techniques, among many other possible applications (OECD, 2009, p.74).

Exhibit 4: Biotechnology Applications in Industry

	Processes and Techniques	Products
Energy		- Production of **fuels and power** from biomass in bio-refineries. Currently, the main types of biofuels in use are **bioethanol** and **biodiesel**. In 2008, the United States and Brazil accounted for 86 per cent of the ethanol production in the world, while the European Union was responsible for approximately 60 per cent of the world's biodiesel production. Canada's production of ethanol represented 1.5 per cent of the world production, while its biodiesel production accounted for 0.7 per cent of the world production (bioethanol data from RFA, 2010, p. 22; biodiesel data from Index Mundi).
Environment	- **Bioremediation** "uses micro-organisms to reduce, eliminate, contain, or transform to benign products contaminants present in soil, sediments, water, or air" (DOE, 2003). Examples of bioremediation technologies include **phytoremediation** (the use of plants in the treatment of environmental problems), and **biofiltration** (the use of living material to isolate and decompose pollutants).[7]	- **Biosensors** are analytical devices that "use an immobilised biologically-related agent (such as an enzyme, antibiotic, organelle or whole cell) to detect or measure a chemical compound" (FAO, n.d.).
Mining and Resource Extraction	- **Biomining** techniques are starting to be used in metal ore mining. Examples of such techniques are **bioleaching**, which uses "bacteria in liquid solution to extract metals from ore and is employed in copper and gold mining operations" (OECD, 2009, p. 77), and **bio-oxidation**, which "uses bacteria to release encapsulated metals of interest (OECD, 2009, p. 77). Compared to traditional techniques, both bioleaching and bio-oxidation have extremely high recovery rates (85-95 per cent versus 15-30 per cent in the case of gold recovery). - **Microbial enhanced oil recovery (MEOR)** makes use of micro-organisms to improve the efficiency of oil extraction, increasing the quantity of oil recovered from wells.	
Manufacturing	- **Enzymes**[8] are used as catalysts in the production processes of several industrial sectors. In particular, they are used in the production of: a) food and feed; b) detergents; c) textiles; d) pulp and paper. The advantages of biotechnology over traditional chemical processes are three-fold: 1) Improved efficiency through more specific reactions; 2) Lower energy consumption due to the capacity of enzymes to work at room temperature; 3) Reduced amounts of waste (Zika *et al.*, 2007, p. 83).	- **Bulk chemicals**, e.g. citric acid; **specialty chemicals**, e.g.enzymes, amino acids, acids, vitamins, and antibiotic derivatives. - **Bioplastics** are the most important biomaterial currently in use. They are manufactured from biopolymers, and used in packaging and catering items (such as cutlery and bowls). Some bioplastics are biodegradable. Others, while not biodegradable, are recyclable. - Biotechnology can also be used to produce biobased **fabrics**, and **durable goods** such as car components. - In food manufacturing, biotechnology is used to produce **functional foods** and **nutraceuticals**. Functional foods can be consumed like conventional foods while providing physiological benefits and/or reducing the risk of chronic diseases. E.g. Corn and soy with stanol ester, which reduces cholesterol. Nutraceuticals are derived from foods and are generally sold in medicinal form. Like functional foods, they have physiological benefit. E.g. Omega-3 from fish oils.

Source: Zika *et al.* (2007), and OECD (2009).

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[7] Although bioremediation techniques do not necessarily use modern biotechnology, its use can increase the overall efficiency of bioremediation methods.

[8] "Enzymes are proteins that can repeatedly catalyse biochemical reactions without being damaged by those reactions" (OECD, 2009, p. 74)

B. Data Sources

As Traoré (2004) notes, modern biotechnology is best understood as a cross-sectoral/cross-industrial activity. There is no single NAICS[9] code that encompasses all firms that use and develop biotechnology applications. This makes it a major challenge to gather detailed and reliable statistics on biotechnology.[10]

In Canada, the main source of biotechnology data was Statistics Canada's Biotechnology Use and Development Survey (BUDS). This survey was conducted biannually from 1999 to 2005, after which it was terminated due to lack of funding.[11] Its focus was on innovative biotech firms, i.e. firms that were developing at least one new biotech product or process. In this sense, the survey probably *underestimated* biotechnology activity, because data on firms that used modern biotechnology but were not developing new processes/products were not included in the overall results.

Exhibit 5: NAICS Codes Included in Statistics Canada's Biotechnology Use and Development Survey

NAICS code	Activity
1125	Animal Aquaculture
2111	Oil and Gas Extraction
221112	Fossil Fuel Electric Power Generation
221119	Other Electric Power Generation
311	Food Manufacturing
321216	Particle Board and Fibreboard Mills
3221	Pulp, Paper and Paperboard Mills
325	Chemical Manufacturing
4145	Pharmaceuticals, Toiletries, Cosmetics and Sundries Wholesaler Distributors
4183	Agricultural Supplies Wholesaler Distributors
5417	Scientific Research and Development Services
6215	Medical and Diagnostic Laboratories

* Excluding sugar and confectionery product manufacturing (3113), bakeries and tortilla manufacturing (3118), and other food manufacturing (3119).

Source: Statistics Canada, Biotechnology Use and Development Survey, http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getDocumentation&Item_Id=41251&TItem_Id=15015&lang=en&db=imdb&adm=8&dis=2.

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[9] The acronym NAICS refers to the North American Industry Classification System. For more information on NAICS, see Statistics Canada (2007).

[10] For more on the challenges related to analyzing and measuring the role of modern biotechnology in the economy, see de la Mothe and Niosi (2000).

[11] Statistics Canada currently conducts two related surveys: 1) The Bioproducts Production and Development Survey, sponsored by Agriculture and Agri-Food Canada. Bioproducts are defined as "products other than food, feed and medicines that are made directly or indirectly from biomass" (Sparling *et al.*, 2009, p. 3). Although there is significant overlap between the "biotech sector" and the "bioproducts sector", not all biotech firms are classified as bioproduct firms, and vice-versa. More information on this survey can be found at: http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5073&lang=en&db=imdb&adm=8&dis=2; 2) The Functional Foods and Natural Health Products Survey. Again, a significant share of the firms included in this survey would be considered part of the "biotech sector" as defined by BUDS, but not all. For more information on this survey, see: http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5038&lang=en&db=imdb&adm=8&dis=2.

The survey consisted of two stages. In the first stage, a simple questionnaire was sent to firms belonging to certain NAICS categories in order to identify if those firms used or developed biotechnology processes or products (see Exhibit 5 for a list of the NAICS categories included). One of the questions asked was: "Does your firm currently use or develop biotechnology activities?" The firms that answered yes to this question were sent another, much more detailed, questionnaire that inquired about the number of employees actively engaged in biotech activities, the salaries of those employees, biotech revenues, the kind of products/processes the firm was developing, etc.[12] The survey did not include non-profit organizations, universities, government laboratories, hospitals, and firms that used only traditional biotechnologies.[13] The key results of BUDS are discussed in McNiven (2001), McNiven, Raoub and Traoré (2003), Raoub, Salonius and McNiven (2005), and Lomno and McNiven (2007).

The main source for international biotechnology statistics is the OECD Biotechnology Statistics Program. The most recent report (OECD, 2009a) provides data for 22 OECD countries and four non-member countries, obtained from national surveys (see Appendix Table 1 for details).[14] The OECD differentiates between three types of biotechnology surveys: 1) *dedicated surveys* are specifically interested in biotechnology firms; 2) general *R&D surveys* that include questions on biotech R&D; 3) *databases* include data on biotechnology firms from a variety of secondary sources. Of the 26 countries included in the report, 14 ran R&D firm surveys, and 12 conducted dedicated surveys (in addition to conducting a biotech survey, four countries also constructed biotech databases). According to this categorization, Statistics Canada's Biotechnology Use and Development Survey is a dedicated survey.

The OECD defines a biotechnology firm as any firm that uses biotechnology to produce goods/services or to conduct R&D. Of course, there is a large variation on the extent to which a firm's economic activity is attributable to biotechnology. For some firms, biotechnology represents the core of their activities, while for others it accounts for only a small share of total economic activity. Although the national biotechnology survey of some countries gathers data for all firms engaged in biotechnology, most of the national surveys focus on one of two main subgroups of biotech firms:

- *Dedicated biotech firms* are those whose main activity entails the application of biotechnology processes and techniques to produce goods/services or R&D;

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[12] The first stage questionnaire can be found at http://www.statcan.gc.ca/imdb-bmdi/instrument/4226_Q2_V1-eng.pdf. The second stage questionnaire can be found at http://www.statcan.gc.ca/imdb-bmdi/instrument/4226_Q1_V5-eng.pdf.

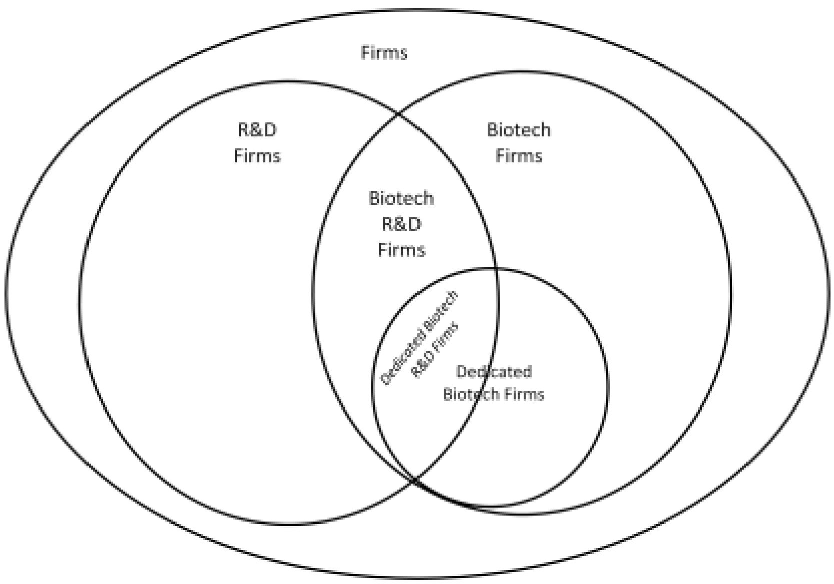
[13] For a list of modern biotechnologies, see Exhibit 1.

[14] For a discussion on the challenges underlying the gathering of internationally comparable biotech data, see Pattinson *et al.* (2001), and OECD (2005).

- *Biotech R&D firms*, as the name implies, are engaged in biotech R&D. If 75 per cent or more of the firm's research expenditures are devoted to biotech, then the firm is referred to as a *dedicated biotech R&D firm*.

Of the 26 countries covered, 9 countries covered all biotech companies in their surveys, 15 focused on biotech R&D firms, and 2 gathered data only on dedicated biotech firms. As mentioned previously, Statistics Canada's BUDS focuses on innovative biotech firms, i.e. firms that are developing at least one new biotech-related product/process. In the first part of their OECD report, van Beuzekom and Arundel (2009) correctly identify these firms as biotech R&D firms (p. 12). For some reason, however, the rest of the report refers to Canadian firms as dedicated biotech firms, which appears incorrect. Looking at Exhibit 6, it becomes clear that the main problem with surveys that accounted for only biotech R&D firms or dedicated biotech firms is that they do not capture the entire range of firms that produce biotech-related goods and services in the economy.

Exhibit 6: Biotechnology Firms



Source: Adapted from van Beuzekom and Arundel (2009), p. 10.

III. An Overview of the Canadian Biotechnology Sector

This section provides an overview of the Canadian biotechnology sector, and analyzes the main economic indicators that are used in this report to measure the sector's contribution to the Canadian economy. We also compare the Canadian biotech sector to that of other OECD countries. The indicators discussed here include number of firms, employment, R&D expenditures, and revenues in the biotech sector. As mentioned in the previous section, data for Canada comes from Statistics Canada's Biotechnology Use and Development Survey, and spans the 1999-2005 period (or, in some cases, the 1997-2005 period). International comparison data are taken from the OECD Biotechnology Statistics Program.

A. Number of Biotech Firms

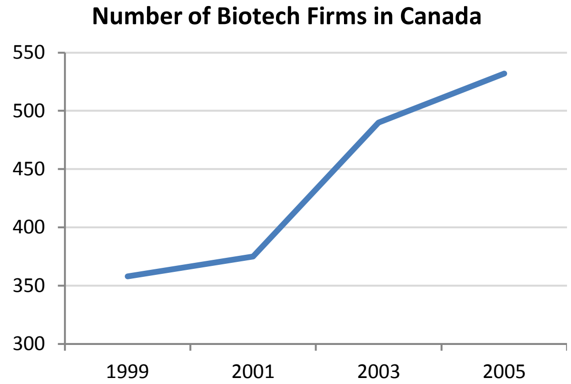
In 2005, Canada had 532 innovative biotech firms (or biotech R&D firms, using the OECD classification), up from 358 in 1999, which represents an increase of 48.6 per cent (Table 1, Chart 1). Biotech firms were largely concentrated in Quebec, Ontario, and British Columbia, which accounted jointly for 78.8 per cent of innovative biotech firms in Canada. It is interesting to note that Quebec's share in the total number of biotech firms increased from 29.9 per cent in 1999 to 34.0 per cent in 2005, a 4.1 percentage point increase, while Ontario's share fell from 31.0 per cent to 27.1 per cent, a 3.9 percentage point drop. Despite this small reduction in Ontario's share of total biotech firms in Canada, the province still had the second largest number of biotech firms in the country.

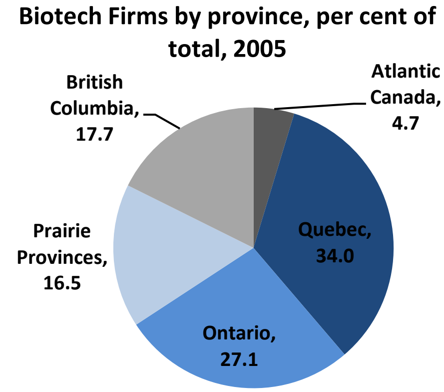
Table 1: Innovative Biotechnology Firms by Size, Canada, 1999-2005

	1999	2001	2003	2005	1999-2005
		(number of firms)			(per cent change)
Innovative Biotechnology Firms	358	375	490	532	48.6
Atlantic	19	23	25	25	31.6
Quebec	107	130	146	181	69.2
Ontario	111	101	129	144	29.7
Manitoba	6	11	21	19	216.7
Saskatchewan	16	17	34	18	12.5
Alberta	28	24	44	51	82.1
British Columbia	71	69	91	94	32.4
		(share of total)			(percentage point change)
Innovative Biotechnology Firms	100.0	100.0	100.0	100.0	0.0
Atlantic	5.3	6.1	5.1	4.7	-0.6
Quebec	29.9	34.7	29.8	34.0	4.1
Ontario	31.0	26.9	26.3	27.1	-3.9
Manitoba	1.7	2.9	4.3	3.6	1.9
Saskatchewan	4.5	4.5	6.9	3.4	-1.1
Alberta	7.8	6.4	9.0	9.6	1.8
British Columbia	19.8	18.4	18.6	17.7	-2.2

Source: Statistics Canada, Biotechnology Use and Development Survey (CANSIM Table 358-0120).

Chart 1: Innovative Biotechnology Firms, Canada, 1999-2005





Source: Statistics Canada, Biotechnology Use and Development Survey (CANSIM Table 358-0120).

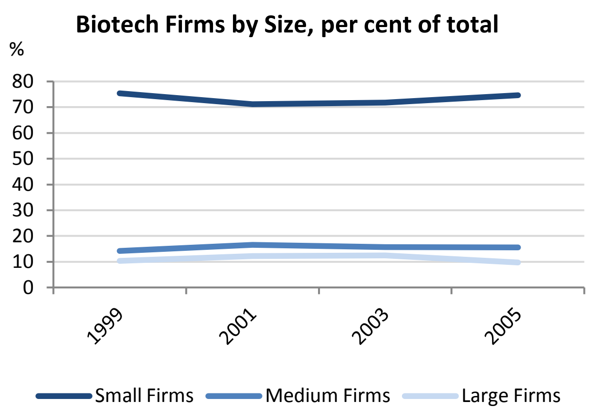
Of the 532 biotech firms, 397 were small firms (less than 50 employees), 83 were medium-sized firms (between 50 and 149 employees), and 52 were large firms (150 or more employees) (Table 2). Small firms represented 74.6 per cent of total biotech firms in Canada, followed by medium and large firms, which accounted for 15.6 and 9.8 per cent of total biotech firms, respectively. Chart 2 shows how these shares remained relatively stable throughout the 1999-2005 period.

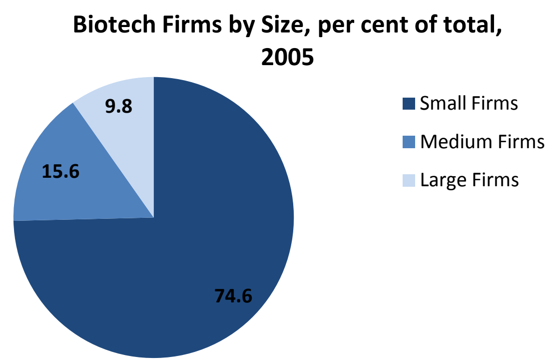
Table 2: Innovative Biotechnology Firms by Size, Canada, 1999-2005

	1999	2001	2003	2005	1999-2005
		(number of firms)			(per cent change)
Innovative Biotechnology Firms	358	375	490	532	48.6
Small Firms (0 to 49 employees)	270	267	352	397	47.0
Medium Firms (50 to 149 employees)	51	62	77	83	62.7
Large Firms (150 employees and over)	37	46	61	52	40.5
		(share of total)			(percentage point change)
Innovative Biotechnology Firms	100.0	100.0	100.0	100.0	0.0
Small Firms	75.4	71.2	71.8	74.6	-0.8
Medium Firms	14.2	16.5	15.7	15.6	1.4
Large Firms	10.3	12.3	12.4	9.8	-0.6

Source: van Beuzekom and Arundel (2009), p. 10.

Chart 2: Innovative Biotechnology Firms by Size, Canada, 1999-2005



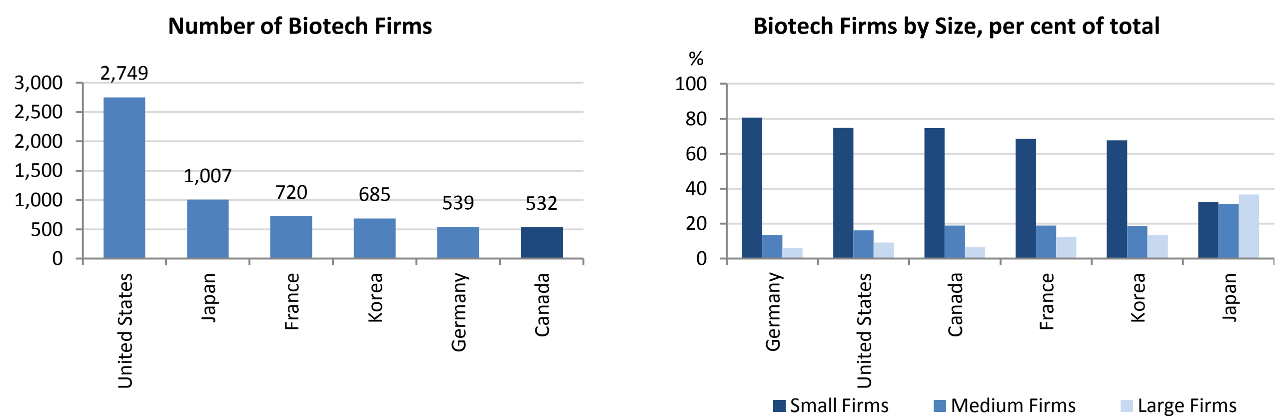


Source: Statistics Canada, Biotechnology Use and Development Survey (CANSIM Table 358-0120).

Chart 3 compares the number of biotech firms in Canada with that of other OECD countries. The United States had by far the largest number of biotech firms in the world in 2005 (2,749 firms), followed by Japan (1,007 firms), France (720 firms), South Korea (685 firms), Germany (539 firms), and Canada (532 firms). As we saw in the previous section, however, there are significant differences in how countries collect data on firms that use modern biotechnology. While data on Canadian, French, and U.S. biotech firms refer to only *biotech R&D firms* (to use the terminology proposed by the OECD), data on German, Japanese and Korean firms encompass *all* biotech firms in the country. Thus, the figures discussed above underestimate the actual number of biotech firms in Canada, the United States, France, and Germany. It is interesting to note, furthermore, that Canada is relatively "over-represented" in terms of biotech R&D firms when compared to the United States: although the Canadian economy is roughly equivalent to 10 per cent of the U.S. economy, the number of biotech R&D firms in Canada represented 20 per cent of the U.S. number.

In terms of firm size distribution, all of the countries depicted in Chart 3, with the exception of Japan, follow a pattern similar to the one observed in Canada, with small biotech firms representing between 67 and 80 per cent of total biotech firms in each country, followed by medium-sized firms, and large firms. Japan's distribution of biotech firms by size is unusual, with small, medium, and large biotech firms having approximately the same importance (albeit with a slight predominance of large firms).

Chart 3: Biotechnology Firms by Size, International Comparison, 2005



Notes: 1) Canadian, U.S., and French data refer to biotech R&D firms, while Japanese and Korean data refer to all biotech firms, and German data to dedicated biotech firms; 2) The OECD report defines small firms as having less than 50 employees, medium firms as having between 50 and 249 employees, and large firms as having 250 or more employees (for Japan, medium firms are defined as having between 50 and 300 employees, and large firms as having 301 or more employees).
Source: van Beuzekom and Arundel (2009), pp. 21-22.

Out of the 532 innovative biotech firms in Canada in 2005, the majority of the firms (58.3 per cent) were developing applications in medicine and healthcare, followed by firms involved in agriculture and related areas (20.1 per cent), and those engaged in industrial biotech (18.6 per cent) (Table 3). The remainder of the firms (3.0 per cent) developed applications related to platform technologies in biotech.

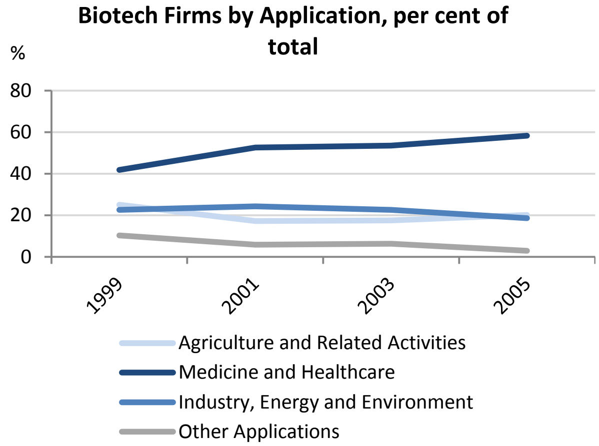
Table 3: Innovative Biotechnology Firms by Application, Canada, 1999-2005

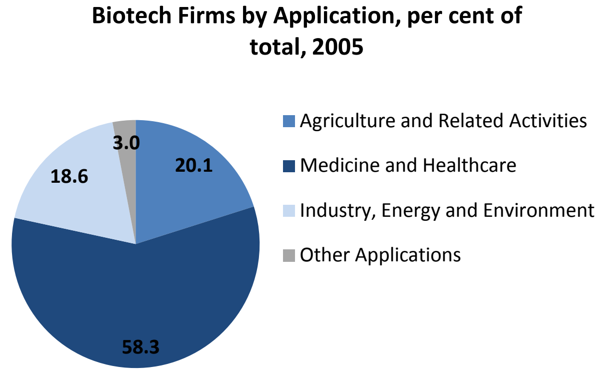
	1999	2001	2003	2005	1999-2005
	(number of firms)				(per cent change)
Innovative Biotechnology Firms	358	375	490	532	48.6
Agriculture and Related Activities	90	65	86	107	18.9
Medicine and Healthcare	150	197	262	310	106.7
Industry, Energy and Environment	81	91	111	99	22.2
Food and Beverages Processing	28	48	52	39	39.3
Industrial Processing	0	0	0	0	..
Natural Resources	18	10	21	21	16.7
Environment	35	33	38	39	11.4
Other	37	22	31	16	-56.8
	(share of total)				(percentage point change)
Innovative Biotechnology Firms	100.0	100.0	100.0	100.0	0.0
Agriculture and Related Activities	25.1	17.3	17.6	20.1	-5.0
Medicine and Healthcare	41.9	52.5	53.5	58.3	16.4
Industry, Energy and Environment	22.6	24.3	22.7	18.6	-4.0
Food and Beverages Processing	7.8	12.8	10.6	7.3	-0.5
Industrial Processing	0.0	0.0	0.0	0.0	0.0
Natural Resources	5.0	2.7	4.3	3.9	-1.1
Environment	9.8	8.8	7.8	7.3	-2.4
Other	10.3	5.9	6.3	3.0	-7.3

Notes: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: van Beuzekom and Arundel (2009), p. 64.

The number of firms engaged in medicine and healthcare biotech more than doubled over the 1999-2005 period, from 150 to 310. Meanwhile, the number of firms involved in agriculture and related activities, and industrial biotech rose at a much slower pace. This led to a significant increase in the share of medical biotech firms, from 41.9 per cent in 1999 to the aforementioned 58.3 per cent in 2006 (a 16.4 percentage point increase in only 7 years), while the share of agricultural, and industrial biotech firms declined (Chart 4). Another interesting development was the fall in the absolute number of firms under the "Other" category, which caused a sharp drop in its share of total biotech firms, from 10.3 per cent in 1999 to only 3.0 per cent in 2007.

Chart 4: Biotechnology Firms by Application, Canada, 1999-2005

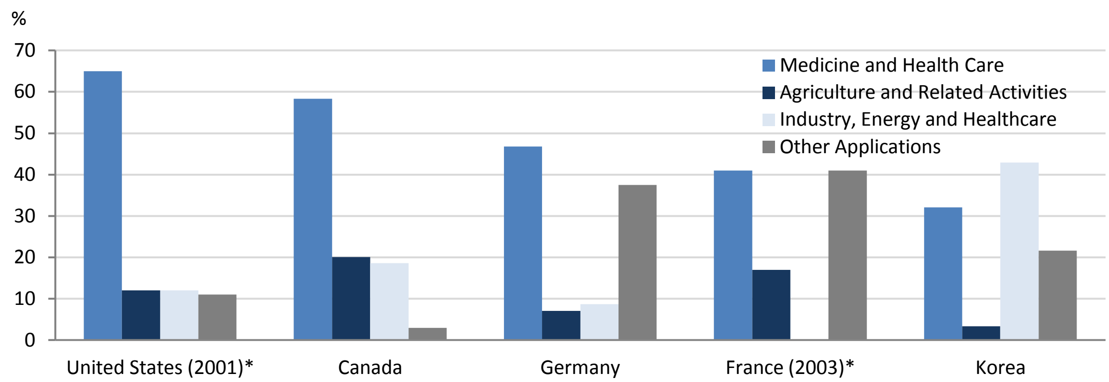




Notes: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: van Beuzekom and Arundel (2009), p. 64.

When comparing the distribution of biotech firms in Canada by area of application with that of other countries, we can see that, with the exception of Korea, biotech firms tended to concentrate in activities related to medicine and healthcare. Furthermore, in Canada, the United States, and Germany, the share of firms that fell under the "Agriculture and Related Activities" category was roughly the same as the share of firms classified under the "Industry, Energy and Environment" category.

Chart 5: Biotechnology Firms by Application, International Comparison, 2005



Notes: 1) Data for Canada, France, and the United States refer to biotech R&D firms, while data for Korea and Germany refer to all biotech firms; 2) Data for the United States and France refer to 2001 and 2003 (respectively); 3) For the United States and France, the "Agriculture and Related Activities" category also includes food processing applications; 4) For France, the "Other Applications" category includes firms that use and/or develop industrial biotech applications; 5) In general, however, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: Data for Canada, Korea, and Germany taken from van Beuzekom and Arundel (2009), p. 64; data for the United States and France taken from van Beuzekom and Arundel (2006), p. 40.

B. Employment

In 2005, 13,433 employees worked in innovative biotech firms in Canada, up from 7,749 employees in 1999, which represents an average annual growth rate of 9.6 per cent during the 1999-2005 period (Table 4) Of the total number of employees, 7,065 (52.6 per cent) worked in R&D.

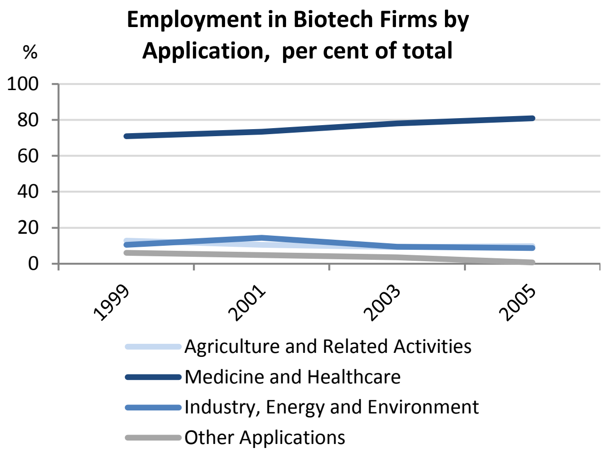
Biotech employment was heavily concentrated in the medicine and healthcare area, which was responsible for 80.9 per cent of total employment in biotechnology in 2005. This represents an increase of 10.1 percentage points from the (already high) share of 70.8 per cent observed in 1999 (Chart 6). Biotech employment in agricultural and industrial applications accounted for only 9.8 and 8.6 per cent (respectively) of total employment, less than their contribution in 1999 (12.7 per cent and 10.5 per cent, respectively). The contribution of other biotechnology applications to employment was negligible in 2005 (0.7 per cent), although this category played a somewhat relevant role in terms of employment in 1999 (6.0 per cent).

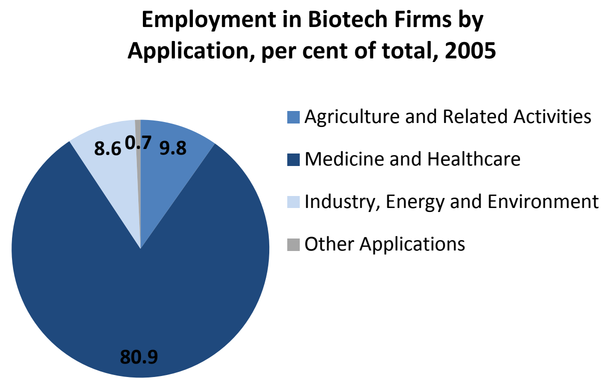
Table 4: Employment in Biotechnology Firms by Application, Canada, 1999-2005

	1999	2001	2003	2005	1999-2005
	(number of employees)				(compound annual growth rates, per cent)
Innovative Biotechnology Firms	7,749	11,863	11,863	13,433	9.6
Agriculture and Related Activities	985	1,249	1,085	1,317	5.0
Medicine and Healthcare	5,487	8,699	9,255	10,866	12.1
Industry, Energy and Environment	810	1,700	1,113	1,157	6.1
Food and Beverages Processing	338	973	747	438	4.4
Industrial Processing	0	0	0	0	..
Natural Resources	149	C	120	240	8.3
Environment	323	727	246	479	6.8
Other	467	C	410	93	-23.6
	(share of total)				(percentage point change)
Innovative Biotechnology Firms	100.0	100.0	100.0	100.0	0.0
Agriculture and Related Activities	12.7	10.5	9.1	9.8	-2.9
Medicine and Healthcare	70.8	73.3	78.0	80.9	10.1
Industry, Energy and Environment	10.5	14.3	9.4	8.6	-1.8
Food and Beverages Processing	4.4	8.2	6.3	3.3	-1.1
Industrial Processing	0.0	0.0	0.0	0.0	0.0
Natural Resources	1.9	..	1.0	1.8	-0.1
Environment	4.2	6.1	2.1	3.6	-0.6
Other	6.0	..	3.5	0.7	-5.3

Note: 1) Firms developing aquaculture applications were included in the “Other Applications” category instead of “Agriculture and Related Activities”; 2) Besides aquaculture, the “Other Applications” category includes mainly firms developing platform technologies, such as bioinformatics.
Source: van Beuzekom and Arundel (2009), p. 66.

Chart 6: Employment in Biotechnology Firms by Application, Canada, 1999-2005



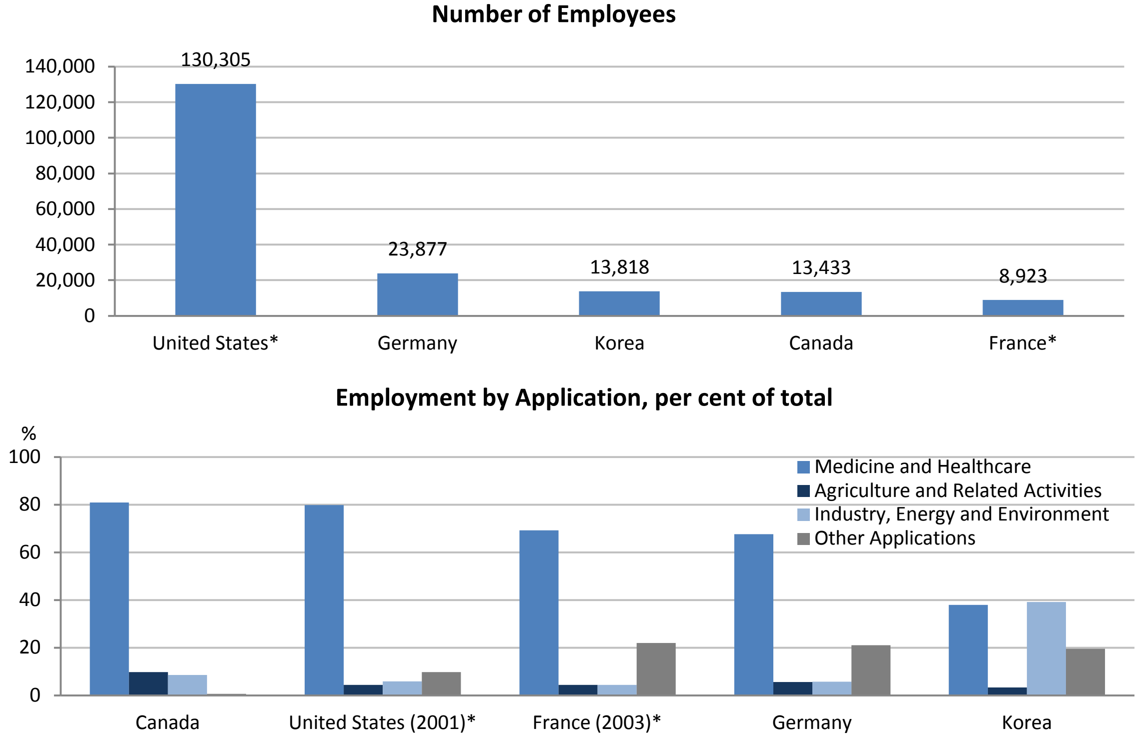


Note: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: van Beuzekom and Arundel (2009), p. 64.

An international comparison shows that, unsurprisingly, the number of biotech employees in the U.S. overshadowed biotech employee figures in every other country studied with 130,305 biotech employees (Chart 7). Germany had the second highest figure (23,877 employees), followed by Korea (13,818 employees), Canada (13,433 employees), and France (8,923 employees). Note that, in terms of employment in biotech R&D firms, Canada was not "over-represented" relatively to the United States (as was the case when we looked at number of biotech R&D firms in both countries): employment in biotech R&D firms in Canada corresponds to about 10 per cent that of the United States, as would be expected.

With the exception of Korea, medicine and healthcare comprised the largest share of biotech employees in every country studied. In Korea, industrial application made up the largest share of biotech employees. In every country studied (again, with the exception of Korea), the share of biotech employees in agricultural and industrial biotech applications were roughly the same.

Chart 7: Employment in Biotechnology Firms, International Comparison, 2005



Notes: 1) Data for Canada, France, and the United States refer to biotech R&D firms, while data for Korea and Germany refer to all biotech firms; 2) Data for the United States and France refer to 2001 and 2003 (respectively); 3) For the United States and France, the "Agriculture and Related Activities" category also includes food processing applications; 4) For France, the "Other Applications" category includes firms that use and/or develop industrial biotech applications; 5) In general, however, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: Data for Canada, Korea, and Germany taken from van Beuzekom and Arundel (2009), p. 66; data for the United States and France taken from van Beuzekom and Arundel (2006), p. 43.

Private companies, however, represent only part of the total biotech activity in Canada (and in the rest of the world), since the government sector and the higher education sector also actively conduct and promote biotech R&D. According to Statistics Canada (2005, 2009, 2010), the federal government employed 2,104 people in biotech-related activities in 2008, up from 1,141 people in 1998 (Table 5). The number of federal employees in biotech-related functions grew at an average annual rate of 6.31 per cent during the 1998-2008 period.

In 1998, 90 per cent of these federal employees were directly engaged in biotech R&D, but by 2008 this number had dropped to 65.3 per cent, a drastic decline of 24.7 percentage points. This happened because the number of employees involved in biotech R&D increased at a much slower pace than that of employees in related scientific activities during the period (2.96 per cent per year versus 20.40 per cent per year, respectively). [15] A breakdown by personnel type shows a decrease in the share of scientific and professional personnel (from 45.0 per cent in 1998

[15] Examples of "Related Scientific Activities" include tasks related to data collection, information services, special services and studies, education support, administration of extramural programs, etc.

to 36.8 per cent in 2008), and an increase in the shares of technical personnel (from 38.1 per cent in 1998 to 42.2 per cent in 2008) and other personnel (from 16.9 per cent in 1998 to 21.1 per cent in 2008).

Table 5: Federal Government Personnel Engaged in Biotechnology Science and Technology Activities, Canada, 1998-2008

	1998	2001	2003	2005	2008	1998-2008	1999-2005
	(number of full time equivalent employees)					(CAGR, per cent)	
Federal Government Personnel Engaged in Biotechnology	**1,141**	**1,505**	**1,708**	**1,868**	**2,104**	**6.31**	**7.15**
	Breakdown by Activity						
Research and Development	1,027	1,324	1,305	1,326	1,374	2.96	3.29
Related Scientific Activities	114	181	403	542	730	20.40	25.16
	Breakdown by Personnel Type						
Scientific and Professional Personnel	513	601	729	785	774	4.19	5.23
Technical Personnel	435	620	625	641	887	7.39	6.55
Other Personnel	193	284	354	442	443	8.67	12.59
	(share of total)					(percentage point change)	
Federal Government Personnel Engaged in Biotechnology	100	100	100	100	100	0.0	0.0
	Breakdown by Activity						
Research and Development	90.0	88.0	76.4	71.0	65.3	-24.7	-17.5
Related Scientific Activities	10.0	12.0	23.6	29.0	34.7	24.7	17.6
	Breakdown by Personnel Type						
Scientific and Professional Personnel	45.0	39.9	42.7	42.0	36.8	-8.2	-4.8
Technical Personnel	38.1	41.2	36.6	34.3	42.2	4.0	-1.2
Other Personnel	16.9	18.9	20.7	23.7	21.1	4.1	6.1

Note: 1) Examples of "Related Scientific Activities" include tasks related to data collection, information services, special services and studies, education support, administration of extramural programs, other administrative activities, etc.; 2) The "Other Personnel" category includes administrative and foreign service, administrative support, operational personnel, and military personnel.

Source: Statistics Canada (2005, 2009, 2010).

C. R&D Expenditures

Nominal business expenditures in biotech R&D (biotech BERD) in Canada reached $1,704 million in 2005, double the value of $831 million in 1999 (Table 6). The growth rate of 12.7 per cent per year experienced by biotech BERD over the 1999-2005 period was substantially higher than the one observed for total BERD in Canada, 7.0 per cent per year. This explains why the share of biotech BERD in terms of total economy BERD increased from 8.0 per cent in 1999 to 10.9 per cent in 2005, a 2.9 percentage point increase. Even though the rate of increase of biotech BERD remained above that of total BERD throughout the entire period, growth in biotech BERD slowed over time, from 62.0 per cent between 1999 and 2001 to 10.3 per cent in the 2001-2003 period, and 14.8 per cent in the 2003-2005 period.[16]

[16] Real biotech BERD (expressed in constant 2002 dollars) shows a similar trend. In 2005, there were $1,545 million in real biotech BERD, up from $881 million, which represents a growth rate of 9.8 per cent per year during the period. After an initial increase in real R&D expenditures of 53.5 per cent between 1999 and 2001, growth in the 2001-2003 period dropped to only 6.4 per cent. Growth remained relatively stable at that level during the 2003-2005 period, when biotech BERD increased by 7.4 per cent.

Table 6: Business Enterprise R&D (BERD) in Biotechnology by Application, Canada, 1999-2005

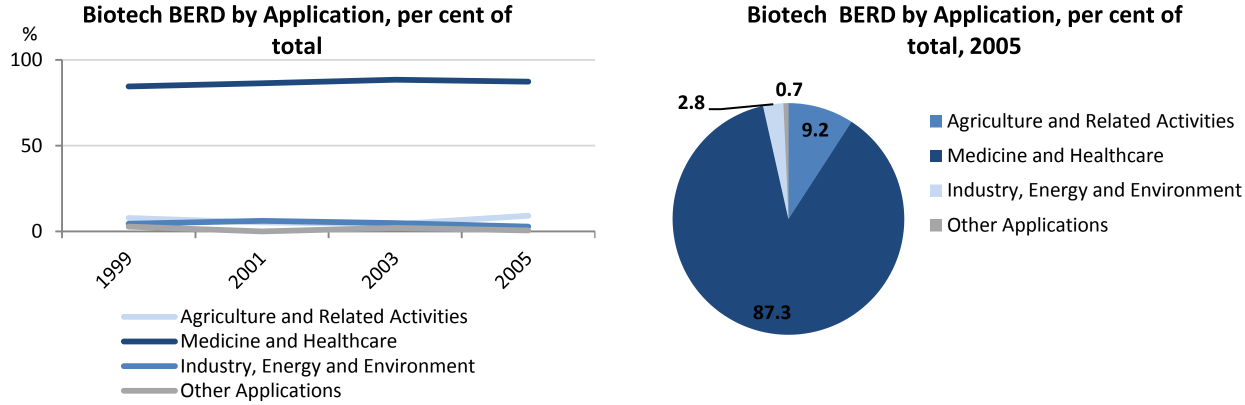
	1999	2001	2003	2005	1999-2005
	(millions of current dollars)				(compound annual growth rates, per cent)
Total Business Enterprise Expenditures in R&D	**10,399**	**14,266**	**14,095**	**15,638**	**7.0**
Total Biotechnology R&D	**831**	**1,346**	**1,485**	**1,704**	**12.7**
Agriculture and Related Activities	66	66	66	156	15.4
Medicine and Healthcare	703	1,177	1,314	1,488	13.3
Industry, Energy and Environment	38	78	73	48	4.0
Food and Beverages Processing	7	48	23	10	6.0
Industrial Processing	0	0	0	0	..
Natural Resources	28	13	13	24	-2.5
Environment	3	17	37	14	29.4
Other	24	25	32	12	-10.9
	(share of total)				(percentage point change)
Total Business Enterprise Expenditures in R&D	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**
Total Biotechnology R&D	**8.0**	**8.7**	**10.5**	**10.9**	**2.9**
	(share of total)				(percentage point change)
Total Biotechnology R&D	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**
Agriculture and Related Activities	7.9	4.9	4.4	9.2	1.2
Medicine and Healthcare	84.6	87.4	88.5	87.3	2.7
Industry, Energy and Environment	4.6	5.8	4.9	2.8	-1.8
Food and Beverages Processing	0.8	3.6	1.5	0.6	-0.3
Industrial Processing	0.0	0.0	0.0	0.0	0.0
Natural Resources	3.4	..	0.9	1.4	-2.0
Environment	0.4	1.3	2.5	0.8	0.5
Other	2.9	..	2.2	0.7	-2.2

Notes: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.

Source: van Beuzekom and Arundel (2009), p. 65. OECD figures were originally in PPP adjusted U.S. dollars. They were converted to non-PPP adjusted Canadian dollars using the adjustment factors found at http://stats.oecd.org/Index.aspx?datasetcode=SNA_TABLE4.

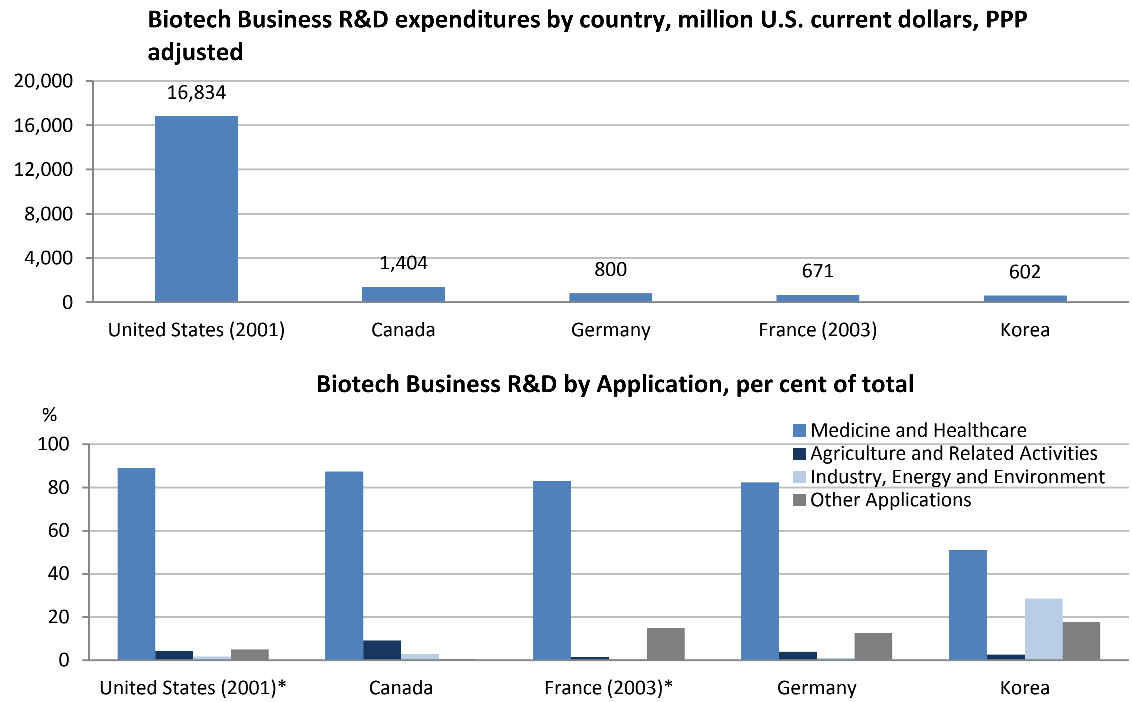
Biotech BERD was heavily concentrated in medicine and healthcare applications, which were responsible for 87.3 per cent of total biotech BERD in 2005, followed by applications in agriculture and related activities (9.2 per cent) and industry (2.8 per cent) (Chart 8). R&D in other biotech applications accounted for only 0.7 per cent of total biotech BERD. During the 1999-2005 period, there was a slight movement towards (more) concentration of biotech BERD in medicine and healthcare, as well as agriculture and related activities, with the share of biotech R&D in these areas increasing by 2.7 and 1.2 percentage points, respectively. Conversely, the shares of biotech R&D in industrial applications and other applications declined by 1.8 and 2.2 percentage points.

Chart 8: Business Enterprise R&D (BERD) in Biotechnology by Application, Canada, 1999-2005



Note: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: van Beuzekom and Arundel (2009), p. 65.

Chart 9: Business Expenditures in Biotech R&D, International Comparison, 2005



Notes: 1) Data for Canada, France, and the United States refer to biotech R&D firms, while data for Korea and Germany refer to all biotech firms; 2) Data for the United States and France refer to 2001 and 2003 (respectively); 3) For the United States and France, the "Agriculture and Related Activities" category also includes food processing applications; 4) For France, the "Other Applications" category includes firms that use and/or develop industrial biotech applications; 5) In general, however, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: Data for Canada, Korea, and Germany taken from van Beuzekom and Arundel (2009), p. 64; data for the United States and France taken from van Beuzekom and Arundel (2006), p. 40.

When comparing biotech R&D expenditures from a select group of developed countries, we can see that, with US$16,834 million (PPP adjusted), R&D expenditures in the United States dwarfed R&D expenditures in Canada (US$1,404 million), Germany (US$800 million), France (US$671 million), and Korea (US$602 million) (Chart 9). Note that Canada came second in terms of biotech R&D spending, even though Canadian spending represented only 8.3 per cent of U.S. spending. In every country studied, over 80 per cent of R&D expenditures were made in medicine and healthcare, except in Korea, where only 51.1 per cent of biotech R&D expenditures were made in medicine and healthcare.

Biotech BERD represents only a part of total biotech R&D. As mentioned previously, the government sector and the higher education sector also play an important role in conducting and promoting biotech R&D. According to Statistics Canada's Biotechnology Scientific Activities in the Federal Government Departments and Agencies, the federal government funded $937 million in biotech science and technology expenditures in 2008, up from $319 million in 1998, which entails a growth rate of 11.36 per cent per year during the 1998-2008 period (Chart 7). Federal biotech-related expenditures represented only 5.5 per cent of total federal expenditures in science and technology in 1998, but by 2008 they accounted for 8.9 per cent, a 3.4 percentage point increase.

Biotech R&D accounted for approximately 96 per cent of total (federal) biotech science and technology expenditures over the period, with related scientific activities accounting for the rest. The main performer of federal biotech R&D (and related scientific activities) was the higher education sector, responsible for 58.7 per cent of federal biotech expenditures in 2008, followed by the federal government itself (intramural expenditures), responsible for performing 29.0 per cent of federal biotech-related expenditures. The role of the higher education sector has increased significantly over time. In 1998, the sector was responsible for performing 49.0 per cent of federal biotech expenditures, 9.7 percentage points less than it performed in 2008. On the other hand, the federal government's role declined sharply, from performing 44.7 of federal biotech science and technology expenditures to performing the aforementioned 29.0 per cent, a 15.7 percentage point drop.

Table 7: Federal Government R&D Funding Expenditures in Biotechnology by Performer, Canada, 1998-2008

	1998	1999	2001	2003	2005	2008	1998-2008	1999-2005
	(millions of current dollars)						(CAGR, per cent)	
Total Federal Science and Technology Expenditures	**5,802**	**6,252**	**8,169**	**8,765**	**9,449**	**10,573**	**6.18**	**7.13**
Research and Development	3,578	3,890	4,989	5,462	6,042	6,655	6.40	7.61
Related Scientific Activities	2,224	2,362	3,180	3,303	3,407	3,918	5.83	6.30
Federal Biotech Science and Technology Expenditures	**319**	**392**	**557**	**756**	**865**	**937**	**11.36**	**14.10**
	Breakdown by Activity							
Research and Development	**309**	**380**	**538**	**723**	**823**	**891**	**11.18**	**13.77**
Related Scientific Activities	**10**	**13**	**19**	**33**	**42**	**45**	**15.84**	**22.40**
	Breakdown by Performer							
Intramural	143	185	233	256	277	271	6.62	7.02
Business Enterprise Sector	16	34	33	27	17	20	2.11	-11.39
Higher Education Sector	157	169	206	379	469	550	13.39	18.51
Other Performer	1	1	80	89	97	88	60.74	119.01
Foreign Performer	3	2	4	5	5	7	9.00	18.69
	(share of total)						(percentage point change)	
Total Federal Science and Technology Expenditures	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**	**0.0**
Federal Biotech Science and Technology Expenditures	5.5	6.3	6.8	8.6	9.2	8.9	3.4	2.9
	(share of total)							
Federal Biotech Science and Technology Expenditures	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**	**0.0**
	Breakdown by Activity							
Research and Development	96.7	96.8	96.6	95.6	95.1	95.2	-1.6	-1.7
Related Scientific Activities	3.3	3.2	3.4	4.4	4.9	4.8	1.6	1.7
	Breakdown by Performer							
Intramural	44.7	47.1	41.8	33.9	32.1	29.0	-15.8	-15.0
Business Enterprise Sector	5.1	8.8	6.0	3.6	1.9	2.1	-2.9	-6.9
Higher Education Sector	49.0	43.2	37.1	50.1	54.2	58.7	9.7	11.0
Other Performer	0.2	0.2	14.3	11.7	11.2	9.4	9.2	11.0
Foreign Performer	0.9	0.5	0.8	0.7	0.6	0.8	-0.2	0.1

Note: 1) The "Other Performer" category includes non-profit institutions, and provincial and municipal governments; 2) Examples of "Related Scientific Activities" include tasks related to data collection, information services, special services and studies, education support, administration of extramural programs, etc.
Source: Statistics Canada (2005, 2009, 2010).

D. Revenues

In nominal terms, Canadian biotech firms generated $53,614 million in revenues in 2005, almost three times its value in 1999, $18,730 (Table 8). Biotech-related revenues, however, were only $4,202 million, which represented 7.8 per cent of total revenues. Biotech-related revenues increased at an average annual rate of 13.7 per cent during the 1999-2005 period, slower than the growth rate experienced by total revenues of biotech firms (19.2 per cent). This explains why the share of biotech-related revenues in total revenues fell from 10.4 per cent in 1999 to the aforementioned 7.8 per cent (Chart 10). Even though biotech revenues have increased over time, the rate at which these revenues have increased has declined, from 82.3 per cent between 1999 and 2001 to 8.0 per cent in the 2001-2003 period, and 9.5 per cent in the 2003-2005 period.[17]

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[17] Real biotech revenues (expressed in constant 2002 dollars) show very similar trends. In 2005, there were $3,812 million in real biotech revenues, up from $2,074 million, which represents a growth rate of 10.7 per cent per year during the period. After an initial real revenue increase of 74.0 per cent between 1999 and 2001, real revenue increases in biotech became much more modest (3.0 per cent in the 2001-2003 period, and 2.5 per cent in the 2003-2005 period).

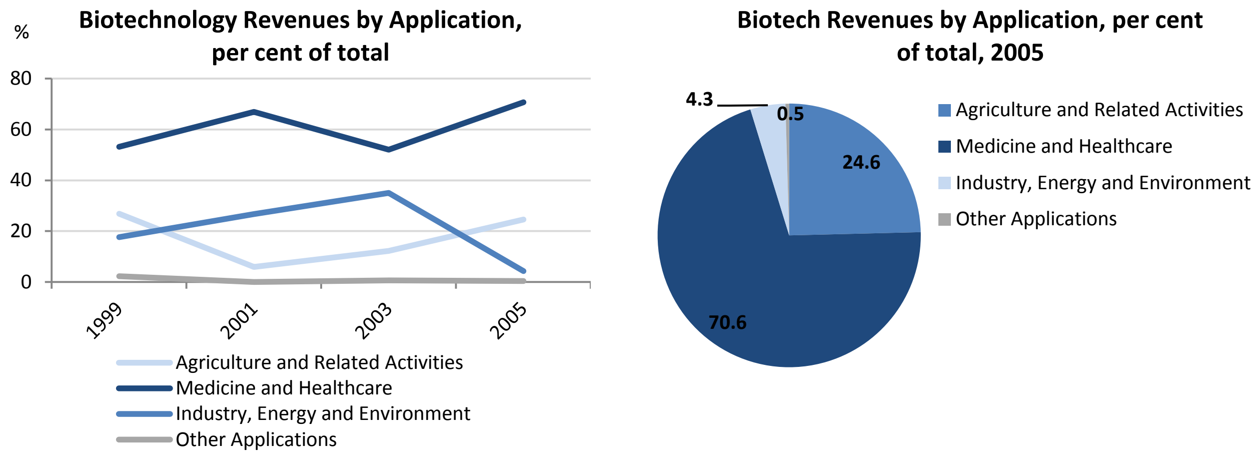
Table 8: Revenues of Biotechnology Firms by Application, Canada, 1999-2005

	1999	2001	2003	2005	1999-2005
	(millions of current dollars))				(compound annual growth rates, per cent)
Total Revenues of Biotech Firms	**18,730**	**26,747**	**30,802**	**53,614**	**19.2**
Total Biotech Revenues	**1,948**	**3,552**	**3,835**	**4,202**	**13.7**
Agriculture and Related Activities	524	198	469	1,034	12.0
Medicine and Healthcare	1,036	2,461	1,995	2,967	19.2
Industry, Energy and Environment	343	893	1,345	181	-10.1
Food and Beverages Processing	185	626	1,262	49	-19.9
Industrial Processing	0	0	0	0	..
Natural Resources	113	n.a.	47	40	-15.9
Environment	45	267	36	92	12.6
Other	45	n.a.	26	19	-13.3
	(share of total)				(percentage point change)
Total Revenues of Biotech Firms	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**
Total Biotech Revenues	**10.4**	**13.3**	**12.5**	**7.8**	**-2.6**
	(share of total)				(percentage point change)
Total Biotech Revenues	**100.0**	**100.0**	**100.0**	**100.0**	**0.0**
Agriculture and Related Activities	26.9	5.6	12.2	24.6	-2.3
Medicine and Healthcare	53.2	69.3	52.0	70.6	17.4
Industry, Energy and Environment	17.6	25.1	35.1	4.3	-13.3
Food and Beverages Processing	9.5	17.6	32.9	1.2	-8.3
Industrial Processing	0.0	0.0	0.0	0.0	0.0
Natural Resources	5.8	..	1.2	1.0	-4.8
Environment	2.3	7.5	0.9	2.2	-0.1
Other	2.3	..	0.7	0.5	-1.9

Note: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.

Source: van Beuzekom and Arundel (2009), p. 67. OECD figures were originally in PPP adjusted U.S. dollars. They were converted to non-PPP adjusted Canadian dollars using the adjustment factors found at http://stats.oecd.org/Index.aspx?datasetcode=SNA_TABLE4.

Chart 10: Biotechnology Revenues by Application, Canada, 1999-2005



Note: 1) Firms developing aquaculture applications were included in the "Other Applications" category instead of "Agriculture and Related Activities"; 2) Besides aquaculture, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.

Source: CSLS calculations based on van Beuzekom and Arundel (2009), p. 67.

The medicine and healthcare area was responsible for the majority of biotech revenues in 2005, $2,967 million, which represented 70.6 per cent of total biotech-related revenues. Revenues in this area increased at a robust growth rate of 19.2 per cent per year during the 1999-2005 period, significantly faster than total biotech-related revenues growth, and the reason why the area's share in total biotech revenues increased 17.4 percentage points during the period (from 53.2 per cent in 1999 to 70.6 per cent in 2005).

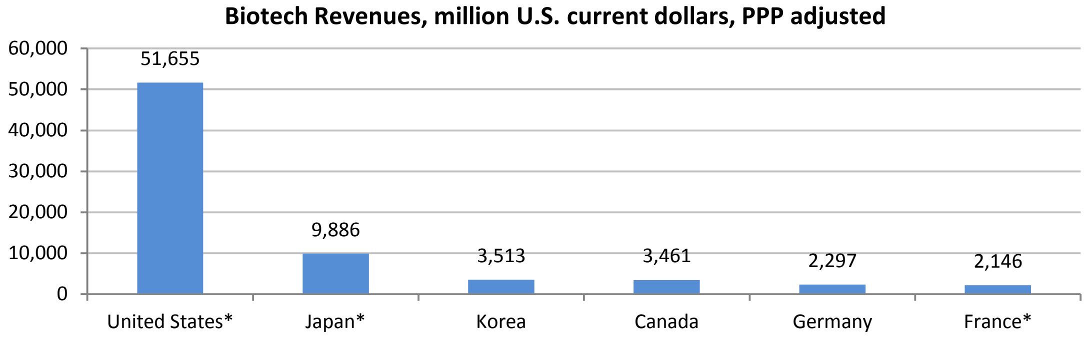
Agriculture was the second most important biotech application in terms of revenue, reaching $1,034 million in 2005 (24.6 per cent of total biotech revenues). Agricultural biotech revenues grew at an average annual rate of 12.0 per cent per year during the 1999-2005 period, slower than the growth of total biotech revenues. Consequently, the share of agricultural biotech revenues in total biotech revenues declined slightly in the period, from 26.9 per cent in 1999 to 24.6 per cent in 2005 (a 2.3 percentage point reduction).

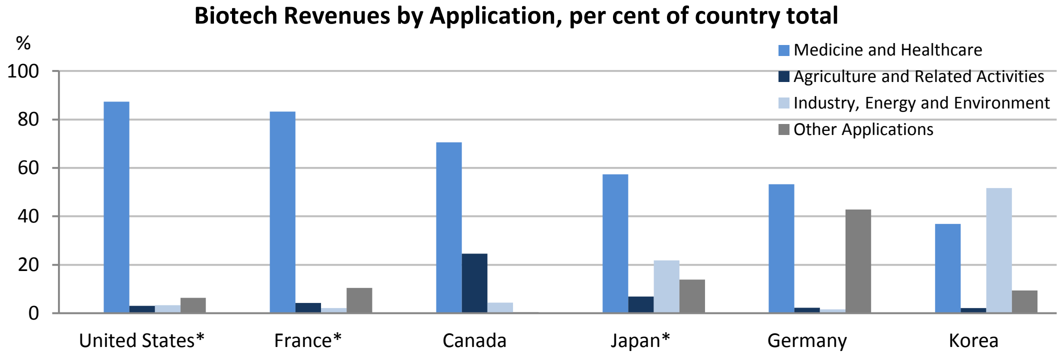
Industrial applications in biotech accounted for only $181 million in 2005, down from $343 million in 1999, a decline of 10.1 per cent per year during the period. This led to a marked drop in the share of industrial biotech in total biotech revenues, from 17.6 per cent in 1999 to only 4.3 per cent in 2005 (a 13.3 percentage point drop). The fall in revenue was caused by the drastic revenue drop in food and beverages processing, and natural resources applications. Revenues from environmental biotech applications actually increased over the period.

Other biotech applications were responsible for only $19 million in 2005 (0.5 per cent of total biotech revenues), down from $45 million in 1999 (2.3 per cent of total biotech revenues).

An international comparison makes it clear that biotech revenues were highest in the United States (US$51,655 million, PPP adjusted), followed by Japan (US$9,866 million), Korea (US$3,513 million), Canada (US$3,461 million), Germany (US$2,297 million), and France (US$2,146 million) (Chart 11). In Korea, industrial biotech made up the largest share of biotech revenues whilst in every other country studied medicine and healthcare applications constituted the most important source of biotech revenues.

Chart 11: Biotech Revenues, International Comparison, 2005





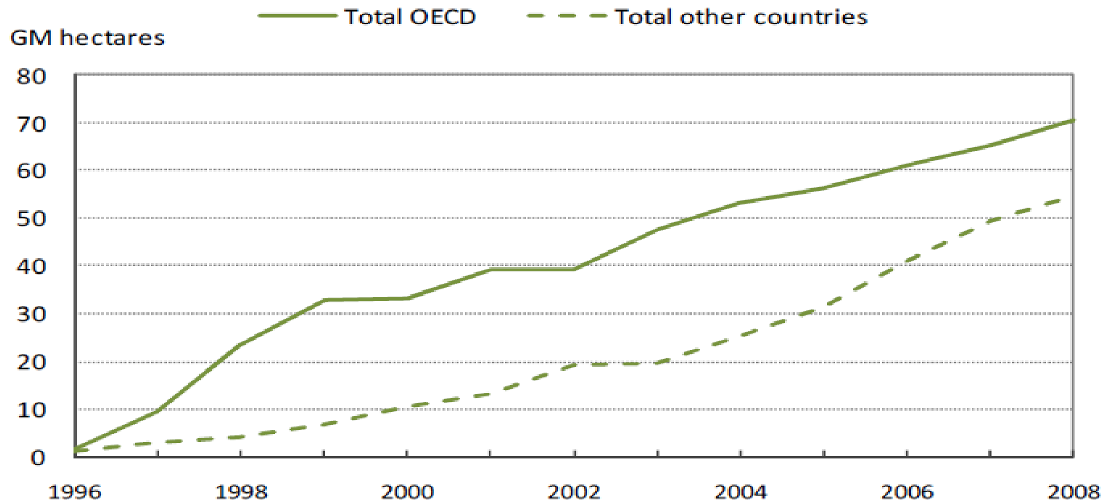
Notes: 1) Data for Canada, France, and the United States refer to biotech R&D firms, while data for Korea and Germany refer to all biotech firms; 2) Data for the United States and France refer to 2001 and 2003 (respectively); 3) For the United States and France, the "Agriculture and Related Activities" category also includes food processing applications; 4) For France, the "Other Applications" category includes firms that use and/or develop industrial biotech applications; 5) In general, however, the "Other Applications" category includes mainly firms developing platform technologies, such as bioinformatics.
Source: Data for Canada, Korea, and Germany taken from van Beuzekom and Arundel (2009), p. 67; data for the United States and France taken from van Beuzekom and Arundel (2006), p. 42.

E. GM Crops

One of the most important applications of biotechnology in agriculture is the development of new types of crops, with improved characteristics. Genetic modification (GM) can be used for a variety of purposes: it can make crops herbicide tolerant or pest resistant, improve a plant's agronomical or technical traits, etc.

Chart 12 plots the dramatic increase in GM crops over the 1996-2008 period, from little more than 1.7 million hectares in 1996 to 125 million hectares in 2008, which implies an average annual growth rate of 43 per cent over the period. Although developed countries are still responsible for the majority of GM crops produced in the world, developing countries seem to be quickly catching up.

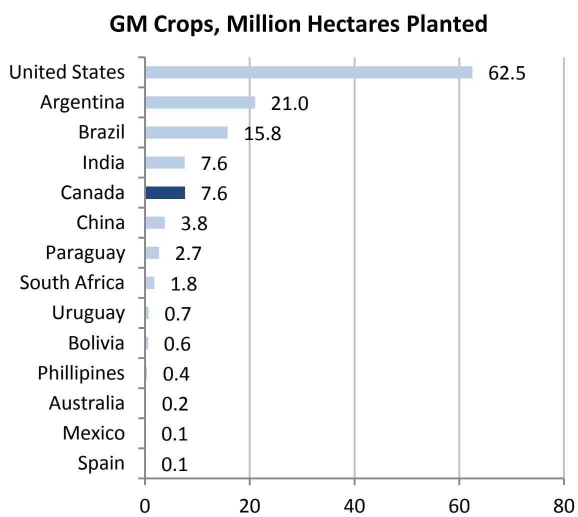
Chart 12: GM Crops, Million Hectares Planted, 1996-2008

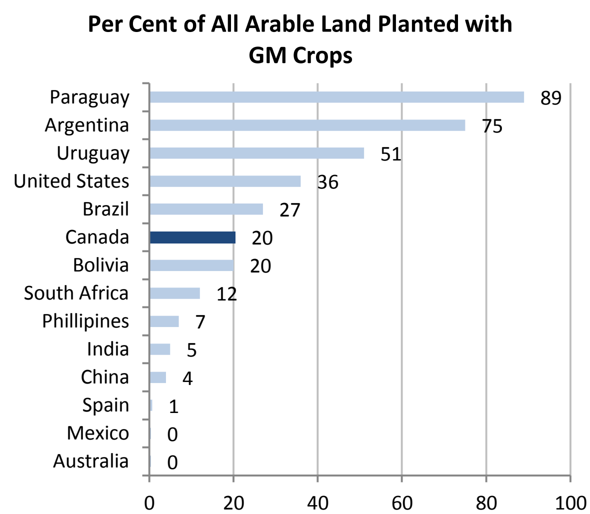


Source: van Beuzekom and Arundel (2009).

In absolute terms the United States is, by far, the most important producer of GM crops in the world, with 62.5 million hectares of GM crops in 2008 (Chart XXX). However, in relative terms, GM crops played a much larger role in Paraguay, where they accounted for 89 per cent of arable land, Argentina (75 per cent), and Uruguay (51 per cent) than in the United States (36 per cent).

Chart 13: GM Crops, International Comparison, 2008





Source: 1) The chart on the left is based on James (2009), p. 15; 2) The chart on the right is adapted from van Beuzekom and Arundel (2009), p. 77 (the figure for Canada was updated, but all other figures remain the same).

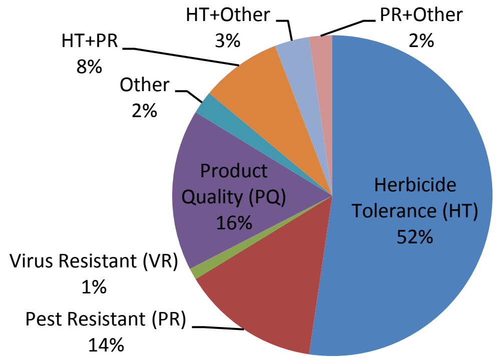
As mentioned previously, most of the approved GM crops are either herbicide tolerant or pest resistant. As of August 2011, 80 per cent of the 86 GM crop varieties approved in Canada had at least one of the two aforementioned traits, while crop varieties with improved product quality accounted for 16 per cent of the total, and other types of GM crops (with improved agronomical traits or changes in technical traits) were responsible for the remaining 4 per cent (Table 9, Chart 14).[18] Worldwide, even though more than a dozen plant species have received regulatory approval, the majority of GM crops (by hectare planted) are different varieties of canola, corn, soybeans, and cotton.

Table 9: Biotech Crops Approved in Canada by GM Trait, 2011[19]

	Number of Varieties	Herbicide Tolerance (HT)	Pest Resistant (PR)	Virus Resistant (VR)	Product Quality (PQ)	Other	HT+PR	HT+Other	PR+Other
Corn	27	10	6		3		7	1	
Canola	12	7			3			2	
Soybean	8	4			4				
Cotton	8	4	4						
Wheat	7	7							
Tomato	4		1		3				
Potato	4	1	1						2
Sunflower	4	3			1				
Rice	4	4							
Sugarbeet	2	2							
Squash	2					2			
Flax	1	1							
Lentil	1	1							
Papaya	1			1					
Alfalfa	1	1							

Source: Health Canada, Approved GM Foods & Other Novel Foods (http://www.hc-sc.gc.ca/fn-an/gmf-agm/appro/ofb-095-264-a-eng.php).

Chart 14: Health Canada Approved GM Varieties as of August 2011, by trait



Source: Health Canada, Approved GM Foods & Other Novel Foods (http://www.hc-sc.gc.ca/fn-an/gmf-agm/appro/ofb-095-264-a-eng.php).

Three of the four major GM crops in the world are planted in Canada, namely: canola, soybeans, and corn. The fourth most important GM crop in Canada is sugarbeet.[20] In 2009, there

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[18] For a list of the approved varieties of GM crops, refer to Appendix Table 2.

[19] The fact that a certain GM crop has been approved by Health Canada does not necessarily imply that this crop variety is currently grown in Canada. In fact, most of the approved varieties are not grown or grown in very small quantities. For a list of all approved GM crops, refer to Appendix Table 2.

[20] The importance of sugarbeet should not be overstated, however. In 2010, sugarbeet crops accounted for merely 0.1 per cent of total cash receipts in Canadian crop production.

were 8,200 thousand hectares of GM crops in Canada, which accounted for 22.3 per cent of total seeded area in the country (Table 10). Looking at crop cash receipts, the importance of GM crops is even greater. In 2009, GM canola, GM corn, GM soybeans, and GM sugarbeet accounted jointly for $7,027 million, 30.3 per cent of total crop cash receipts in Canada.

Table 10: Biotech Crops, Canada, 1997 and 2005-2009

	1997	2005	2006	2007	2008	2009	1997-2009
	Cropland Area, thousand hectares						(compound annual growth rates, per cent)
Total	**35,102**	**35,718**	**35,695**	**36,642**	**37,048**	**36,902**	**0.4**
Total GM	*1,230*	*4,200*	*5,250*	*6,958*	*7,574*	*8,236*	17.2
GM Canola	1,200	4,200	4,500	5,100	5,500	6,000	14.4
GM Corn	30	-	-	1,170	1,190	1,221	36.2
GM Soybeans	0	-	750	688	880	995	115.4
GM Sugarbeet	-	-	-	-	4	20	n.a.
	Total GM Crop Area as a Share of Total Cropland Area, per cent						(percentage point change)
Total	100.0	100.0	100.0	100.0	100.0	100.0	0.0
Total GM	*3.5*	*11.8*	*14.7*	*19.0*	*20.4*	*22.3*	*18.8*
	GM Crop Area as a Share of Total Crop Area (e.g. GM canola/total canola)						(percentage point change)
Canola	30.0	82.0	84.0	86.0	86.0	93.0	63.0
Corn	2.8	-	-	90.0	99.2	99.3	96.5
Soybeans	0.0	-	-	62.5	73.3	71.1	71.1
Sugarbeet	-	-	-	-	59.0	96.0	37.0
	Cash Receipts, millions of current dollars						(compound annual growth rates, per cent)
Total	**14,094**	**13,526**	**14,784**	**18,520**	**22,959**	**23,182**	4.2
Canola	*2,128*	1,826	2,503	3,467	4,915	5,107	7.6
Corn	*696*	623	754	1,051	1,559	1,321	5.5
Soybeans	*814*	760	680	1,032	1,124	1,329	4.2
Sugarbeet	*34*	32	38	35	24	23	-3.4
	Estimated Biotech Cash Receipts, millions of current dollars						(compound annual growth rates, per cent)
Total GM	*658*	*1,497*	*2,103*	*4,573*	*6,611*	*7,027*	21.8
Canola	638	1,497	2,103	2,981	4,227	4,750	18.2
Corn	19	-	-	946	1,546	1,312	42.0
Soybeans	0	-	-	645	824	944	..
Sugarbeet	-	-	-	-	14	22	56.8
	GM Cash Receipts as a Share of Total Crops Receipts, per cent						(percentage point change)
Total GM	*4.7*	*11.1*	*14.2*	*24.7*	*28.8*	*30.3*	*25.6*

Notes 1) GM crop area as a share of total crop area, and GM cash receipts calculated by the CSLS; 2) Cash receipts for GM crops calculated assuming that the prices for GM and non-GM crop varieties were equal.
Source: GM crop data from James (1998, 2005, 2006, 2007, 2008, and 2009) and GMO Compass (http://www.gmo-compass.org). Data on total seeded hectares and cash receipts from Statistics Canada, Field Crop Reporting Series (CANSIM Table 10010) and Net Farm Receipts (CANSIM Table 20001), respectively.

Among GM crops, GM canola had the largest seeded area by far in 2009, 6,000 thousand hectares (accounting for 73 per cent of total GM cropland area in Canada), followed by corn (1,221 thousand hectares or 15 per cent of GM cropland area)), soybeans (995 thousand hectares or 12 per cent of GM cropland area), and sugarbeet (4 thousand hectares or 0.05 per cent of GM cropland area). In 2009, practically all production of canola, corn and sugarbeet used GM seeds

(93 per cent, 99.3 per cent, and 96.0 per cent, respectively). A significant proportion of soybeans agriculture also used GM seeds (71.1 per cent).[21]

BOX 2: Top Medical Biotech Firms in the World and in Canada in 2010

Med Ad News publishes a yearly ranking of the top 100 medical biotech companies in the world. In 2010, the world's top five medical biotech companies by revenue were Roche Inc. (US$29,580 million, biotech estimate), Amgen Inc. (US$15,053 million), Gilead Sciences Inc. (US$7,949 million), Biogen Idec Inc. (US$4,716 million), and UCB (US$4,267 million). Each of these five firms specializes in very different areas: Roche develops diagnostics and drugs for a variety of diseases, including cancer, autoimmune diseases, inflammatory diseases, metabolic disorders, and diseases of the central nervous system; Amgen focuses on therapeutics for cancer, kidney disease, bone diseases, and other serious illnesses; Gilead Sciences focuses primarily on HIV/AIDS, liver disease, and serious cardiovascular/metabolic and respiratory conditions; Biogen provides therapies for multiple sclerosis, non-Hodgkin's lymphoma, and rheumatoid arthritis; and UCB seeks to develop and market treatments for severe conditions such as Crohn's disease, systemic lupus erythematosus, rheumatoid arthritis, and asthma.

Five Canadian biotech firms made it to the Med Ad News list in 2010: Cangene Corp. (31st place, revenue of US$ 152 million), QLT Inc. (57th place, US$45 million), Bioniche Life Sciences (58th place, US$44 million), Theratechnologies Inc. (69th place, US$ 31 million), and AEterna Zentaris Inc. (74th place, US$ 28 million). Note that the biotech revenues of the world's leading biotech firm, Roche, were 194 times greater than those of Cangene, Canada's leading biotech company. As was the case with the top 5 firms, each of the top 5 Canadian firms focuses on different areas: Cangene’s primary focus is immune therapeutics; QLT specializes in the treatment of ocular diseases; Bioniche Life Sciences has developed therapies for bladder cancer, and cattle vaccines for E. coli; Theratechnologies concentrates itself on therapeutic peptide products; AEterna Zentaris concentrates its efforts in developing biotech-based cancer treatments.

Ranking firms by profits, Roche maintained the lead, followed by Amgen, Gilead Sciences, Biogen Idec, and finally UCB. Although profitable, UCB's profits were only 1.6 per cent those of those of Roche's. With regards to Canadian biotech firms, Theratechnologies had the greatest profits (US$8.11 million), followed by Cangene (US$8.05 million). The other three Canadian firms experienced net losses in 2010. Notably, the sum of the net income of the top five medical biotech firms in Canada yields a negative number.

Rank	Country	Name	Revenue (USD millions)	Net income/ loss (USD millions)	R&D (USD millions)
1	Switzerland	Roche Inc.	29,580	8,523	9,611
2	USA	Amgen Inc.	15,053	4,627	2,894
3	USA	Gilead Sciences Inc.	7,949	2,901	1,073
4	USA	Biogen Inc.	4,716	1,005	1,249
5	Belgium	UCB	4,267	137	935
31	Canada	Cangene Corp.	152	8	15
57	Canada	QLT Inc.	45	-18	33
58	Canada	Bioniche Life Sciences Inc.	44	-2	17
69	Canada	Theratechnologies Inc.	31	8	14
74	Canada	Aeterna Zentaris Inc.	28	-23	21

Source: Med Ad News, http://www.pharmalive.com/magazines/medad/.

[21] For further discussion on GM crops (and GM food) in Canada, see McHughen (2002).

IV. Literature Review: Measuring the Contribution of Biotechnology to the Economy

This section discusses the efforts made so far to measure the contribution of biotechnology to the economy. Each of the subsections below describes one paper or report, and is divided into two parts. The first part is descriptive, and focuses on how modern biotechnology or (in some cases) the "biotechnology sector" is defined, the methodology used, and the overall results. In the second part, we highlight possible criticisms to the papers' definitions, methodologies, and results.

A. Ernst & Young (2000)

One of the first efforts to measure the economic importance of biotech was Ernst & Young (2000), which estimated the contributions of the biotech sector to the U.S. economy in terms of revenues, jobs, labour compensation, and taxes generated.

The report included in the sector only "U.S. companies that are primarily engaged in biotechnology activities" (p. 9). As Exhibit 7 shows, these companies are a subset of all the companies categorized under the Standard Industrial Classification (SIC) codes 2833 (medicinal chemicals and botanical products), 2834 (pharmaceutical preparations), 2835 (in vitro and in vivo diagnostic substances), 2836 (biological products, except diagnostic substances), and 8731 (commercial physical and biological research). According to Ernst & Young's definition, the biotech sector included firms involved in medical, agricultural, environmental, and industrial biotechnology. Their definition excluded, however, companies such as Merck, which are primarily pharmaceutical companies (even though most of them have a biotech division),[22] contract research organizations, and equipment manufacturers.

Exhibit 7: Ernst & Young's Definition of the Biotechnology Sector

SIC Code	Industry
2833	Medicinal chemicals and botanical products
2834	Pharmaceutical preparations
2835	In vitro and in vivo diagnostic substances
2836	Biological products, except diagnostic substances
8731	Commercial physical and biological research

Firms INCLUDED in the Biotech Sector
Medical biotechnology (e.g., Amgen, Genentech)
Agricultural biotechnology (e.g., Mycogen)
Environmental & industrial biotechnology

Firms EXCLUDED from the Biotech Sector
Primarily pharmaceuticals (e.g., Merck)
Contract research organizations (e.g., Quintiles)
Equipment manufacturers (e.g., PE Biosystems)

Source: Ernst & Young (2000), pp. 3 and 9.

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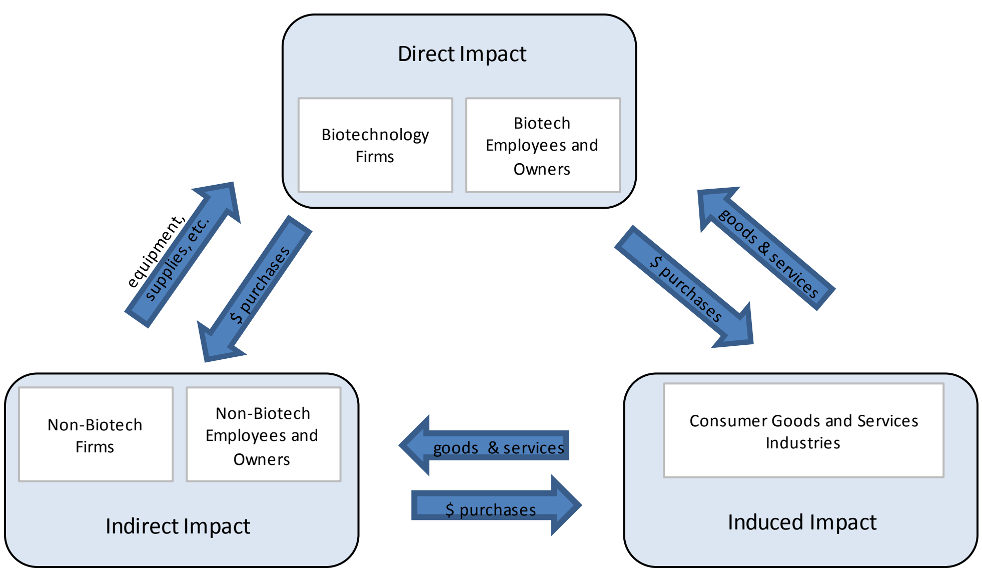
[22] If data for pharmaceutical companies' biotech divisions were available, they were also included as part of the biotech sector.

The authors use an input-output model developed by the University of Minnesota, the IMPLAN model, to assess the overall economic impact of the biotech sector on the U.S. economy. Using this model's framework, the total economic impact of the biotech sector can be decomposed into three parts:

- The *direct impact* is the economic impact that is "directly attributable to biotechnology firms" (p. 4);
- The *indirect impact* is created by the purchases of intermediate goods and services by biotech firms from non-biotech firms, which generates economic activity in supporting industries (backward linkages);
- The *induced impact* is the result of employees and employers of biotech firms and supporting industries spending their salaries and capital income on final goods and services (income multiplier effect).

Thus, the economic activity created by biotech firms causes ripples throughout the entire economy, which are the indirect and induced impacts, and this results in a total effect that is significantly greater than the original direct impact. Exhibit 8 illustrates the relationship between these three effects.

Exhibit 8: Direct, Indirect and Induced Economic Impacts



Source: Ernst & Young (2000), p. 4.

According to the study, the U.S. biotech sector was directly responsible for 150,800 jobs, $20.2 billion in revenues, and $14.8 billion of personal income in 1999 (Table 11). The total impact of the sector in the economy, however, was much greater. Overall, when considering the direct, indirect, and induced impacts, the biotech sector accounted for 437,400 jobs, US$46.5 billion in revenues, and US$28.8 billion of personal income. As a share of total economic activity in the United States, the total impact of the biotech sector accounted for 0.3 per cent of U.S. employment and GDP (using personal income as a proxy of value added). Comparing the total effect with the initial direct effect, we can have an estimate of the economic activity multipliers in the biotech sector.

Table 11: Economic Contribution of the Biotech Sector, United States, 1999 (Ernst & Young, 2000)

	Employment	Revenues	Personal Income
	(number of jobs)	(billions of U.S. dollars)	(billions of U.S. dollars)
Direct Impact	150,800	20.2	14.8
Indirect Impact	45,000	4.8	..
Induced Impact	241,600	21.5	..
Total Impact	*437,400*	*46.5*	*28.8*
	(multiplier = total impact/direct impact)		
Multiplier	2.9	2.3	2.0

Source: Ernst & Young (2000), pp. 4-5.

There are three main criticisms that can be made to this report. First, its definition of the biotech sector excludes pharmaceutical companies (unless they have a separate biotech division). As we have seen in the overview section, applications in medicine and healthcare were responsible for the lion's share of the biotech-related economic activity in the United States. Excluding pharmaceutical companies thus leads to a significant underestimation of the size of the biotech sector whether we look at employment, revenues or personal income numbers.

A second problem with the report is that, although it takes into account the economic impact of backward linkages, it completely ignores the role of forward linkages. Examples of important forward linkages include the use of GM seeds in crop production, and the use of enzymes in food manufacturing.

Finally, revenues are not a good measure of total economic activity due to double-counting. The cost of intermediate goods purchased by a biotech firm is part of the total cost of production of the final good sold by this firm, and is therefore factored into the price of the final good. The intermediate goods are, at the same, a source of revenue to the firms that sell them to the biotech firms. Hence, when we consider the total impact of biotech in revenues, the cost of intermediate goods is counted twice: once on the direct impact, once on the indirect impact. To avoid this double-counting, a value added measure should be used instead of revenues.

B. Hevesi and Bleiwas (2005)

Hevesi and Bleiwas (2005) also use the IMPLAN model, this time to estimate the economic impact of biotech and pharmaceutical industries in the state of New York. Although mainly interested in the biotech sector, the authors argue that

> The economic impact of biotechnology as a distinct industry is currently difficult to evaluate because of the manner in which data is collected; however, it is possible to calculate the combined impact of the biotech and pharmaceutical industries (p. 1).

Using the North American Industry Classification System (NAICS) as a reference, the study identifies two five-digit industries that account for the majority of jobs in the biotech sector (although also including the pharmaceutical industry): pharmaceutical and medicine manufacturing (NAICS code 32541), and research and development in the physical, engineering, and life sciences (NAICS code 54171).

The authors estimate that the biotech and pharmaceutical sectors in the state of New York directly accounted for 54,469 jobs and US$3.3 billion in wages in 2003 (Table 12). Once again, due to the indirect and induced impacts, the total economic effect was much greater than the direct effect, 109,532 jobs and US$5.9 billion in wages. Assuming that wages accounted for 60 per cent of biotech-related value added (with capital compensation representing the remaining 40 per cent), we estimate that total biotech value added reached US$9.8 billion, equivalent to 1.2 per cent of New York State's GDP in 2003.

Table 12: Economic Contribution of the Biotech and Pharmaceutical Sectors, New York State, 2003 (Hevesi and Bleiwas, 2005)

	Employment	Wages
	(number of jobs)	(billions of U.S. dollars)
Direct Impact	54,469	3.3
Indirect + Induced Impacts	55,063	2.7
Total Impact	*109,532*	*5.9*
	(multiplier = total effect/direct effect)	
Multiplier	2.0	1.8

Source: Hevesi and Bleiwas (2005), p. 3.

Since the Hevesi and Bleiwas paper also uses the IMPLAN model, it suffers from the same methodological limitation seen in Ernst & Young (2000) with respect to ignoring the impact of forward linkages. Hevesi and Bleiwas (2005) partially address, however, the two other problems seen in Ernst & Young (2000).

The paper readily acknowledges the problem of calculating the economic contribution of biotech excluding pharmaceutical companies. However, since the authors had no means of differentiating between pharmaceutical companies that used biotech and those that did not, their estimates include pharmaceutical and medicine manufacturing in its entirety, which overstates the importance of biotechnology. At the same time, the definition of the biotech sector used in Hevesi and Bleiwas (2005) seems too narrow, including only two five-digit NAICS codes. When compared to Statistics Canada's BUDS, which included establishments from 12 NAICS codes, this seems to indicate that a significant number of biotech firms were left out.

C. Genoma España (2005)

Genoma España (2005) calculates the economic impact of modern biotechnology in the Spanish economy. The study includes in the biotech sector two types of firms: 1) Firms that fit the OECD definition of fully devoted biotech companies; 2) Firms that are only partly dedicated to biotech. Accounting for the second category is not as straightforward as accounting for the first. The problem is that the biotech "content" of each partly dedicated firm is not known. Thus, the authors assume that "their biotechnology activities are proportional to the number of researchers in relation to the total number of employees" (p. 36).

Even though the study does not use the IMPLAN model, it uses its framework, breaking down the economic contribution of the biotech sector in direct, indirect, and induced impacts. The study finds that the Spanish biotech sector was directly responsible for €1,332 million in revenues and 11,890 jobs in 2002 (Table 13). When the indirect and induced impacts are also taken into account, the sector generated a total of €2,754 million in revenues, and 26,035 jobs. Overall, the sector represented 0.4 per cent of Spain's GDP in 2002.

Table 13: Economic Contribution of the Biotech Sector, Spain, 2002 (Genoma España, 2005)

	Employment	Revenues
	(number of jobs)	(millions of Euros)
Direct Impact	11,890	1,322
Indirect Impact	7,768	795
Induced Impact	6,377	637
Total Impact	*26,035*	*2,754.0*
	(multiplier = total effect/direct effect)	
Multiplier	2.2	2.1

Source: Genoma España (2005), p. 37.

Two criticisms that can be made to this report and that have already been made to previous reports are that: 1) it ignores forward linkages; 2) it focuses on revenues as a measure of economic activity. For a discussion of these issues, see the subsection on the Ernst & Young (2000) report. Another issue is the assumption that the intensity of biotech activities is proportional to the share of *total* researchers relative to total employees. This might lead to an overestimation of total biotech activities, because the number of biotech researchers might be significantly smaller than the number of total researchers.

D. Zika *et al.* (2007)

Zika *et al.* (2007) estimate the contribution of modern biotechnology to the European Union's economy in terms of gross value added (GVA). The authors distinguish between direct and indirect economic impacts of modern biotech, although their definitions are different from the ones used in the IMPLAN model framework. The *direct impact* refers to the economic gains that arise "from the activities of producers of modern biotechnology products, such as pharmaceutical companies, breeders, enzyme manufacturers, etc." (p. 135). The *indirect impact*, on the other hand, refers to "the effects arising from use of these products and may affect several links along the production chain" (p. 135). Examples of the indirect impact of modern biotechnology in the economy can be seen in the use of genetically modified seeds in agriculture, the use of enzymes in food processing, etc.

The authors' approach to measuring the overall contribution of the biotech sector to the economy differs from previous approaches in that they estimate the economic contribution of different biotech *applications* and *products*, instead of looking only at specific firms or NAICS/SIC categories. In most production processes, the use of modern biotechnology applications does not account for the entire process. The relative importance of biotechnology in each production process varies according to its purpose: "it is highest where biotechnology is a core technology, and the GVA generated may be allocated 100% to modern biotechnology; it is lowest where it is a supportive technology, and its main role is in improving the efficiency of production processes and hence overall competitiveness" (p. 13). However, its relative contribution to the value added of a specific activity is very hard to quantify, because it is not usually observable. This led *Zika et al.* to attribute 100 per cent of a product's value added to modern biotechnology whenever it played a role in this product's production process:

> Where modern biotechnology (direct) or derived products (indirect) are used at some steps of a production process, the entire output is calculated as the impact of modern biotechnology, even if the modern biotechnology-based process is only one amongst several non-biotechnological steps in production (p. 137).

The study estimated that the direct contribution of modern biotechnology to the European's Union gross value added represented 0.13-0.14 per cent of the European Union's GVA in 2002 (Table 14). Of this total direct contribution, around 55 per cent was due to applications related to industrial production, energy and the environment, 25 per cent to medicine and healthcare, and 20 per cent to agriculture and the agro-food sector. The indirect contribution of modern biotechnology was much more significant, representing around ten times its direct contribution, and accounted for approximately 1.43 to 1.69 per cent of the EU's GVA.

Zika *et al.* estimate that 1.5 million employees worked in industrial biotech activities in the E.U. in 2002 (not including those in pharmaceutical or chemical production. The authors do not present an employment estimate for biotech applications in medicine and healthcare, and primary production and agro-food, arguing that those are hard to quantify due to data availability issues and difficulty in taking into consideration indirect employment effects.

Table 14: Economic Contribution of the Biotech Sector, European Union, 2002 (Zika *et al.*, 2007)

A) Direct Impact of the Biotech Sector – Revenue and Gross Value Added

	Revenue	Gross Value Added (GVA)
	(billions of Euros)	
Medicine and Healthcare	9.0	3.1
Primary Production and Agro-Food	3.0 - 5.6	0.9 - 1.7
Industrial Production	..	*6.2*
Total	..	*10.2-11.0*

B) Direct and Indirect Impacts of the Biotech Sector as a Share of EU-25 Gross Value Added

	Direct	Indirect	Total
		(per cent)	
Medicine and Healthcare	0.04	..	0.04
Primary Production and Agro-Food	0.01 - 0.02	1.30 - 1.55	1.31 - 1.57
Industrial Production	0.08	..	0.08
Total	0.13 - 0.14	1.30 - 1.55	1.43 - 1.69

Note: Numbers in italics calculated by the CSLS based on data from Zika *et al.* (2007).
Source: Zika *et al.* (2007).

E. Pellerin and Taylor (2008)

Pellerin and Taylor (2008) estimate the size of the biobased economy in Canada. According to the authors, the concept of a biobased economy is broader than the standard definitions of biotechnology:

> The concept of the biobased economy goes beyond the traditional definition of biotechnology. The biobased economy focuses on biological tools and products from renewable resources to create wealth and sustainability in the production of medical treatments, diagnostics, more nutritional foods, energy, chemicals, and materials, while improving the quality of the environment (p. 363).

Exhibit 9 lists the NAICS categories that are included in the authors' definition of a biobased economy, and any adjustments made to account for their contribution to the Canadian economy in terms of GDP.

The *total* contribution of the biobased economy to GDP is calculated in three steps: 1) The *direct* contribution of the bioeconomy (see Exhibit 9) is calculated as a percentage of total economy GDP; 2) This percentage is applied to direct spin-off sectors (wholesale trade, retail trade, and professional services), as well as to the remainder of the economy, to take into account the multiplier effect of the biotech sector in generating more economic activity; 3) Finally, the totals found in each phase are aggregated to produce the overall biobased economy GDP.

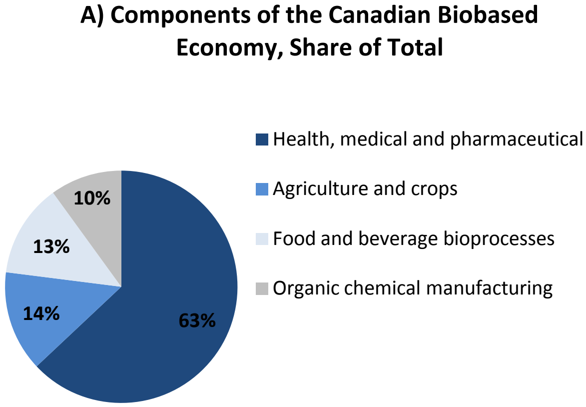
Exhibit 9: The Biobased Economy (Pellerin and Taylor, 2008)

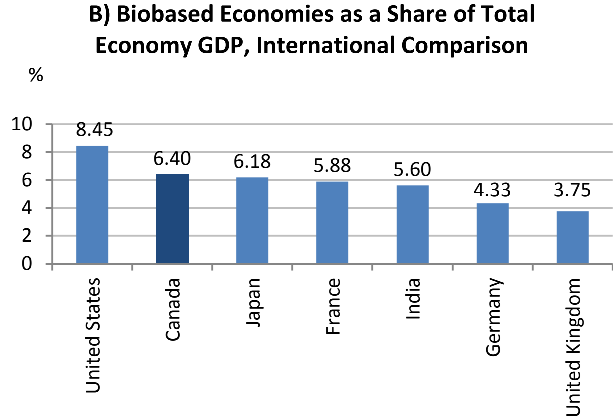
NAICS code	Activity	Observations	Adjustments
62	Healthcare and social assistance		Subtract GDP from social assistance (NAICS 624) and multiply the resulting total by the percentage of health expenditures related to pharmaceuticals).
111	Crop Production		Multiply crop production GDP by share of GM crops in total crops planted in Canada.
212233	Copper-Zinc Ore Mining	Accounts for bioprocesses used in copper mining.	Adjusted by an unknown percentage.
3254	Pharmaceutical and medical manufacturing		
32519	Other basic organic chemical manufacturing		
3251	Basic chemical manufacturing	Accounts for organic acids and derivatives, and alcohol peroxides and ethers.	Subtract NAICS 32519 to avoid double counting. Adjusted by an unknown percentage.
3121	Beverage Manufacturing	Accounts for breweries, wineries and distilleries	Subtract soft drink and ice manufacturing (NAICS 3211).
31151	Dairy product (except frozen) manufacturing		Adjusted by an unknown percentage.

Source: Pellerin and Taylor (2008), p. 366.

The authors find that the Canadian biobased economy accounted for $78.3 billion (2002 dollars) in 2007, equivalent to 6.40 per cent of total economy GDP. Health, medical and pharmaceutical applications represented the bulk of the Canadian biobased economy (63 per cent of the total), followed by applications in agriculture and crops (14 per cent), food and beverage (13 per cent), and organic chemical manufacturing (10 per cent) (Chart 15). Furthermore, the Canadian biobased economy ranked second when compared to a select group of other large world economies, only behind the United States.

Chart 15: The Canadian Biobased Economy, 2007 (Pellerin and Taylor, 2008)





Source: Pellerin and Taylor (2008), p. 366.

In our opinion, the main limitations of this paper refer to its broad (and somewhat vague) definition of the biobased economy. Our criticisms are listed below.

- The paper includes in the biobased economy the entire value added of pharmaceutical and medical manufacturing industry, instead of just the share of the industry that uses biotechnology, which overstates the importance of biotechnology.

- The value added of the healthcare sector (minus social assistance) is weighted by the percentage of pharmaceutical expenditures in the sector's gross output even though not all pharmaceutical expenditures are due to biopharmaceuticals.

- Crop production GDP is adjusted by the share of GM crops in total crops planted in Canada, but the value added generated by crop production varies widely depending on the type of crop produced.

- It is never clear what are the criteria used to calculate the share of the value added of copper-zinc ore mining, basic chemical manufacturing, and dairy product manufacturing to be included in the biobased economy.

V. Methodology

This section describes the methodology and assumptions used to measure the contribution of biotechnology to the Canadian economy. It is divided into two subsections: the first one details the framework used to calculate the current (and historical) contribution of biotech to the total economy, while the second one discusses the assumptions adopted by the CSLS to forecast the economic contribution of the sector up to 2030.

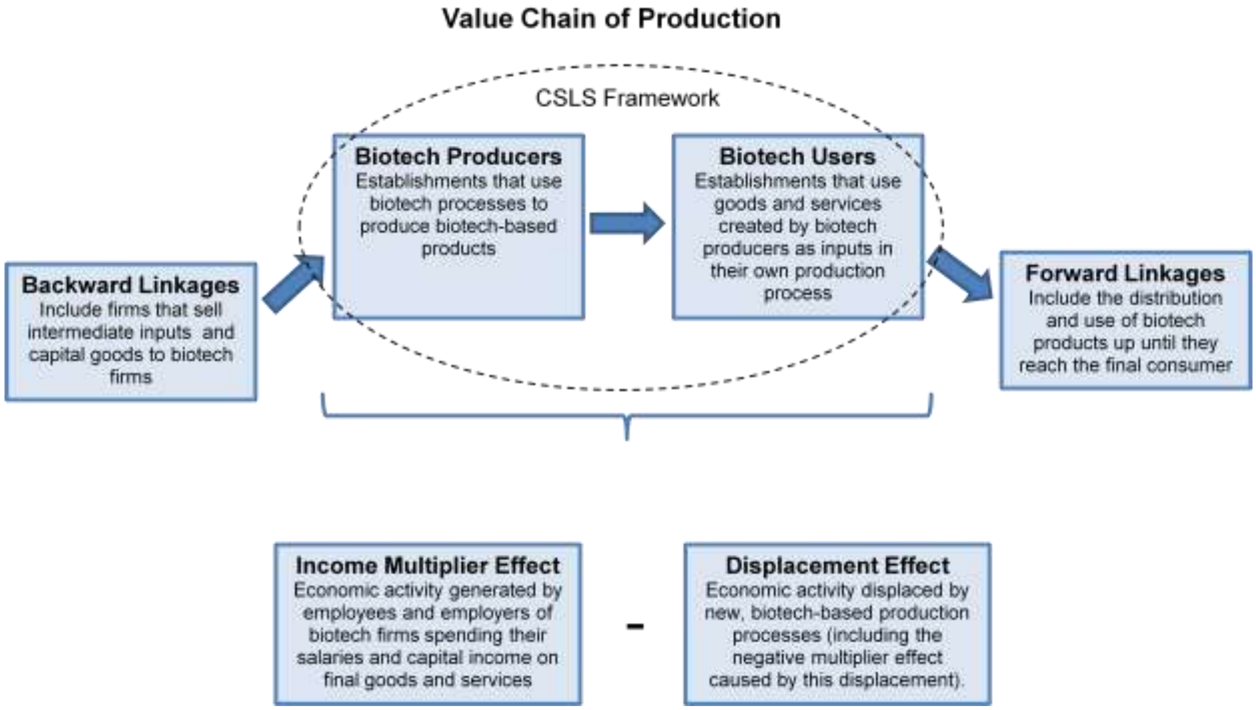
A. Measuring the Economic Contribution of the Biotech Sector

The use and development of biotechnology affects the economy through multiple channels: it creates jobs, generates value added, improves the efficiency of production processes, reduces environmental damage, enhances human health, etc. This report does not attempt to measure all of the effects of biotechnology on Canadian society. Rather, it focuses on the value added generated by biotechnology.

Exhibit 10 describes the biotech value chain of production. It starts with firms selling intermediate and capital goods to *biotech producers*, which are establishments that produce biotech-based goods and services. The links between biotech producers and their suppliers are called *backward linkages*. Biotech producers can then sell the goods they produced to *biotech users*, which are firms that use biotech-based goods/services as intermediate inputs in their own production processes. Next, biotech users sell their goods to wholesalers, retailers, and other firms in the economy, developing *forward linkages*. Throughout this entire process, employees are paid wages and employers make profits. They spend most their income buying goods and services offered by the rest of the economy, which in turn creates additional economic activity. This represents the *income multiplier effect*.

All of the elements described above play a role in increasing the economy's output. However, technological innovations such as the ones generated by biotechnology activities can create new goods and services (as well as new ways to produce conventional goods and services) by displacing economic activity. In other words, goods and services that were previously useful become obsolete, and the firms producing them close down. The displacement effect is often ignored when the economic impact of biotechnology is estimated using input-output models, because these models assume that increases (or decreases) in the demand for biotech-based goods and services are driven exogenously, which is unlikely.

Exhibit 10: Measuring the Economic Contribution of Biotechnology



Source: CSLS.

As a concrete example, we can picture the case of GM corn. Companies like Monsanto and Sygenta (biotech producers) produce GM seeds using intermediate inputs bought from other companies (backward linkages). The GM seeds, in turn, are planted by farmers (biotech users) to produce GM corn. The GM corn is then processed by a miller, and sold to wholesalers and retailers (forward linkages). Finally, the product reaches the movie theatre in the form of popcorn, which is sold to consumers (forward linkages).

One important reason why estimates of biotechnology activity differ so much among the papers and reports discussed in the previous section is that each of them measured different parts of the biotech value chain of production (Exhibit 11). As was the case with previous studies, this report does not attempt to measure the entire biotech value added chain of production. The estimates and forecasts discussed here refer only to biotech producers and biotech users. The rationale for this choice is the fact that these two groups constitute the actual core of biotechnology activity, i.e. they are the ones responsible for the production of biotech-based goods and services. The focus on biotech producers and users allows us to understand the relevance of biotech-based products and services in the economy, and allows us to compare the "biotech sector" with other sectors in the economy. Thus, this report will not provide estimates of backward linkages, forward linkages, the income multiplier effect, nor the displacement effect associated with biotechnology activity in Canada. In this sense, the reader should be aware that whenever the expression "total biotech contribution" is used here, it refers specifically to the sum of the direct economic contribution of biotech producers and biotech users.

Exhibit 11: Different Approaches to Measuring the Economic Contribution of Biotechnology

	Backward Linkages	Biotech Producers	Biotech Users	Forward Linkages	Income Multiplier Effect	Displacement Effect
CSLS		X	X			
Ernst & Young (2000)	X	X			X	
Hevesi and Bleiwas (2005)	X	X			X	
Genoma España (2005)	X	X			X	
Zika *et al.* (2007)		X	X			
Pellerin and Taylor (2008)		X	X	X	X	

Source: CSLS.

Exhibit 12 shows the framework developed by the CSLS to measure the economic contribution of biotechnology using an **income-based approach**. This exhibit details the actors that either produce or use biotechnology, the ideal way to measure the output of each actor, and data sources used.

The first step in estimating the contribution of biotechnology to the Canadian economy is to identify the actors engaged in biotech-related activities. As mentioned previously, we can identify two main groups of actors involved in biotech-related activities:

- *Biotech producers* are establishments that use biotech processes/techniques to produce biotech-based products. This includes activities of "producers of modern biotechnology products, such as pharmaceutical companies, breeders, enzyme manufacturers, etc." (Zika *et al.*, 2007, p.135), as well as R&D expenditures to develop these products. Private firms are not the only biotech producers, since the government sector and the higher education sector play an important role in conducting biotech R&D, and their contribution also has to be taken into account. The economic effect of biotech producers is what Zika *et al.* (2007) called the *direct impact* of biotechnology.

- *Biotech users* are establishments that use goods and services created by biotech producers as inputs in their own production process. Examples of biotech users are farmers that use GM seeds to produce GM crops, firms that use enzymes bought from enzyme breeders to produce foodstuffs, detergents, pulp and paper, textiles, etc. The economic effect of biotech users is what Zika *et al.* (2007) called the *indirect impact* of biotechnology.

Exhibit 12: Measuring the Economic Contribution of Biotechnology Activities, Processes, and Products in Canada

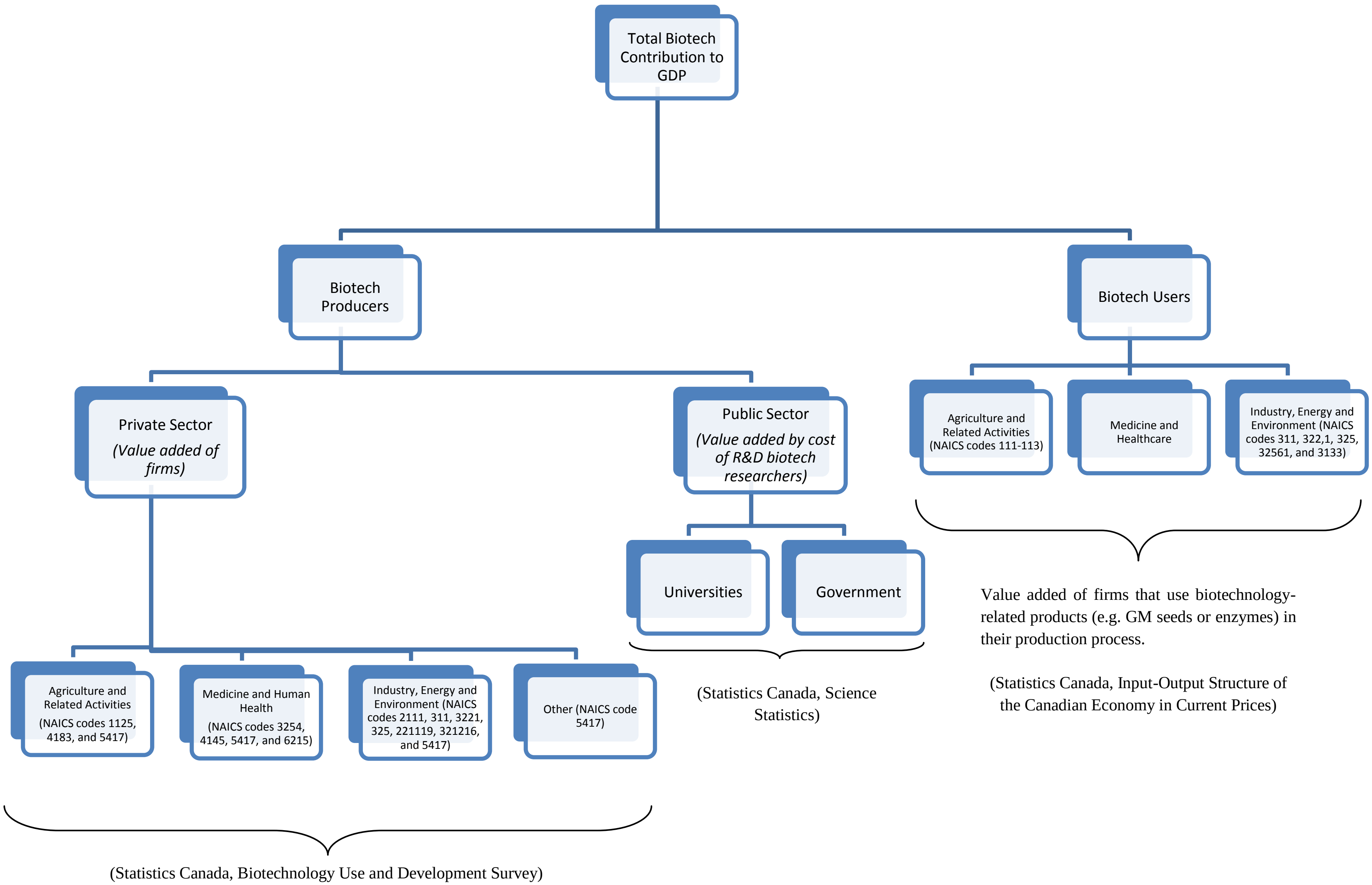


Exhibit 13 lists the NAICS codes of establishments that are potential biotech producers and biotech users, along with examples of biotech-related activities in each case.

Exhibit 13: Potential Biotechnology Users and Producers, NAICS codes

	NAICS codes	Examples of Activities
Biotech Producers		
Private Sector		
Agriculture and Related Activities	Aquaculture (1125), agricultural supplies wholesaler distributors (4183), and scientific research and development services (5417).	Production of GM seeds and feed additives; development of diagnostic kits and therapeutics for plants and animals; development of propagation techniques to support breeding efforts.
Medicine and Healthcare	Pharmaceutical and medicine manufacturing (3254), pharmaceutical, toiletries, cosmetics, and sundries wholesale-distributors (4145), research and development services (5417), and medical and diagnostic laboratories (6215).	Production of biopharmaceuticals, and small molecule drugs; development of new diagnostic methods and therapeutic techniques.
Industry, Energy and Environment	Oil and gas extraction (2111), food manufacturing (311)*, pulp , paper and paperboard mills (3221), chemical manufacturing (325), other electric power generation (221119), particle board and fibreboard mills (321216), research and development services (5417).	Production of bulk chemicals (e.g. citric acid), and specialty chemicals (e.g. enzymes, amino acids, acids, vitamins, etc.); production of bioplastics; production of functional foods and nutraceuticals.
Other	Scientific research and development services (5417).	Platform technologies R&D, e.g. bioinformatics.
Biotech Users		
Agriculture and Related Activities	Crop production (111), animal production (112), forestry and logging (113).	Use of GM seeds to produce GM crops; use of marker assisted selection to improve animal and plant breeding efforts.
Medicine and Healthcare	Healthcare and social assistance (62).	Use of biopharmaceuticals in medical treatments; use of biotech-based therapeutic techniques and diagnostic methods to identify and treat illnesses.
Industry, Energy and Environment	Food manufacturing (311), paper and paperboard mills (3221), chemical manufacturing (325), soap and cleaning compound manufacturing (32561), pulp , textile and fabric finishing and fabric coating (3133).	Use of enzymes as catalysts in the production processes of foodstuffs, detergents, textiles, pulp and paper, chemicals, etc; use of biomining techniques; use of enhanced microorganisms in bioremediation;

*Excluding sugar and confectionery product manufacturing (3113), bakeries and tortilla manufacturing (3118), and other food manufacturing (3119).

Souce: 1) NAICS codes for biotech producers were taken from Statistics Canada's BUDS website (http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=4226&lang=en&db=imdb&adm=8&dis=2), but assigned to a specific category (Agriculture and Related Activities, Medicine and Healthcare, etc.) by the CSLS; 2) NAICS codes for biotech users were identified by the CSLS.

Once the main actors involved in biotech-related activities have been identified, the second step is to choose the ideal measure that should be used to estimate the contribution of biotechnology to the economy. There are two main output measures: gross output and value added.

The gross output of the "biotechnology sector" consists of all goods and services produced by the sector during a certain period of time. This concept of output includes the contribution of primary factors of production (labour and capital), as well as that of intermediate inputs. In the case of marketed biotech goods and services, the revenue (or sales) of biotech firms is the value of the sector's gross output.[23] Value added, on the other hand, reflects only the contribution of the primary factors of production (labour and capital), excluding the value of intermediate inputs.

Overall, value added is a better measure of output because it avoids double-counting, i.e. if a biotech firm produces a good that is used by another biotech firm in their production process, summing the revenue of the two firms will count the value of the good twice.[24] Thus, ideally, we would like to measure the economic contribution of biotechnology in terms of value added, which is the same as gross domestic product (GDP) at basic prices.

Note that the estimation of value added differs depending on whether we are analyzing the private sector or the public sector. In the private sector, since the output of (most) firms is marketed, value added can be calculated in terms of market prices. Start-up biotech firms that have no marketed product (yet) and are only engaged in R&D have a net value added of zero, [25] because the positive contribution of labour compensation (wages and salaries) is entirely offset by the negative profits.[26] In the public sector, output is not marketed, and value added has to be calculated based on the cost of inputs. Since most biotech activity in the public sector takes the form of R&D, the cost of wages and salaries in biotech R&D is our best measure of value added in this sector.[27]

Another issue that arises when measuring the value added of biotech firms is that the extent to which these firms use biotechnology varies widely. In some firms, biotech plays a supporting role and accounts for only a small part of the total value added, while in others it is a core technology that accounts for most of the value added generated in the activity. However, as Zika *et al.* (2007) argue, the relative contribution of biotech to the value added of a specific activity is very hard to quantify, because it is not usually observable. This report adopts the assumption used by Zika *et al.* (2007), attributing 100 per cent of a product's value added *at the*

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[23] In reality, sales and gross output are not exactly equivalent for two reasons: 1) Business units frequently sell inventories of finished goods; 2) Business units can place finished goods produced in the current period as inventories. Gross output is, thus, total sales adjusted by the value of changes in inventories (Harchaoui *et al.*, 2001, p. 145). For our purposes, however, sales can be considered a very close proxy of gross output.

[24] Of course, the extent to which double-counting happens depends on how often biotech firms rely on each other to purchase inputs for their production process.

[25] Currently, Statistics Canada sees R&D expenditures as a cost of production. This will change in the next revision of the Canadian System of National Economic Accounts (CSNA), scheduled to happen in 2012, which will include R&D expenditures either as a distinct type of output or as an intangible investment. For more information on the current CSNA, see Statistics Canada (2008). The latest developments related to the CSNA and a list of planned revisions can be found at http://www.statcan.gc.ca/pub/13-605-x/2003001/chrono/4066065-eng.htm.

[26] This type of firm manages to operate during their initial years by running down their initial capital and/or debt.

[27] Wages and salaries represent, however, only part of the total value added of economic activity. Ideally, we would also include capital compensation. Unfortunately, we do not have any estimate of capital compensation of biotech-related activities performed by the public sector. Therefore, we assume that it is zero. The reader should keep in mind that, by doing so, we are underestimating the value added generated by biotech-related activities performed by the public sector.

firm level to modern biotechnology whenever it played a role in this product's production process.

Once the most appropriate measure of economic activity has been identified (value added), the next step consists of checking data availability, and, if the ideal data are not available, finding the second best alternative. The main obstacle in measuring the importance of biotechnology to the economy is the cross-sectoral/cross-industrial nature of biotech-related activities. Firms that use biotechnology do not fit into a single NAICS category. Therefore, establishments cannot be classified as belonging to the "biotech sector" *a priori*, e.g. not all pharmaceutical and medicine manufacturing establishments (NAICS code 3254) use biotechnology.

Exhibit 14 details data availability issues for each of the main sectors involved in biotech-related activities. As it can be seen, GDP data specifically for biotech producers and biotech users are not available at all. However, Statistics Canada's BUDS provides detailed employment, revenue, and R&D expenditure estimates for the private sector biotech producers. Furthermore, Statistics Canada's Science Statistics has data on biotech-related employment at the federal level, and biotech R&D expenditures funded by the federal government, which provides a partial figure of the public sector R&D performers. Data for biotech users are scarcer, because there is no general survey that identifies biotech users in the Canadian economy. Consequently, data for biotech users reflect only partial information. The main exception here is data on the use of GM seeds in Canada, which is provided in detail by James (1998, 2005-2009).

Exhibit 14: Data Availability for Biotech Users and Producers in Canada

	Employment	GDP	Revenues	R&D Expenditures	Data Sources	Observations
Biotech Producers						
Private Sector						
Primary Production	1999, 2001, 2003, 2005	n.a.	1999, 2001, 2003, 2005	1999, 2001, 2003, 2005	STC's BUDS	
Medicine and Healthcare	1999, 2001, 2003, 2005	n.a.	1999, 2001, 2003, 2005	1999, 2001, 2003, 2005	STC's BUDS	
Industrial Applications	1999, 2001, 2003, 2005	n.a.	1999, 2001, 2003, 2005	1999, 2001, 2003, 2005	STC's BUDS	
Other	1999, 2001, 2003, 2005	n.a.	1999, 2001, 2003, 2005	1999, 2001, 2003, 2005	STC's BUDS	
Public Sector (R&D Performers)						
Government Sector	1998-2008	n.a.	n.a.	1998-2008	STC's Science Statistics	Data reflect only R&D funded by the federal government.
Higher Education Sector	n.a.	n.a.	n.a.	1998-2008	STC's Science Statistics	Data reflect only R&D funded by the federal government.
Biotech Users						
Primary Production	n.a.	n.a.	n.a.	n.a.	Clive James (1998, 2005-2009)	GM crop data.
Medicine and Healthcare	n.a.	n.a.	n.a.	n.a.	STC's BUDS, CIHI (2011)	Share of biopharmaceuticals in total drug expenditures.
Industrial Applications	n.a.	n.a.	n.a.	n.a.	OECD (2009), Zika *et al.* (2007)	Adoption rates of biotech-related processes and techniques.

Notes: STC's BUDS – Statistics Canada's Biotechnology Use and Development Survey.

The last step of the process is to make explicit assumptions that will allow us to aggregate the above data in order to produce estimates of the contribution of biotechnology to GDP in Canada. We use value added-gross output (VA-GO) ratios to convert revenue data for private sector biotech producers to GDP. Ideally, the VA-GO ratios used would be based on the NAICS codes listed in Exhibit 13. In most cases, however, nominal GDP and gross output data for activities identified by four-digit, five-digit, and six-digit NAICS codes were not available. Whenever this happened, we used nominal GDP and gross output data from the closest two-digit or three-digit NAICS code for which data were available. In the case of public sector biotech producers, value added is estimated based on the cost of biotech researchers.

For biotech users, we calculate biotech GDP by multiplying an industry's GDP by an estimated *biotech adoption rate* that ranges from 0.0 to 1.0. In this context, biotech adoption rates refer to the share of firms in a particular industry that use biotech products and/or techniques as intermediate inputs in their own production process. The main downside to this approach is that it ignores differences in firm size, which can lead to potentially significant distortions in our estimates depending on an industry's market structure. Below, we detail all the assumptions and data adjustments used to calculate our estimates.

Biotech Producers, Private Sector

- Agriculture and Related Activities – Revenue data from Statistics Canada's BUDS are multiplied by the VA-GO ratio of a specific industry aggregation composed of the following NAICS codes: crop and animal production (111-112), wholesale trade (41), and professional, scientific and technical services (54). In 2005, the VA-GO ratio for agricultural biotech producers was 0.55.

- Medicine and Healthcare – Revenue data from Statistics Canada's BUDS are multiplied by the VA-GO ratio of a specific industry aggregation composed of the following NAICS codes: chemical manufacturing (325), wholesale trade (41), professional, scientific and technical services (54), and healthcare and social assistance (62). In 2005, the VA-GO ratio for medical biotech producers was 0.56.

- Industry, Energy and Environment – Revenue data from Statistics Canada's BUDS are multiplied by the VA-GO ratio of a specific industry aggregation composed of the following NAICS codes: oil and gas extraction (211), electric power generation, transmission and distribution (2211), food manufacturing (311), paper manufacturing (322), chemical manufacturing (325), and professional, scientific and technical services (54). In 2005, the VA-GO ratio for industrial biotech producers was 0.53.

- Other Applications – Revenue data from Statistics Canada's BUDS are multiplied by the VA-GO ratio of the professional, scientific and technical services sector (NAICS code 54). In 2005, the VA-GO ratio for firms engaged in developing other biotech applications was 0.60.

Biotech Producers, Public Sector

- Government Sector – Includes the federal and provincial governments, provincial research organizations, and the non-profit sector. Government R&D data are converted into value added in two steps:

  1) As mentioned previously, available data on publicly funded biotech R&D refer only to federal R&D expenditures. To have an approximate picture of total public biotech R&D expenditures, we assume that the relationship between *federally funded* R&D expenditures performed by the government and *total* R&D expenditures performed by the government also holds for biotech R&D in particular. This can be understood as:

$$\frac{GovRD_{bio,fed}}{GovRD_{bio,all}} = \frac{GovRD_{total,fed}}{GovRD_{total,all}}$$

  where $GovRD_{bio,fed}$ stands for biotech R&D expenditures performed by the government sector and funded by the federal government, $GovRD_{bio,all}$ is the unknown and represents all biotech R&D expenditures performed by the government (all funders), $GovRD_{total,fed}$ refers to total natural sciences and engineering R&D expenditures performed by the government sector and funded by the federal government, and $GovRD_{total,all}$ is total natural sciences and engineering R&D expenditures performed by the government sector (all funders). In 2005, federally funded R&D performed by the government represented 83.7 per cent of total R&D performed by the government.[28] Since, federally funded biotech R&D expenditures performed by the government sector were equal to $374 million, using the above formula we have that total biotech R&D expenditures performed by the government were equal to

$$\frac{374\ million}{GovRD_{bio,all}} = 0.837 \rightarrow GovRD_{bio,all} = 447\ million$$

  2) The adjusted R&D data are then multiplied by the share of wages and salaries in R&D expenditures in natural sciences and engineering. Since government data on the cost of wages and salaries was not available, BERD data was used to calculate the aforementioned

[28] The reader should keep in mind that the definition of "government" being used here is quite broad, including not only the federal government, but also the provincial governments, provincial research organizations, and even non-profit organizations. If our definition included only the federal government, then the ratio between federally funded R&D expenditures performed by the federal government and total R&D expenditures performed by the federal government would be 0.97 in 2005 (in the case of R&D expenditures in natural sciences and engineering).

share (Statistics Canada, R&D in Canadian Industry, CANSIM Table 358-0024). In 2005, wages and salaries accounted for 54.5 per cent of total R&D expenditures in natural sciences and engineering. Multiplying this number by the $447 million found in step 1, we have that the value added of government biotech R&D was approximately equal to $244 million in 2005.

- Higher Education Sector – Analogously to the adjustments done to government biotech R&D data, higher education R&D data are converted into value added in two steps:

1) We assume that the relationship between *federally funded* R&D expenditures performed by the higher education sector and *total* R&D expenditures performed by the higher education sector also holds for biotech R&D in particular. This can be understood as:

$$\frac{HERD_{bio,fed}}{HERD_{bio,all}} = \frac{HERD_{total,fed}}{HERD_{total,all}}$$

where $HERD_{bio,fed}$ stands for biotech R&D expenditures performed by the higher education but funded by the federal government, $HERD_{bio,all}$ is the unknown and represents all biotech R&D expenditures performed by the higher education sector (all funders), $HERD_{total,fed}$ refers to total natural sciences and engineering R&D expenditures performed by the higher education sector and funded by the federal government, and $HERD_{total,all}$ is total natural sciences and engineering R&D expenditures performed by the higher education sector (all funders). In 2005, federally funded R&D performed by the higher education sector represented 27.9 per cent of total R&D performed by the higher education sector. Since, federally funded biotech R&D expenditures performed by the higher education sector were equal to $469 million, using the above formula we have that total biotech R&D expenditures performed by the government were equal to

$$\frac{469\ million}{HERD_{bio,all}} = 0.279 \rightarrow HERD_{bio,all} = 1{,}680\ million$$

2) The adjusted R&D data are then multiplied by the share of wages and salaries in R&D expenditures in natural sciences and engineering. Since data on the cost of wages and salaries in the higher education sector was not available, BERD data was used to calculate the aforementioned share (Statistics Canada, R&D in Canadian Industry, CANSIM Table 358-0024). In 2005, wages and salaries accounted for 54.5 per cent of total R&D expenditures in natural sciences and engineering. Multiplying this number by the $1,680 million found in step 1, we have that the value added of higher education sector biotech R&D was approximately equal to $917 million in 2005.

Biotech Users

- Agriculture and Related Activities – Value added of GM crops is calculated in two steps:

  1) Total farm cash receipts of canola, soybeans, corn, and sugarbeets are multiplied by VA-GO ratio of crop and animal production (NAICS codes 111-112) to produce a value added estimate for each crop. In 2005, the VA-GO ratio of crop and animal production was 0.33.

  2) The value added figures computed on step 1 are then multiplied by the share of GM canola, soybeans, corn, and sugarbeets in the total seeded area of each of those crops.

  The value added of other uses of biotechnology in agricultural production (e.g. the use of marker assisted selection in the breeding efforts of plants and animals) is captured by multiplying the GDP of crop production (minus the biotech GDP from GM canola, soybeans, corn, and surgarbeets) and animal production by biotech adoption rates. Based on Zika *et al.* (2007) and OECD (2009), biotech adoption rates in 2005 have been set to 0.10 in both crop production and animal production.

- Medicine and Healthcare – In the case of medical biotech users, since no data regarding biotech adoption rates by healthcare establishments was available, a different approach, similar to the one used in Pellerin and Taylor (2008), was taken. Pellerin and Taylor (2008) multiplied the GDP in the healthcare sector by the share of total pharmaceutical expenditures on medicine and healthcare output, independent of whether those were biotech-based pharmaceuticals or not. Our approach can be broken down into three steps:

  1) First, we find an approximation of the share of biopharmaceuticals in total pharmaceutical and medicine manufacturing. This is done by dividing the revenues of medical biotech producers by the nominal gross output of pharmaceutical and medicine manufacturing (NAICS code 3254).[29] Using this calculation, we find that biopharmaceuticals accounted for 29.7 per cent of pharmaceutical and medicine manufacturing in 2005.

  2) The second step is to multiply the share found in step 1 by the share of drug expenditures in total health expenditures. According to CIHI (2011), drug expenditures represented 16.0 per cent of total health expenditures in Canada in 2005. Multiplying this number by the number calculated in step 1, we find an *adjustment factor* of 4.7 per cent.

  3) Finally, we multiply the adjustment factor computed in step 2 by the GDP of the healthcare sector (NAICS code 62, excluding social assistance).

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[29] This implicitly assumes that all of the revenues of medical biotech producers are due to biopharmaceuticals.

- Industry, Energy and Environment – Biotech adoption rates depend on the area of application:

  1) Food and Beverages Processing – Zika *et al.* (2007) argue that

  > Many enzymatic processes have been universally taken up by the [food and beverages processing] industry and are state-of-the-art technology, which makes a comparison with conventional alternatives impossible. The entire output of the food production processes concerned is therefore considered for calculating the impact of modern biotechnology (p. 90).

  According to Zika *et al.*, the above applies to the production of dairy, starch and sugar, bakery, fruit juice, wine making, brewing, nutrition and dietary supplements. In this report, we adopt a more conservative perspective, assuming a biotech adoption rate of 0.80 (instead of 1.00) in sugar manufacturing (NAICS code 31131), dairy product manufacturing (NAICS code 3115), bread and bakery manufacturing (NAICS code 31181), breweries (NAICS code 31212), and wineries (NAICS code 31213). GDP in the aforementioned activities is multiplied by the biotech adoption rate to find the overall biotech GDP in food and beverages manufacturing.

  2) Detergent Manufacturing – Zika *et al.* (2007) estimate that 30-50 per cent of all detergents sold in the European Union in 2005 contained enzymes (p. 88). In this report, we assume an adoption rate of 0.40 for Canada, and multiply it by GDP in soap and cleaning compound manufacturing (NAICS code 32561) to find the biotech GDP associated with detergent manufacturing.

  3) Pulp and Paper Manufacturing – Based on discussions with experts, Zika *et al.* (2007) assume a biotech adoption rate of 0.15 in E.U. pulp manufacturing in 2005 (pp. 91-92), which accounts basically for pulp mills that have enzyme-aided production processes. To compute the biotech GDP linked to pulp manufacturing, we multiply the aforementioned biotech adoption rate by GDP in pulp manufacturing (NAICS code 32211). Since no data on enzyme use in paper production (NAICS code 32212) was available, the biotech adoption rate for this activity is assumed to be 0.0.

  4) Textile Finishing – Based on discussions with experts, Zika *et al.* (2007) impute a biotech adoption rate of 0.40 for E.U. textile finishing activities in 2005 (p. 95), i.e. 40 per cent of textile-finishing in the European Union was done using enzyme-aided techniques. In this report, we use the same biotech adoption rate for Canada, multiplying it by GDP in textile and fabric finishing and fabric coating (NAICS code 3133) to have an estimate of the biotech GDP associated with textile finishing.

5) Chemical Manufacturing – USDA (2008) estimates that 1.8 per cent of all chemical manufacturing in the world used biotechnology in 2005. To calculate the value added contribution of biotech in chemical manufacturing, we multiply this biotech adoption rate by GDP in chemical manufacturing (NAICS code 325 minus NAICS code 3254, pharmaceutical and medicine manufacturing, to avoid double-counting).

6) Natural Resources – Since no data on use of biotech in mining and oil and gas extraction (NAICS code 21) was available, the biotech adoption rate in this area of application is assumed to be 0.0 in 2005.

7) Environment – Since no data on use of modern biotechnology in waste management and remediation services (NAICS code 562) was available, the biotech adoption rate in this area of application is assumed to be 0.0 in 2005.

The above discussion makes it clear that data for biotech producers (in both the private and public sectors) are more accurate than for biotech users, which (as mentioned before) are based on limited information, since there has never been a general survey on biotech users in Canada.

B. Projecting the Economic Contribution of the Biotech Sector

The increase in world population and income per capita, along with changes in demographic patterns, pose a significant challenge to policy makers devising strategies aimed at sustainable development. According to the OECD, "biotechnology offers technological solutions for many of the health and resource-based problems facing the world" (OECD, 2009, p. 15). Going even further, the OECD study argues that

> The application of biotechnology to primary production, health and industry could result in an emerging "bioeconomy" where biotechnology contributes to a significant share of economic output. The bioeconomy (…) is likely to involve three elements: advanced knowledge of genes and complex cell processes, renewable biomass, and the integration of biotechnology applications across sectors (p. 15).

As mentioned earlier, the purpose of this report is not only to estimate the current contribution of modern biotechnology to the Canadian economy, but also to forecast its contribution twenty years into the future. A reliable forecast of the role of biotechnology in Canada in 2030 requires a good understanding of the driving forces behind the growth of biotechnology applications, which is provided by the OECD (2009). This OECD study identifies a number of factors that could create investment opportunities in modern biotechnology, and thus expand its role in modern society:

- Population growth (highly concentrated in developing countries);
- Income growth (especially in developing countries);
- In the developed world, demographic changes driven by the increase of the share of the population 65 and over, and the decrease in the share of the population 15 and under;
- Increasing demand for energy;
- Climate change;
- Rise in food and water prices;
- Rise in healthcare costs;
- The development of supporting and competing technologies.[30]

Although the above drivers can contribute towards creating investment opportunities in biotechnology, whether or not these opportunities would actually be seized depends on factors such as:

- Public research support;
- Regulations;
- Intellectual property rights;
- Overall social attitudes towards biotechnology.

According to the OECD study, there are two characteristics of biotechnology that allow for a reasonably accurate prediction of its state in the near future. First, biotech applications in primary production and medicine and healthcare can take from 5 to 10 years to be approved. The data trail left by regulatory requirements can thus be used to predict the state of biotechnology in the near future. Second, biotechnology is often used as "a process technology to make existing products such as fuels, plastics, and crop varieties" or "to produce entirely new products such as cancer drugs" (OECD, 2009, p. 26). In all these cases, the "problems that need to be solved are known in advance", which allows for greater accuracy in predictions. Exhibit 15 describes the possible state of biotech in 2015 and 2030 according to the OECD. The OECD report concludes

[30] For a detailed discussion about each of the drivers mentioned above, refer to OECD (2009).

Exhibit 15: The State of Biotechnology in 2015 and 2030

	2015	2030
Agriculture and Related Activities	- Crops with agronomic and product quality traits and smaller market-biotech crops will become available. GM trees could also appear in the market. The share of biotech cotton, corn, rapeseed, and soybean in total global crops is expected to increase. - Low cost and real-time diagnostic methods that can detect multiple pathogens in plants and animals (e.g. microarrays) will become available. - The majority of animal breeding activities will make use of marker assisted selection (MAS). Genetic modification and cloning of animals may be limited as a result of consumer concerns whilst novel compounds and high-value animals may not be limited by such concerns. - New vaccines and biopharmaceuticals that improve meat quality and animal growth are also likely to appear.	- Most plant, livestock, fish, and shellfish breeding will make use of MAS. - GM plants "with improved starch, oil, and lignin content" will be produced specifically with the efficiency of industrial processing in mind (p.195).[31] - Pharmaceuticals and other compounds that use GM plants and animals will be developed. - "Cloning of high-value animal breeding stock" (p.195). - GM, MAS, intragenics and cisgenesis will allow for the development of crops with higher yields, pest resistance, and stress tolerance. - GM technology will enable developing countries to grow crops that have higher vitamin and nutrient content.
Medicine and Healthcare	- It is probable that biotechnology will contribute to the development of new therapeutics and the number of biotherapeutics will increase. - More *in vitro* diagnostics that use biotechnology will be developed. Gene tests will be able to identify multiple genetic mutations. - The number of pharmacogenetic drugs will increase substantially. - Nutritionally enhanced crops and biotech plants with product quality traits will appear in the market. - Insulin produced using tissue engineering could become commercialized.	- New pharmaceuticals and vaccines. - The importance of pharmacogenetics in clinical trials and in prescribing practice will increase while the number of patients that are eligible for a particular treatment will decline. - Improved safety and efficacy of therapeutics. - Detection of multiple genetic risk factors. - Nanotechnology will allow for enhanced drug delivery systems. - New nutraceuticals based on GM micro-organisms. - Low-cost detection of genes that are associated with chronic diseases. - Regenerative medicine will contribute to improved replacement or repair of damaged tissue.
Industry, Energy and Environment	- New biocatalysts, advanced fermentation, and improved metabolic pathway engineering will contribute to the increased share of biobased chemicals in total chemical production. Specialty chemicals and polymers are expected to experience the highest growth within chemical production. - Non-biodegradable plastics will be developed and the share of bioplastics in total plastics is expected increase. - More effective enzymes and production processes. Increased usage of industrial enzymes. - Bioremediation will gain importance as new micro-organisms are developed.	- Improved enzymes in chemical production. - Micro-organisms that can produce more chemicals in one step will be developed. - Biometrics will be used to identify people and biosensors will be used to monitor environmental pollutants. - High energy-density biofuels will be produced using sugar cane and biomass. - Biomaterials such as bioplastics will gain greater importance in the market.

Source: OECD (2009).

[31] FPAC (2011) discusses in detail some of the possible biotech developments in the forestry industry.

that biotechnology could represent 2.7 per cent of the total GDP of OECD countries in 2030 (p. 199).

Our baseline forecast takes a business-as-usual approach, and assumes that biotechnology develops at an incremental pace (no disruptive or radical discoveries are made). Regulations, intellectual property rights, and overall social attitudes towards biotechnology remain unchanged, and the government continues to play an important role in performing and supporting biotech R&D. Increased demand for food, energy and healthcare drives biotech GDP to grow faster than overall economy GDP.

An important assumption in our forecast, also adopted by the OECD forecast (OECD, 2009), is that the sectoral composition of the Canadian economy will remain the same i.e. the share of agriculture, manufacturing, and other sectors in total economy nominal GDP will not change significantly. This works as an upper bound for our forecasts, since the GDP share of biotech producers and users will not be able to exceed the GDP share of the industries identified in Exhibit 13.[32] Nominal GDP growth forecasts are taken from Dungan and Murphy (2011), and assume an average annual growth rate of 4.2 per cent, with annual inflation at about 2 per cent per year. Below, we detail other assumptions and data adjustments used in our baseline forecast.

Biotech Producers, Private Sector

- Agriculture and Related Activities – Agricultural biotech revenues are assumed to grow at an annual growth rate of 12.0 per cent during the 2005-2015 period, the same growth rate observed during the 1999-2005 period. Revenues are assumed to grow at a slightly slower pace of 10.0 per cent per year during the 2015-2030 period.

- Medicine and Healthcare – Biotech revenues in medicine and healthcare are assumed to increase at an annual growth rate of 15.0 per cent during the 2005-2015 period, slower than the historical growth rate of 19.2 per cent per year observed during the 1999-2005 period. For the 2015-2030 period, revenues are assumed to grow 13 per cent per year. A second assumption is that the VA-GO ratio will remain constant at 55.0 per cent, very close to the average of 56.2 per cent seen in the 1999-2005 period.

- Industry, Energy and Environment – Industrial biotech revenues are assumed to grow 15 per cent per year from 2005 to 2015, and 13 per cent per year from 2015 to 2030, significantly faster than the average annual growth rate of -10.1 per cent seen in the 1999-2005 period.

[32] In the case of biotech users, the assumption of no changes in sectoral composition coupled with gradually increasing biotech adoption rates lead to a slow, but inexorable replacement of non-biotech activities in a certain sector by biotech activities. Thus, it implicitly assumes that biotech activities experience higher growth rates than non-biotech activities. Once the biotech adoption rate reaches 1.0, the faster growth of biotech activities reverts back to total economy nominal GDP growth.

During the 2003-2005 period, industrial biotech revenues went from $1,345 million in 2003 to $181 million in 2005, a decline of 86.5 per cent. This drop was largely caused by a drop in biotech revenues associated with food and beverages processing, and seems unlikely. It possibly indicates a data error, given that from 1999 to 2003 industrial biotech revenues grew 40 per cent per year. The chosen growth rate represents less than half of the growth rate observed in the 1999-2003 period. A second assumption is that the VA-GO ratio will remain constant at 50.0 per cent, very close to the average of 49.9 per cent seen in the 1999-2005 period.

- Other Applications – Biotech revenues related to the development of platform technologies or other biotech applications are assumed to grow 7 per cent per year from 2005 to 2015, and 5 per cent per year from 2015 to 2030, in contrast to the average annual growth rate of -13.3 per cent seen in the 1999-2005 period. The main motivation for choosing these growth rates is the expectation that increased demand for food, energy, and healthcare will increase interest in biotechnology, driving up biotech R&D in platform technologies. A second assumption is that the VA-GO ratio will remain constant at 60.0 per cent, very close to the average of 59.2 per cent seen in the 1999-2005 period.

Biotech Producers, Public Sector

- The cost of wages and salaries are assumed to account for 55.0 per cent of total R&D expenditures in the public sector, slightly more than the average of 54.0 per cent observed in the 1999-2008 period.

- Government Sector – Biotech R&D expenditures funded by the federal government and performed by the (overall) government sector are assumed to grow 7.5 per cent per year from 2005 to 2015, in line with the growth rate of 7.6 per cent per year seen in the 1999-2008 period. For the 2015-2030 period, growth in R&D expenditures is assumed to slow down slightly to 5.5 per cent per year.

- Higher Education Sector – Biotech R&D expenditures funded by the federal government and performed by the higher education sector are assumed to grow 10 per cent per year from 2005 to 2015, slightly slower than the growth rate of 14.0 per cent observed during the 1999-2008 period. For the 2015-2030 period, growth in R&D expenditures is assumed to slow down slightly to 8.0 per cent per year.

Biotech Users

- Unless noted otherwise, adoption rates for biotech applications are assumed to increase at an annual rate of 5 per cent per year during the 2005-2030 period. This allows for an incremental growth in the importance of biotech in the industries and sectors were it plays a role. It is important to note that biotech adoption rates range from 0.0 to 1.0. If and when the upper bound of 1.0 is reached, biotech adoption rates are assumed to remain at that level until 2030.

- Agriculture and Related Activities – The following assumptions are made to forecast the role of biotech users in this area: 1) The shares of GM canola, GM corn, GM soybeans, and GM sugarbeets in the total acreage of these crops are assumed to growth at an annual rate of 3 per cent per year (if GM crop shares reach 100 per cent, they are assumed to stay at that level until 2030); 2) Farm cash receipts for these crops are also assumed to grow 5 per cent per year (which is slower than the historical average, except in the case of sugarbeets).

- Chemical Manufacturing – Biotech adoption rates are assumed to grow at an average annual rate of 25.0 per cent from 2005 to 2015, and 5.0 per cent from 2015-2030. These rates are consistent with the OECD (2009) estimate that biotech-based chemical production would increase from 1.8 per cent of chemical manufacturing GDP in 2005 to 12-20 per cent in 2015, and 35 per cent in 2030 (pp. 99 and 201).

In addition to the baseline forecast, we also construct pessimistic and optimistic scenarios. The pessimistic scenario assumes that all growth rates are 2.0 percentage points *lower* than in the baseline scenario for both the 2005-2015 period and the 2015-2030 period. The optimistic scenario, on the other hand, assumes that all growth rates are 2.0 percentage points *higher* than in the baseline scenario.

VI. Results

In this section, we present and discuss our estimates of the contribution of biotechnology to the Canadian economy in terms of value added, as well as forecast its possible importance in 2030.

A. GDP of Biotech Activities, 1999-2005

Following the discussion in the previous section, Table 15 and Table 16 detail the basic data used to calculate our estimates. The first table shows the available data for biotech producers and biotech users. In particular, it shows our assumptions regarding the adoption rates of biotech processes/products by *potential* biotech users in the Canadian economy. The second table describes the non-biotech data that are used to adjust the data on Table 15 in order to find the total value added of biotechnology activities. The first column in each of the tables is an identifier column that can be used to understand how the estimates in Table 17 were calculated.

Table 15: Basic Data for Estimating the Value Added of Biotechnology in the Canadian Economy, Biotech Data, 1999-2005

		1999	2001	2003	2005	CAGR, 1999-2005
						(per cent)
	Biotech Producers					
		(biotech revenues, millions)				
	Private Sector					
(a)	Agriculture and Related Activities	524	198	469	1,034	12.0
(b)	Medicine and Healthcare	1,036	2,235	1,995	2,967	19.2
(c)	Industry, Energy and Environment	343	893	1,345	181	-10.1
(d)	Other	45	*36*	26	19	-13.3
		(biotech R&D expenditures, millions)				
	Public Sector					
(e)	Higher Education Sector	169	206	379	469	18.5
(f)	Government Sector	185	313	345	374	12.4
	Biotech Users					
		(seeded area of GM crop divided by total seeded area of crop, per cent)				
	Agriculture and Related Activities					
(g)	Canola	*37.4*	*52.3*	*67.1*	82.0	14.0
(h)	Soybeans	*6.9*	*20.8*	*34.7*	*48.6*	38.3
(j)	Corn	*12.5*	*31.9*	*51.2*	*70.6*	33.5
(k)	Sugarbeets	..	..	..	..	
		(per cent of crop or livestock production that uses other biotech techniques, e.g. MAS)				
(l)	Other Uses - Crop Production	7.5	8.2	9.1	10.0	..
(m)	Other Uses - Livestock Production	7.5	8.2	9.1	10.0	..
		(share of biopharmaceuticals in total health expenditures, per cent)				
(n)	Medicine and Healthcare	2.6	3.7	2.8	4.7	..
		(biotech adoption rates, per cent)				
	Industry, Energy and Environment					
(o)	Food and Beverages Processing	18.1	18.9	19.8	22.3	..
	Industrial Processing					
(p)	Detergent Manufacturing	29.8	32.9	36.3	40.0	
(q)	Pulp and Paper	11.2	12.3	13.6	15.0	
(r)	Textile Finishing	29.8	32.9	36.3	40.0	
(s)	Chemical Manufacturing	1.3	1.5	1.6	1.8	
(t)	Natural Resources	0.0	0.0	0.0	0.0	..
(u)	Environment	0.0	0.0	0.0	0.0	..

Source: CSLS.

Table 16: Basic Data for Estimating the Value Added of Biotechnology in the Canadian Economy, Non-Biotech Data, 1999-2005

		1999	2001	2003	2005	Observations
	Biotech Producers					
	Private Sector					
		(value added to gross output ratio, per cent)				
(i)	Agriculture and Related Activities	55.4	53.9	54.9	55.3	NAICS codes: 111 + 112 + 41 + 54
(ii)	Medicine and Healthcare	57.4	55.5	56.5	56.0	NAICS codes: 325 + 41 + 54 + 62
(iii)	Industry, Energy and Environment	47.8	49.3	50.3	53.1	NAICS codes: 211 + 2211 + 311 + 322 + 325 + 54
(iv)	Other	57.7	58.5	60.5	60.6	NAICS code: 54
	Public Sector					
		(share of wages and salaries in total R&D, per cent)				
(v)		48.2	48.5	54.0	54.5	
		(share of federally funded R&D divided by total performed R&D in the sector, per cent)				
(vi)	Higher Education Sector	23.5	26.3	28.2	27.9	
(vii)	Government Sector	84.8	84.2	83.5	83.7	
	Biotech Users					
	Agriculture and Related Activities					
		(value added to gross output ratio, NAICS codes 111 and 112, per cent)				
(viii)		38.5	36.2	35.4	33.3	
		(total farm cash receipts, millions of current dollars)				
(ix)	Canola	1,771	1,723	1,890	1,826	
(x)	Soybeans	618	534	758	760	
(xi)	Corn	743	631	787	623	
(xii)	Sugarbeets	31	19	23	32	
		(GDP, millions of current dollars)				
(xiii)	Other Uses - Crop Production	9,633	8,585	10,428	8,120	NAICS codes: 111
(xiv)	Other Uses - Livestock Production	4,810	6,584	4,903	6,495	NAICS codes: 112
		(GDP, millions of current dollars))				
(xv)	Medicine and Healthcare	48,717	56,618	63,811	70,246	NAICS codes: 62 - 624
		(GDP, millions of current dollars)				
	Industry, Energy and Environment					
(xvi)	Food and Beverages Processing	18,999	21,274	22,505	24,616	NAICS codes: 311 + 312 - 3122
	Industrial Processing					
(xvii)	Detergent Manufacturing	868	924	776	586	NAICS code: 32561
(xviii)	Pulp and Paper	2,509	2,821	2,063	2,047	NAICS code: 32211
(xix)	Textile Finishing	239	313	262	280	NAICS code: 3133
(xx)	Chemical Manufacturing	9,291	9,208	9,836	9,356	NAICS codes: 325 - 32561 - 3254
(xxi)	Natural Resources	34,468	59,442	71,545	110,695	NAICS codes: 21
(xxii)	Environment	1,490	1,818	2,476	3,044	NAICS codes: 562

Source: CSLS.

According to the CSLS estimates, the value added of biotech activities reached $15,300 million current dollars in 2005, up from $8,336 million in 1999 (Table 17). This represents an average annual growth rate of 10.7 per cent during the 1999-2005 period, considerably more than the growth experienced by the total economy (5.9 per cent per year), which explains why biotechnology's share of total economy GDP increased from 0.92 per cent to 1.19 per cent (Table 18).

Table 17: The Contribution of Biotechnology to Total Economy GDP in Canada, millions of current dollars, 1999-2005

		1999	2001	2003	2005	CAGR, 1999-2005
		(millions of current dollars)				(per cent)
	Total Economy GDP, Canada	**909,694**	**1,032,172**	**1,128,796**	**1,280,550**	**5.9**
	Total Economy GDP, Canada, % Change		**3.2%**	**5.6%**	**6.6%**	
A=B+K	**Total Biotech Contribution**	**8,336**	**11,029**	**12,122**	**15,300**	**10.7**
B=C+H	**Biotech Producers**	**1,528**	**2,369**	**3,025**	**3,501**	**14.8**
C=D+E+F+G	*Private Sector*	*1,075*	*1,809*	*2,076*	*2,340*	*13.8*
D=(a)*(i)	Agriculture and Related Activities	290	107	257	572	12.0
E=(b)*(ii)	Medicine and Healthcare	595	1,241	1,127	1,661	18.7
F=(c)*(iii)	Industry, Energy and Environment	164	441	676	96	-8.5
G=(d)*(iv)	Other	26	21	16	12	-12.6
H=I+J	*Public Sector*	*453*	*560*	*949*	*1,161*	*17.0*
I=((e)/(vi))*(v)	Higher Education Sector	347	380	726	917	17.6
J=((f)/(vii))*(v)	Government Sector	105	180	223	244	15.0
K=L+R+S	**Biotech Users**	**6,808**	**8,661**	**9,097**	**11,799**	**9.6**
L=M+N+O+P+Q	Agriculture and Related Activities	1,362	1,651	2,014	2,152	7.9
M=(g)*(viii)*(ix)	Canola	255	326	449	498	11.8
N=(h)*(viii)*(x)	Soybeans	17	40	93	123	39.7
O=(j)*(viii)*(xi)	Corn	36	73	143	146	26.5
P=(k)*(viii)*(xii)	Sugarbeets	..	..	..	..	..
Q=((l)*(xiii))+((m)+(xiv))	Other Uses	1,055	1,212	1,328	1,385	4.6
R=(n)*(xv)	Medicine and Healthcare	1,275	2,105	1,813	3,335	17.4
S=T+U+Z+AA	Industry, Energy and Environment	4,171	4,905	5,270	6,312	7.1
T=(o)*(xvi)	Food and Beverages Processing	3,435	4,013	4,452	5,490	8.1
U=V+W+X+Y	Industrial Processing	736	892	818	822	1.8
V=(p)*(xvii)	Detergent Manufacturing	259	304	281	234	-1.7
W=(q)*(xviii)	Pulp and Paper	281	348	281	307	1.5
X=(r)*(xiv)	Textile Finishing	71	103	95	112	7.8
Y=(s)*(xx)	Chemical Manufacturing	125	136	161	168	5.1
Z=(t)*(xxi)	Natural Resources	0	0	0	0	..
AA=(u)*(xxii)	Environment	0	0	0	0	..

Notes: 1) GDP at basic prices; 2) CAGR stands for "Compound Annual Growth Rates".
Source: CSLS.

Table 18: The Contribution of Biotechnology to Total Economy GDP in Canada, as a share of total economy GDP, 1999-2005

	1999	2001	2003	2005	Δ, 1999-2005
	(per cent)				(percentage points)
Total Economy GDP, Canada	**100.00**	**100.00**	**100.00**	**100.00**	0.00
Total Biotech Contribution	**0.92**	**1.07**	**1.07**	**1.19**	0.28
Biotech Producers	**0.17**	**0.23**	**0.27**	**0.27**	0.11
Private Sector	*0.12*	*0.18*	*0.18*	*0.18*	0.06
Agriculture and Related Activities	0.03	0.01	0.02	0.04	0.01
Medicine and Healthcare	0.07	0.12	0.10	0.13	0.06
Industry, Energy and Environment	0.02	0.04	0.06	0.01	-0.01
Other	0.00	0.00	0.00	0.00	0.00
Public Sector	*0.05*	*0.05*	*0.08*	*0.09*	0.04
Higher Education Sector	0.04	0.04	0.06	0.07	0.03
Government Sector	0.01	0.02	0.02	0.02	0.01
Biotech Users	**0.75**	**0.84**	**0.81**	**0.92**	0.17
Agriculture and Related Activities	0.15	0.16	0.18	0.17	0.02
Canola	0.03	0.03	0.04	0.04	0.01
Soybeans	0.00	0.00	0.01	0.01	0.01
Corn	0.00	0.01	0.01	0.01	0.01
Sugarbeets	..	..	..	..	..
Other Uses	0.12	0.12	0.12	0.11	-0.01
Medicine and Healthcare	0.14	0.20	0.16	0.26	0.12
Industry, Energy and Environment	0.46	0.48	0.47	0.49	0.03
Food and Beverages Processing	0.38	0.39	0.39	0.43	0.05
Industrial Processing	0.08	0.09	0.07	0.06	-0.02
Detergent Manufacturing	0.03	0.03	0.02	0.02	-0.01
Pulp and Paper	0.03	0.03	0.02	0.02	-0.01
Textile Finishing	0.01	0.01	0.01	0.01	0.00
Chemical Manufacturing	0.01	0.01	0.01	0.01	0.00
Natural Resources	0.00	0.00	0.00	0.00	0.00
Environment	0.00	0.00	0.00	0.00	0.00

Source: CSLS.

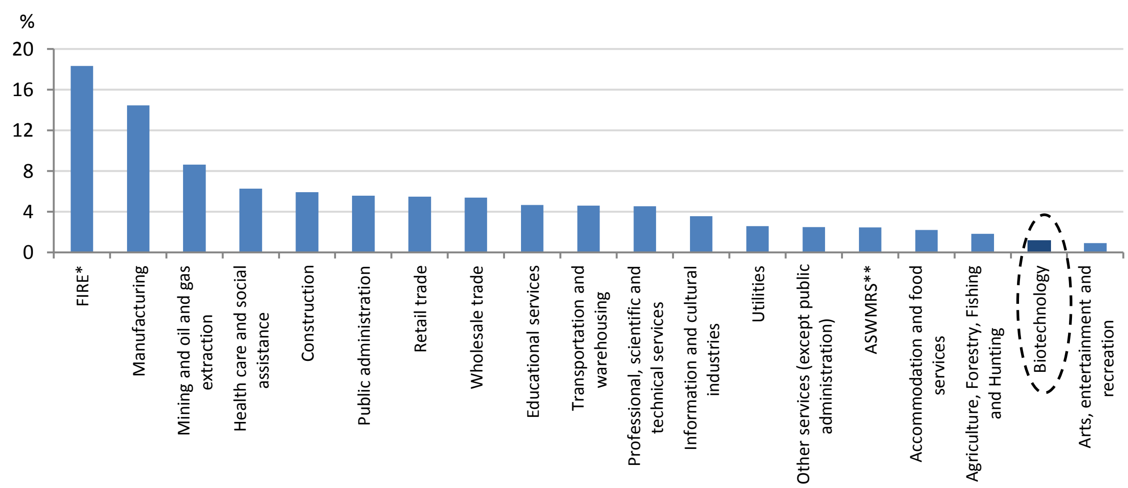
In 2005, biotech producers were estimated to have been responsible for approximately one fourth of the total value added of biotechnology activities, $3,501 million. In the private sector, the most important biotech producers were firms developing applications in medicine and healthcare ($1,661 million), followed by firms involved in agriculture and related activities ($572 million). In the public sector, biotech R&D performed by the higher education sector accounted for $917 million in value added, while government biotech R&D was responsible for $244 million.

As mentioned in the methodology section, the real source of variability in our estimates comes from the biotech users, especially users of industrial biotech applications. The lack of detailed data required us to make broad assumptions regarding the use of biotech in the production processes of a variety of activities, ranging from food and beverages processing and chemical processing to mining and oil extraction, and remediation services.

According to our estimates, biotech users were responsible for three fourths of the total value added of biotech in 2005, $11,799 million. Industrial biotech applications, such as the use of enzymes in food and beverages processing, represented most of the biotech users total value added ($6,312 million). Medical biotech users generated a total value added of $3,335 million, while GM crops and other uses of biotech in agriculture (e.g. MAS) were responsible for a total value added of $2,152 million in 2005.

Comparing the value added contribution of biotechnology activities to that of two-digit NAICS sectors in Canada in 2005, we can see that biotechnology represents a fairly small part of the Canadian economy, close in size to arts, entertainment and recreation (0.91 per cent of total economy GDP), as well as to agriculture, forestry, fishing and hunting (1.84 per cent), but nowhere near the importance of sectors such as finance, insurance, real estate and renting and leasing (FIRE) (18.35 per cent), manufacturing (14.45 per cent), or mining and oil and gas extraction (8.64 per cent) (Chart 16).

Chart 16: Biotech GDP as a Share of Total Economy GDP, Sectoral Comparison (two-digit NAICS), 2005

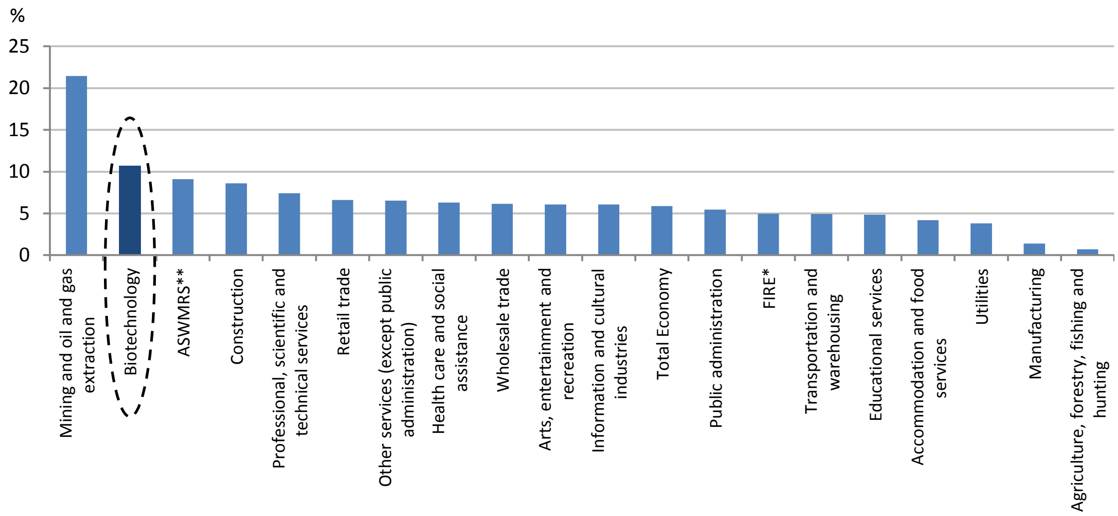


*Finance, insurance, real estate and renting and leasing. ** Administrative and support, waste management and remediation services

Source: Nominal GDP at basic prices data taken from Statistics Canada, Input-Output Structure of the Canadian Economy in Current Prices (CANSIM Table 379-0023).

Looking at growth rates, however, we have a very different picture (Chart 17). The nominal GDP of biotech activities grew at an average annual rate of 10.7 per cent from 1999 to 2005, faster than any two-digit NAICS sector in the Canadian economy with the exception of mining and oil and gas extraction, which grew 20.5 per cent per year. Sectors such as administrative and support, waste management and remediation services (ASWMRS), and construction grew at fast rates (9.1 and 8.6 per cent per year, respectively), but still slightly slower than the growth rate observed in biotech.

Chart 17: Compound Annual Growth Rate of Biotech GDP, Sectoral Comparison (two-digit NAICS), per cent, 1999-2005

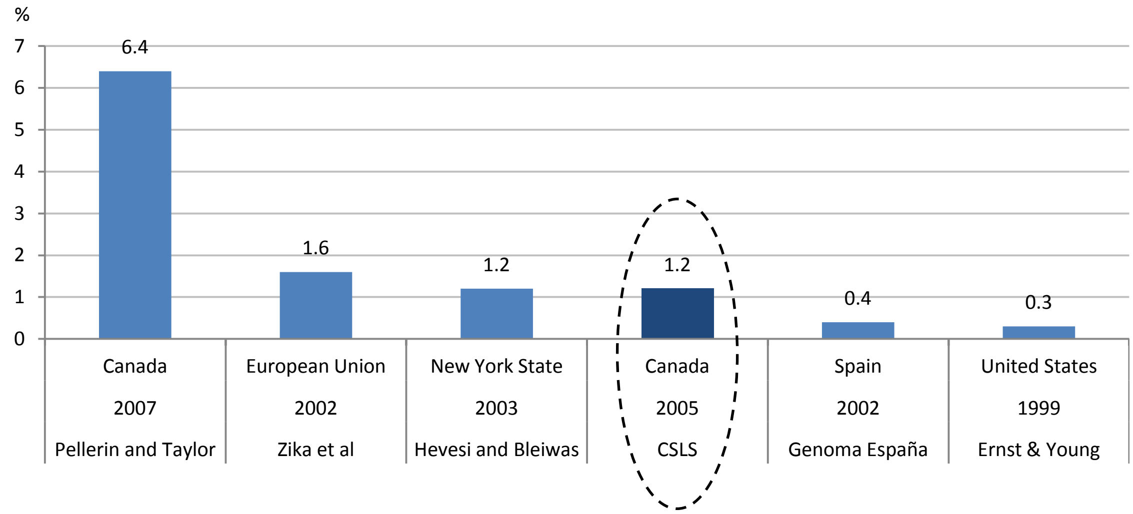


*Finance, insurance, real estate and renting and leasing. ** Administrative and support, waste management and remediation services
Source: Nominal GDP at basic prices data taken from Statistics Canada, Input-Output Structure of the Canadian Economy in Current Prices (CANSIM Table 379-0023).

Chart 18 compares the CSLS estimate of the contribution of biotechnology activity to the Canadian economy in 2005 with the estimates discussed in the literature review section. The differences in estimates are driven by two factors: 1) with the exception of Pellerin and Taylor (2008), estimates refer to different countries and different base years; 2) different methodologies were employed to calculate each estimate – in particular, as Exhibit 11 shows, estimates take into account different parts of the biotech value added chain of production.

Note, in particular, that the CSLS estimate of the economic importance of biotechnology in Canada is significantly smaller than the estimate provided by Pellerin and Taylor (2008). While the CSLS estimates that biotechnology accounted for 1.2 per cent of GDP in Canada in 2005, Pellerin and Taylor (2008) calculate that the biobased economy was responsible for 6.4 per cent of total economy GDP in 2007. Aside from the fact that the CSLS estimate refers to 2005 instead of 2007, which would account for only a very small part of the difference, what are the factors driving this difference?

Chart 18: Estimates of the Economic Contribution of Biotechnology Activity throughout the World as a Share of Country GDP



Source: CSLS calculations based on Ernst & Young (2000), Hevesi and Bleiwas (2003), Genoma España (2005), Zika *et al.* (2007), and Pellerin and Taylor (2008).

One of the main factors behind the difference in the two estimates is the broad definition of "biobased economy" used in Pellerin and Taylor (2008). As shown in Exhibit 9, their definition of biobased economy: 1) includes the entire value added of pharmaceutical and medical manufacturing, instead of just the share of pharmaceutical and medical manufacturing that uses biotechnology; 2) includes the value added of healthcare (minus social assistance) weighted by the percentage of pharmaceutical expenditures even though not all pharmaceutical expenditures are due to biopharmaceuticals. Although there are other differences between the CSLS definition of biotechnology activity and Pellerin and Taylor's concept of biobased economy, the two points delineated above are very important (especially the second), given that health, medical and pharmaceutical applications represented 63 per cent of the "direct" biobased economy. More specifically, health, medical and pharmaceutical applications was responsible for approximately 1.6 per cent of total economy GDP in Pellerin and Taylor's framework, but only 0.4 per cent of total economy GDP in the CSLS estimate.

The most important difference between the CSLS estimate and Pellerin and Taylor (2008) is the fact that the latter takes into account forward linkages, as well as the income multiplier effect. As mentioned previously, the CSLS estimate takes into account neither, since its main objective is to measure the economic contribution of the two groups that constitute the actual core of biotechnology activity: biotech producers and biotech users. The forward linkages and the income multiplier effect were responsible for approximately 3.2 per cent of total economy GDP in Pellerin and Taylor's estimate of the biobased economy.

Once we control for the differences discussed above, Pellerin and Taylor's estimate of the biobased economy declines from 6.4 per cent of total economy GDP to 2.0 per cent. Although this number is still higher than our estimate, the difference is not as drastic as before.[33]

B. Projecting GDP of Biotech Activities, 2006-2030

Using the assumptions described in the methodology section, the CSLS forecasts that nominal biotech GDP will grow at an average annual rate of 9.4 per cent per year during the 2005-2030 period, with the value added associated with biotech users growing faster than that of biotech producers (9.5 per cent versus 8.8 per cent, respectively). In this baseline scenario, nominal biotech GDP will reach approximately $144 billion in 2030, equivalent to 3.99 per cent of forecasted total economy nominal GDP in Canada (Table 19, Table 20). As Chart 19 shows, this implies a growing gap between biotech producers and biotech users.

The OECD calculates that, at most, biotech would be responsible for 5.6 per cent of EU-25 GDP and 5.8 per cent of U.S. GDP in 2030 (OECD, 2009, p. 201). However, their actual estimate is significantly below the upper bound:

> Of course, biotechnology is unlikely to contribute to this level of economic activity by 2030, although it may approach this limit at a later date. Many industrial processes will continue to rely on existing technologies in 2030, with biotechnology possibly contributing to 35% of all chemical production in 2030 within the OECD area. Biotechnology will contribute to the development and production of almost all new pharmaceuticals in 2030, but generics that predate the biotechnology revolution will account for part of the pharmaceutical market. (…) In primary production, biotechnology will not be widely used in boreal forests, but it could contribute to half of agricultural production and almost all of aquaculture and plantation forestry, for a total contribution of approximately 50% of primary production output. Given these shares, a rough estimate is that the potential contribution of biotechnology to GVA by sector in the OECD plus a few other European countries, based on current shares and GVA levels by application, would total USD 1 062 trillion: USD 259 billion in health, USD 381 billion in primary production, and USD 422 billion in industry. This equals approximately 2.7% of total GVA in these countries (p. 201).

Our estimate, despite being higher than that of the OECD by approximately 1.3 percentage points shares an important characteristic with the OECD estimate. Namely, industrial

[33] Other factors that cause the two estimates to be different are: 1) as mentioned before, the CSLS estimate refers to 2005 while Pellerin and Taylor's estimate refers to 2007; 2) the fact that the CSLS estimate was calculated in nominal terms while Pellerin and Taylor's estimate is in real terms (most likely, this factor is responsible for only a small part of the difference, given that both estimates refer to years relatively close to the base year of 2002); 3) again, the broad definition of biobased economy used by Pellerin and Taylor, which includes, for instance, all basic chemical manufacturing, instead of only processes that use modern biotechnology.

biotech accounts for the lion's share of biotech GDP in both estimates. Table 21 compares the baseline CSLS estimate with the OECD estimate.

Table 19: Forecasting Biotech GDP in Canada, current dollars, 2015 and 2030

	2005	2015	2030	CAGR, 2005-2030
	(millions of current dollars)			(per cent)
Total Economy GDP, Canada	**1,280,550**	**1,927,673**	**3,607,512**	**4.2**
Total Biotech Contribution	**15,300**	**40,344**	**144,035**	**9.4**
Biotech Producers	**3,501**	**8,841**	**28,788**	**8.8**
Private Sector	*2,340*	*6,097*	*20,445*	9.1
Agriculture and Related Activities	572	1,475	4,679	8.8
Medicine and Healthcare	1,661	4,233	13,428	8.7
Industry, Energy and Environment	96	366	2,291	13.5
Other	12	22	47	5.8
Public Sector	*1,161*	*2,745*	*8,343*	8.2
Higher Education Sector	917	2,358	7,481	8.8
Government Sector	244	386	862	5.2
Biotech Users	**11,799**	31,503	115,247	9.5
Agriculture and Related Activities	2,152	7,248	21,563	9.7
Canola	498	2,500	5,197	9.8
Soybeans	123	587	1,438	10.3
Corn	146	685	1,424	9.5
Sugarbeets	..	10	22	..
Other Uses	1,385	3,465	13,482	9.5
Medicine and Healthcare	3,335	8,463	32,927	9.6
Industry, Energy and Environment	6,312	15,792	60,757	9.5
Food and Beverages Processing	5,490	12,438	48,390	9.1
Industrial Processing	822	3,354	12,368	11.5
Detergent Manufacturing	234	498	1,432	7.5
Pulp and Paper	307	688	2,677	9.0
Textile Finishing	112	172	493	6.1
Chemical Manufacturing	168	1,996	7,765	16.6
Natural Resources	0	0	0	..
Environment	0	0	0	..

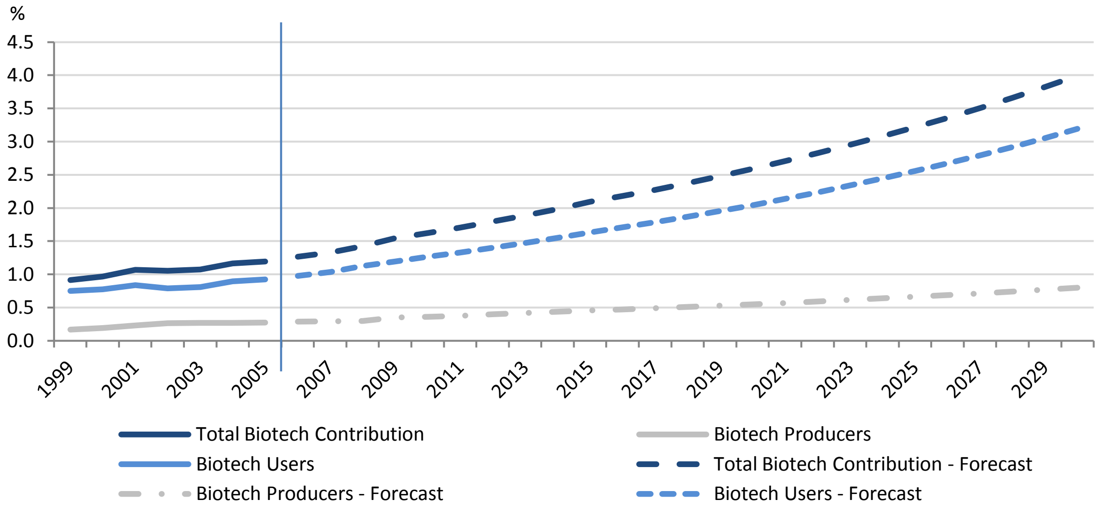
Source: CSLS calculations. Nominal GDP *growth rates* from Dungan and Murphy (2011).

Table 20: Biotech GDP as a Share of Total Economy GDP in Canada, 2005, 2015 and 2030

	2005	2015	2030	Δ, 2005-2030
	(per cent)			(percentage points)
Total Economy GDP, Canada	**100.00**	**100.00**	**100.00**	0.00
Total Biotech Contribution	**1.19**	**2.09**	**3.99**	2.80
Biotech Producers	**0.27**	**0.46**	**0.80**	0.52
Private Sector	*0.18*	*0.32*	*0.57*	0.38
Agriculture and Related Activities	0.04	0.08	0.13	0.09
Medicine and Healthcare	0.13	0.22	0.37	0.24
Industry, Energy and Environment	0.01	0.02	0.06	0.06
Other	0.00	0.00	0.00	0.00
Public Sector	*0.09*	*0.14*	*0.23*	0.14
Higher Education Sector	0.07	0.12	0.21	0.14
Government Sector	0.02	0.02	0.02	0.00
Biotech Users	**0.92**	**1.63**	**3.19**	2.27
Agriculture and Related Activities	0.17	0.38	0.60	0.43
Canola	0.04	0.13	0.14	0.11
Soybeans	0.01	0.03	0.04	0.03
Corn	0.01	0.04	0.04	0.03
Sugarbeets	..	0.00	0.00	..
Other Uses	0.11	0.18	0.37	0.27
Medicine and Healthcare	0.26	0.44	0.91	0.65
Industry, Energy and Environment	0.49	0.82	1.68	1.19
Food and Beverages Processing	0.43	0.65	1.34	0.91
Industrial Processing	0.06	0.17	0.34	0.28
Detergent Manufacturing	0.02	0.03	0.04	0.02
Pulp and Paper	0.02	0.04	0.07	0.05
Textile Finishing	0.01	0.01	0.01	0.00
Chemical Manufacturing	0.01	0.10	0.22	0.20
Natural Resources	0.00	0.00	0.00	0.00
Environment	0.00	0.00	0.00	0.00

Source: CSLS calculations.

Chart 19: Forecasting the Contribution of Biotech GDP as a Share of Total Economy GDP in Canada, 2006-2030



Source: CSLS calculations.

Table 21: Comparison between the CSLS and the OECD forecasts of the Bioeconomy in 2030 as a Share of Total Economy GDP

	CSLS (Canada)	OECD (OECD countries)
Total Biotech Contribution	**3.99**	**2.70**
Public Sector R&D	0.23	..
Industrial Biotech	1.75	1.07
Medical Biotech	1.28	0.66
Agricultural Biotech	0.73	0.97

Note:

Source: OECD shares calculated based on numbers on OECD (2009), pp. 201-202.

The differences between the CSLS and the OECD forecast are driven partly by the fact that Canada and the aggregate of OECD countries have different industry compositions, and partly by methodological differences. Below, we identify the most relevant methodological differences.

- The OECD forecast does not include the role of public sector biotech R&D in generating value added for the economy;

- Different assumptions regarding adoption rates. The OECD forecast assumes a biotech adoption rate of 50 per cent for agriculture and related activities, 80 per cent for medicine and healthcare, and 35 per cent for industry in 2030. In the case of the CSLS forecast, the biotech adoption rates for agriculture and related activities varied according to the activity, but were around 35 per cent in 2030 (a conservative estimate was used due to the lack of data on the use of MAS); the adoption rates for biotech-based industrial applications also varied significantly, ranging from 0.0 per cent in mining and oil and gas extraction and remediation services (due to lack of data), to 35 per cent in chemical manufacturing, 50 per cent in pulp and paper manufacturing, and 100 per cent in detergent manufacturing and textile finishing; the medical biotech adoption rate was 16 per cent, but it is not directly comparable to that of the OECD forecast (more on that below).

- Medical biotech in the OECD forecast refers only to the value added generated by biopharmaceuticals, whereas the CSLS forecast also tries to incorporate in its estimate the use of those biopharmaceuticals by the healthcare system (hospitals, clinics, etc.). Taking into account only the role of biotech producers (which represent, roughly, the firms that produce biopharmaceuticals), the contribution of medical biotech to the economy in the CSLS forecast would drop from 1.28 per cent to 0.37 per cent.

- The OECD forecast does not look into the contribution to GDP of biotech-based food and beverages manufacturing, whereas this industry accounts for most of the CSLS's industrial biotech estimate.[34] On the other hand, the CSLS estimate currently does not include the contribution of biotech-based mining and oil and gas extraction due to lack of data on current adoption rates. Furthermore, the CSLS forecast includes textile finishing, but not textile manufacturing as a whole, as is the case in the OECD forecast. In Canada, for instance, textile finishing represents around 10 per cent of the total gross output of textile and textile product mills (see Statistics Canada, Provincial Gross Output at Basic Prices in Current Dollars, CANSIM Table 381-0016).

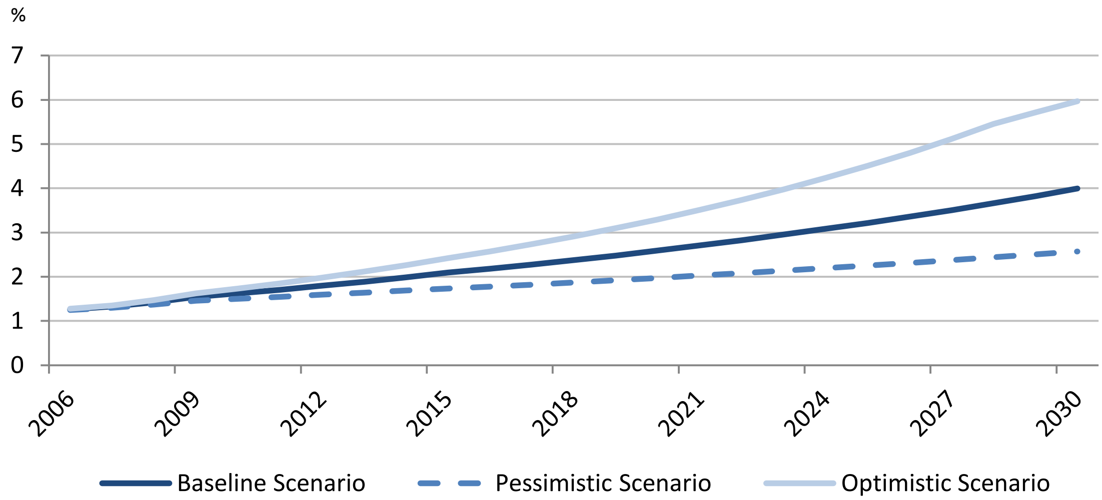
Since long-term forecasts are inherently imprecise, in addition to our baseline scenario, we also constructed two alternative scenarios: one pessimistic, the other optimistic (see methodology section to understand the assumptions underlying each scenario). In the pessimistic scenario, biotech development is hindered by regulations, shrinking public support, among other factors. As a consequence, biotech GDP growth would be significantly slower than in the baselines scenario (7.5 per cent per year from 2006-2030). In 2030, biotech GDP would be responsible for only 2.6 per cent of total economy GDP, approximately 1.4 percentage points less than the baselines scenario estimate.

In the optimistic scenario, on the other hand, the role of biotech in the economy increases, driven by growing demand for food, healthcare, energy, and other goods and services that can potentially be supplied by biotech-based technologies. In this scenario, biotech GDP experiences fast growth (11.2 per cent per year during the 2006-2030 period), and accounts for 6 per cent of

[34] According to Zika *et al.* (2007), biotech-based food and beverages manufacturing accounted for 1.04-1.24 per cent of EU GDP in 2005 (p. 81).

total economy GDP, 2 percentage points higher than the baseline estimate. Chart 20 shows how the three scenarios develop from 2006 to 2030.

Chart 20: Biotech GDP as a Share of Total Economy GDP in Canada, Scenario Comparison, 2006-2030



Source: CSLS calculations.

VII. Conclusion

According to the CSLS estimates, the value added of biotech activities reached $15,300 million current dollars in 2005, up from $8,336 million in 1999. This represents an average annual growth rate of 10.7 per cent during the 1999-2005 period, considerably more than the growth experienced by the total economy (5.9 per cent per year), which explains why biotechnology's share of total economy GDP increased from 0.92 per cent to 1.19 per cent.

In 2005, biotech producers were estimated to have been responsible for approximately one fourth of the total value added of biotechnology activities, $3,501 million, with the largest contribution coming from medical biotech producers, which accounted for 47.4 per cent of total biotech value added. Biotech users, on the other hand, accounted for the remainder three fourths of the total value added of biotech in 2005, $11,799 million. Industrial biotech applications, such as the use of enzymes in food and beverages processing, represented most of the biotech users total value added (53.5 per cent).

Using the assumptions described in the methodology section, the CSLS forecasts that nominal biotech GDP will grow at an average annual rate of 9.4 per cent per year during the 2005-2030 period, with the value added associated with biotech users growing faster than that of biotech producers (9.5 per cent versus 8.8 per cent, respectively), and nominal GDP growth for the total economy averaging 4.2 per cent per year. In this baseline scenario, nominal biotech GDP will reach approximately $144 billion in 2030, equivalent to 3.99 per cent of forecasted total economy nominal GDP in Canada.

As we have seen throughout the report, the estimation of the economic contribution of biotechnology to the overall economy is in its early stages of development and is fraught with definitional, conceptual, and methodological problems, not to mention the difficulty of obtaining actual data. This report, along with Pellerin and Taylor (2008), represents an initial effort in assessing the importance of biotechnology activities in generating value added in the Canadian economy.

The present study could be strengthened by research in two particular areas. First, a biotech survey which included firms in all industries that *potentially* use biotechnology products and/or techniques in their own production process would allow for a more accurate identification of biotech users. This, in turn, would generate better quality estimates of revenues, value added, employment, and biotech adoption rates. Second, our forecasts are largely based on historical growth rates and on the assumption that sectoral nominal GDP growth equals total economy GDP growth (which implies that sectoral composition remains unchanged throughout time). These, however, are not necessarily valid assumptions. We believe that biotechnology experts could provide valuable insights regarding future developments in biotechnology activities, and thus help construct better growth rate estimates for biotech output and other variables of interest.

From a methodological perspective, we believe that the income-based approach taken in the report is the preferred approach to estimate the economic contribution of biotechnology, given that: 1) it avoids double-counting; 2) focuses on biotech producers and biotech users, which are the core of biotech activity; 3) takes into account the role of government and higher education in performing biotechnology R&D. However, independent of the chosen framework, the accuracy of the estimates is constrained by data availability. This is a particularly serious problem in the case of biotechnology because of its cross-sectoral/cross industrial nature (i.e. there is no single NAICS code that represents the “biotech sector” or the “biotech industry”).

In this sense, Statistics Canada’s Biotechnology Use and Development Survey (BUDS) marked a significant step in the right direction, providing detailed data on innovative biotech firms, including firm size, location, revenues, R&D expenditures, employment, “type” of biotech (medical, agricultural, industrial), etc. The discontinuing of BUDS represented a massive blow to the efforts of researchers in measuring and understanding the impact of biotech in the Canadian economy, and poses a significant problem in the construction of more recent estimates.

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Appendix

Appendix Table 1: Characteristics of Biotechnology Data Sources

	Year	Biotech definition	Biotech firms	Only Innovative firms	Sample frame used	Mandatory	Conducted survey	RR	Extra-polation	Type of survey
Australia	2006	OECD	All	Yes	Secondary	No	GOV	27%	Yes	Dedicated
Austria (1)	2006	NR	All	No	Secondary	NR	GOV	NR	No	Database
	2006	NR	NR	Yes	R&D	Yes	GOV	97%	No	R&D survey
Belgium (1)	2006	OECD	All	NR	NR	NR	Federal govt., Regions & Communities	44%	Partial	R&D survey
	2006	OECD	All	No	Secondary	No	GOV	54%	Yes	Database
	2006	OECD	All	No	Secondary	No	GOV	16%	Yes	Dedicated
	March 2008 version	OECD	All	NR	Census	NR	BvDEP: BEL-FIRST database	NR	Partial	NR
Belgium (Flanders)	2007	OECD	All	No	Secondary	Yes	Technopolis-GOV	80%	No	Dedicated
Canada	1999	OECD	R&D	Yes	Secondary	Yes	GOV	80%	Yes	Dedicated
	2001	OECD	R&D	Yes	Secondary	Yes	GOV	84%	Yes	
	2003	OECD	R&D	Yes	Secondary	Yes	GOV	80%	Yes	
	2005	OECD	R&D	Yes	Secondary	Yes	GOV	70%	Yes	
Czech Republic	2007	OECD	R&D	Yes	R&D	Yes	GOV	87%	Partial	R&D survey
Finland	2007	OECD	R&D	Yes	R&D	Yes	GOV	81%	Yes	R&D survey
France	2003	OECD	R&D	Yes	R&D	Yes	GOV	72%	Yes	R&D survey
	2004	OECD	R&D	Yes	R&D	Yes	GOV	75%	Yes	R&D survey
	2005	OECD	R&D	Yes	R&D	Yes	GOV	73%	Yes	R&D survey
	2006	OECD	R&D	Yes	R&D	Yes	GOV	73%	Yes	R&D survey
Germany	2005	OECD	Dedicated	Yes	Secondary	No	BIOCOM-GOV	91%	Partial	Dedicated
	2006	OECD	Dedicated	Yes	Secondary	No	BIOCOM-GOV	89%	Partial	
	2007	OECD	Dedicated	Yes	Secondary	No	BIOCOM-GOV	88%	Partial	
Ireland	2005	OECD	R&D	Yes	R&D	No	GOV	56%	Yes	R&D survey
Italy	2002	OECD	R&D	Yes	R&D	Yes	GOV	58%	No	R&D survey
	2003	OECD	R&D	Yes	R&D	Yes	GOV	50%	No	
	2004	OECD	R&D	Yes	R&D	Yes	GOV	43%	No	
	2005	OECD	R&D	Yes	R&D	Yes	GOV	36%	No	
	2006	OECD	R&D	Yes	R&D	Yes	GOV	42%	No	
Japan	2005	All	All	No	Secondary	No	GOV	55%	No	Dedicated
Korea	2002-2006	Modern	All	Yes	Secondary	No	GOV	100%	No	Dedicated
	2006	All	Yes	Yes	R&D	No	GOV	85%	No	R&D survey
Netherlands	2005	OECD	R&D	Yes	Secondary	No	GOV	NR	Partial	Database
New Zealand	2005	OECD	All	No	Secondary	Yes	GOV	93%	No	Dedicated
	2007	OECD	All	No	Secondary	Yes	GOV	96%	No	
Norway	2005	OECD	R&D	Yes	R&D	Yes	GOV	95%	Yes	R&D survey
Poland	2005-2007	OECD	All	Yes	Secondary	Yes	GOV	62%	No	Dedicated
Portugal	2005	None	R&D	Yes	R&D	Yes	GOV	74%	No	R&D survey
Slovak Republic	2005	OECD	R&D	Yes	R&D	Yes	GOV	87%	No	R&D survey
	2006	OECD	R&D	Yes	R&D	Yes	GOV	88%	No	
Spain	2004	OECD	R&D	Yes	R&D	Yes	GOV	80%	Yes	Dedicated (with innovation survey)
	2005	OECD	R&D	Yes	R&D	Yes	GOV	86%	Yes	
	2006	OECD	R&D	Yes	R&D	Yes	GOV	86%	Yes	
Sweden	1997-2006	Modern	Dedicated	Yes	Secondary	NR	VINNOVA-GOV	NR	NR	Database
	2007	OECD	R&D	Yes	R&D	Yes	GOV	92%	Yes	R&D survey
Switzerland	2004	OECD	R&D	Yes	R&D	No	GOV	81%	Yes	R&D survey
United States	2004	OECD	R&D	Yes	R&D	No	GOV	81%	No	R&D survey
	2005	OECD	R&D	Yes	R&D	No	GOV	79%	No	
	2006	OECD	R&D	Yes	R&D	No	GOV	77%	No	
Brazil (2)	2007	All	Dedicated	..	Secondary	..	BIOMINAS	..	..	Dedicated
Philippines	2006-2007	OECD	All	Yes	Secondary	No	BPC	33%	No	Dedicated
Slovenia	2006	None	R&D	Yes	R&D	No	GOV	75%	No	R&D survey
South Africa	2006	OECD	All	Yes	Secondary	No	GOV	81%	No	Dedicated

➔ RR = Response rate; NR = Not Relevant; .. = Information not available.

1. Biotechnology data were obtained by matching a database of biotechnology firms / dedicated biotechnology firms with results of existing surveys or databases.

2. The biotechnology definition includes firms that 'commercialise' products or services. Excluded are multinationals that only have a local sales office. Also included are techniques that are not modern biotechnology (e.g. embryo transfer). As a result biotechnology activities may be overestimated.

Source: van Beuzekom and Arundel (2009), p. 12.

Appendix Table 2: GM Crops Approved in Canada as of August 2011

Name	Traits
Corn hybrid 3417IR	Herbicide Tolerant (imidazolinone)
Transgenic canola lines MS1, RF1	male sterility, fertility restoration and Herbicide Tolerant (glufosinate)
Transgenic canola line GT73	Herbicide Tolerant (glyphosate)
Canola line HCN92	Herbicide Tolerant (glufosinate ammonium)
FLAVR SAVR™ tomato	PQ (increased thickness and consistency)
Canola varieties NS738, NS1471 and NS1473	HT (imidazolinone)
Canola lines MS1, RF2	HT (glufosinate ammonium)
NewLeaf™ potato lines BT06, BT10, BT12, BT16, BT17, BT18 and BT23	PR (Colorado potato beetle)
Transgenic tomato line 1345-4	PQ (delayed ripening)
Transgenic corn line 176	PR (insects, particularly the European Corn Borer)
Transgenic canola lines 23-198 and 23-18-17	PQ (developed to produce oil with significant lauric acid content)
Transgenic soybean line GTS 40-3-2	HT (glyphosate)
Transgenic tomato hybrids 1401F, H282F, 11013F and 7913F	PQ (reduced pectin degradation)
Canola lines 45A37 and 46A40	Developed to produce oil with high oleic acid content in combination with low linolenic acid content
Transgenic corn line BT11	PR (insects, particularly the European Corn Borer) and HT (glufosinate ammonium)
Transgenic NewLeaf™ potato cultivars Atlantic (ATBT04-6, ATBT04-27, ATBT04-30, ATBT04-31, ATBT04-36) and Superior (SPBT02-5, SPBT02-7)	PR (Colorado potato beetle)
Maize line DLL25	HT (glufosinate)
Transgenic maize line MON 809	PR (resistant to insect damage)
Corn lines DK412SR and DK404SR	HT (sethoxydim)
Transgenic corn line MON810	PR (resistant to insect damage)
Canola transformant T45	HT (glufosinate ammonium)
Canola (derived from a new hybridization system)	MS (MS8), fertility restoration (RF3), HT (glufosinate ammonium)
Transgenic maize line DBT418	PR (lepidopteran insects, particularly European Corn Borer) and HT (glufosinate)
Corn transformants T14 and T25	HT (glufosinate ammonium)
Corn hybrid EXP1910IT	HT (imidazolinone, specifically imazethapyr)
canola line designated Westar-Oxy-235	HT (bromoxynil)
Corn (derived from a new hybridization system)	male sterility (MS3) and HT (glufosinate ammonium)
Corn line MON 832	HT (glyphosate)
Corn line MON 802	HT (glyphosate) PR (insects)
Transgenic canola line GT200	HT (glyphosate)
Transgenic flax line CDC Triffid - FP967	HT (sulfonylurea, specifically triasulfuron and metsulfuron-methyl)
Transgenic squash line CZW-3	VR (watermelon mosaic virus 2 (WMV2), zucchini yellows mosaic virus (ZYMV) and cucumber mosaic virus (CMV))
Transgenic squash line ZW-20	VR (watermelon mosaic virus 2 (WMV2) and zucchini yellows mosaic virus (ZYMV))
Corn hybrid 3417IR	HT (imidazolinone)
Transgenic NewLeaf-Y™ potato cultivars Shepody (SEMT15-02, SEMT15-15) and Russet Burbank (RBMT15-101)	PR (Colorado potato beetle) and VR (plant potyvirus, potato virus Y)
Transgenic NewLeaf-Plus™ potato cultivars Russet Burbank (RBMT21-129, RBMT21-350 and RBMT22-082)	PR (Colorado potato beetle) and vR (plant luteovirus, potato leafroll virus)
Transgenic corn line GA21	HT (glyphosate)
Triticum aestivum line SWP965001 (Wheat)	HT (imidazolinone)
Soybean lines G94-1, G94-19, and G168	PQ (developed to produce oil with elevated levels of oleic acid)
Tomato line 5345	PR (insect pests, Lepidopteran species)
Soybean (Glycine max) line OT96-15	PQ (reduced linolenic acid content)
Soybean lines A2704-12 and A5547-127	HT (glufosinate ammonium)
Sugar beet event T120-7	HT (glufosinate ammonium)
Transgenic corn line 603	HT (glyphosate)

Source: Health Canada, Approved GM Foods & Other Novel Foods (http://www.hc-sc.gc.ca/fn-an/gmf-agm/appro/ofb-095-264-a-eng.php).

Appendix Table 2: GM Crops Approved in Canada as of August 2011 (cont.)

Name	Traits
Canola-quality Brassica juncea (L.) Czern. lines PC 97-03, PC98-44 and PC98-45	PQ (less than 2% erucic acid in oil and less than 30 moles of aliphatic glucosinolates per gram in canola meal)
Corn line 1507	PR (Cry 1F insect resistant) and HT (glufosinate-ammonium)
Corn line MON 863	PR (Coleopteran insects)
Clearfield wheat (Triticum aestivum) line AP602CL	HT (imidazolinone)
ClearfieldTM sunflower variety X81359	HT (imidazolinone)
NuSun™ mid-oleic sunflower oil	PQ (longer shelf life and increased stability during frying)
Triticum aestivum line AP205CL (Wheat)	HT (imidazolinone)
Clearfield lentil (*Lens culinaris*) variety RH44	HT (imidazolinone)
Triticum aestivum line Teal 11A (Wheat)	HT (imidazolinone)
Sugar beet lines containing event H7-1	HT (glyphosate)
Clearfield™ sunflower variety X81359	HT (imidazolinone)
Corn event DAS-59122-7	HT (glufosinate) and PR (Bacillus thuringiensis (B.t) Cry34/35/Ab1 insect resistant)
MON 88017 corn	HT (glyphosate) and PR (Coleopteran pests such as corn rootworms)
Bread wheat varieties (BW255-2 and BW238-3) with an *Als3*	HT (imidazolinone)
Corn lines containing the transformation event TC6275	PR (insects) and HT (glufosinate)
Corn lines containing the transformation event LY038	PQ (elevated levels of free lysine)
Genetically modified malolactic wine yeast ML01	PQ (removes the malic acid from wines, without the use of starter cultures)
Soybean line 93M01	PQ (reduced levels of linolenic acid)
Wine yeast ECMo01	PQ (ethyl carbamate, a suspected carcinogen in humans)
Durum wheat varieties (DW1 and DW12)	HT (Als2 and Als3 imidazolinone)
Bread wheat variety (BW7)	*HT (Als1b* imidazolinone)
TUSC1 corn	PQ (increased digestibility, potentially causing an increase in the available energy of corn grain)
Glyphosate Tolerant soybean (MON 89788)	HT (glyphosate)
Transformation event MIR604 (Corn)	PR (larvae of corn rootworm)
ExpressSun™ Sunflower SU7	HT (Als1 sulfonylurea)
Alpha-amylase corn event 3272	PQ (this corn produces a thermostable AMY797E alpha-amylase for use in the dry-grind ethanol production from corn grain)
Transformation event MON 89034	PR (Lepidopteran insect pests such as the European corn borer (ECB), the Southwestern corn borer (SWCB), the corn earworm (CEW), and the fall armyworm (FAW))
Enhanced Stearate Soybean (ESS)	PQ (increased levels of stearic acid, and reduced levels of linolenic acid)
Herbicide Tolerant 98140 Corn event DP-Ø9814Ø-6 (trade name Optimum GAT corn)	HT (ALS-inhibiting herbicides and herbicides containing glyphosate)
Soybean Event 356043	HT
The 531 and 757 lines of cotton	PR (lepidopteran insects such as the cotton bollworm, pink bollworm and tobacco bollworm)
Transgenic cotton line BXN™	HT (bromoxynil)
Cotton line 1445	HT (glyphosate)
Cotton event 15985	PR (lepidopteran family of insects)
Cotton (*Gossypium hirsutum* L..) lines based upon transformation event 3006-210-23	PR (lepidopteran pests)
Cotton (*Gossypium hirsutum* L..) lines based upon transformation event 281-24-236	PR (lepidopteran pests)
Cotton varieties containing event MON 88913	HT (glyphosate)
Grain from the Oryza sativa lines CL 121, CL141, CFX51 (Rice)	HT (imidazolinone)
Oryza sativa line PWC16	HT (imidazolinone)
Papaya line 55-1	VR (papaya ringspot virus (PRV))
Cotton lines containing event LLCotton25	HT (Glufosinate -ammonium)
Alfalfa lines containing events J101 and J163	HT (Glyphosate)
Rice lines containing event LLRICE62	HT (Glufosinate)
Rice varieties (CL IMINTA 1 and CL IMINTA 4)	HT (Als imidazolinone)

Source: Health Canada, Approved GM Foods & Other Novel Foods (http://www.hc-sc.gc.ca/fn-an/gmf-agm/appro/ofb-095-264-a-eng.php).