The Future of Manufacturing in Ontario:

New Technologies, New Challenges and New Opportunities

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About the Future of Manufacturing Project

Does the manufacturing industry have a future in Ontario? And if so, in which sub-sectors will this future flourish? This project seeks to help shed lights on these questions through the development of both quantitative and qualitative analyses of key sectoral trends and technological innovations. This research builds on the 2014 DEEP Centre report, Canada's Billion Dollar Firms: Contributions, Challenges and Opportunities.

This report will include five complementary areas of focus:

1. Extraction of Ontario-specific insights from the Billion Dollar Firms' dataset.
2. Development of a comprehensive overview of manufacturing sector performance in Ontario.
3. Review of how and where new technologies may provide significant opportunities for manufacturing growth.
4. A qualitative assessment of the key growth challenges and opportunities facing Ontario manufacturers in key sectors.
5. A list of actionable initiatives to help Ontario firms in specific manufacturing sub-sectors address the challenges to growth currently facing them.

All together, the project aims to provide a strong evidence base for the development of targeted policy initiatives focused on Ontario's manufacturing sector, and the key areas of growth within it.

This Manufacturing Sector Analysis is generously supported by the Ontario Ministry of Economic Development, Employment and Infrastructure.

The DEEP Centre

The Centre for Digital Entrepreneurship and Economic Performance (DEEP Centre) is a Canadian economic policy think-tank based in Waterloo, Ontario. Founded in 2012 as a non-partisan research firm, the DEEP Centre's work shapes how jurisdictions build fertile environments for launching, nurturing and scaling companies that will thrive in an increasingly connected world. The DEEP Centre provides objective research and advice on the changing drivers of success in the global economy and the critical interconnections between technology, entrepreneurship, and long-run economic performance. Our goal is to help policy-makers identify and implement powerful new policies, programs, and services to foster innovation, growth, and employment in their jurisdictions.

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Executive Summary

The demise of Ontario's, and Canada's, manufacturing sector is far too easily accepted as fact. Despite dramatic job losses over the past decade, green shoots of growth exist across Ontario's manufacturing sector. In auto parts, food production, and highly technical, advanced manufacturing sub-sectors, Ontario companies are showing not just the capacity to compete, but rather the capacity to be at the heart of a vibrant ecosystem of next-generation Ontario manufacturers.

Their growth, however, cannot be taken for granted. Across these sub-sectors, issues related to skills and labour, financing, and other systems of government support must be addressed to ensure that Ontario-based manufacturers are on an equal footing with their competitors abroad. The research conducted for this report points to the need for immediate action in nine priority areas. Doing so will help address the aforementioned challenges and better enable Ontario manufacturers to compete and win.

There's no doubt that Ontario's manufacturing industry has and will continue to face significant challenges. The ongoing processes of industrial upgrading seen in emerging economies, as well technological evolution around the globe, will only hasten the need for Ontario firms to upgrade, reinvest, and reinvent themselves to match these competitive pressures. However, as exogenous competitive pressures grow, it is in the Government of Ontario's best interest to work as closely as possible with industry to ensure the opportunities offered by new markets and new technologies are not stifled by the new challenges they bring. The insights included herein are meant to highlight starting points for how policy-makers in Ontario might choose to do so.

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Introduction

Can vibrant manufacturing industries be sustained in mature North American jurisdictions? The prognosis has become increasingly optimistic in recent years, thanks to a reversal in the significant cost advantages that once accrued to manufacturing operations in emerging markets. Dramatic shifts in the costs of energy have restructured manufacturers' offshore equation; so too have higher wages and currency values in emerging and developing economies. These trends are dramatically changing the global manufacturing environment, and providing new opportunities and challenges for Canadian and Ontario-based manufacturers.

Renewed competitiveness in North American manufacturing industries—once thought impossible—is increasingly probable, given the shrinking gap between the wage and cost structures found in mature and emerging markets. The Boston Consulting Group calculates that, adjusted for productivity, wage rates in China have gone from a 4.6 times advantage (for China) a decade ago, to just half of that now. Once transportation and logistics (total landed cost) are accounted for, the cost differential is increasingly small, making a sustained return of the manufacturing sector a real possibility (Boston Consulting Group 2014). These trends combine with growing consumer demand for "made local," making efforts aimed at the revitalization of North American manufacturing quite attractive.

However, these aggregate trends hide a far more complicated reality.

Years of underinvestment in the sector, coupled with an uncertain understanding of assets and capabilities, will make capturing the potential of a resurgent manufacturing sector far more difficult. Canada, in particular, faces challenges owing to its weak productivity growth performance. Canada's relative cost competitiveness continues to decline owing to high wage growth and almost no growth in productivity. By way of contrast, the US is seen to have increased its competitiveness over the same period owing to moderate wage gains that have been mitigated by growth in productivity and reductions in energy costs. Other comparable economies, such as the Netherlands and the United Kingdom, have balanced wage gains with productivity increases to see overall manufacturing cost competitiveness remain stable. Since 2011, employment gains in manufacturing have surpassed 5% in both the US and the UK, and have remained stable in the Netherlands. Conversely, employment in Ontario's sector has declined by 3% over the same period.

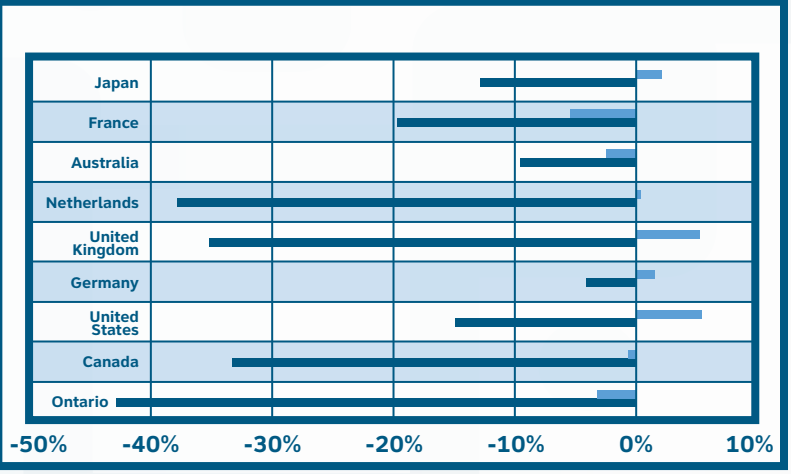
This recent trend indicates that Ontario will face challenges in its efforts to recapture manufacturing investment looking for a North American home. While Ontario's manufacturing sector has slack capacity, it suffers from an increasingly large productivity gap with competitors in the US. A 2014 report released by the Ontario Ministry of Finance estimates that over the period 2001–2011, Ontario's labour productivity increased just 0.4% annually, compared to 2.4% in the US (Government of Ontario 2014). Employment in the province's manufacturing sector mirrors this trend, one that has its roots, at least in part, in significant underinvestment in capital and machinery

and technology as compared to the US manufacturing sector (and even a bigger gap as compared to German peers). Over the 2001–2011 period, the province's manufacturing sector has seen its share of total employment decrease by 5.5%. This decrease translates to over 300,000 jobs. Updating the data to reflect the 2004–2014 period, manufacturing employment in Ontario peaked at over 1.1 million jobs in 2004. By 2014, nearly one-third of this employment was lost (Statistics Canada 2015).

To be sure, Ontario is far from alone in this manufacturing employment challenge. The Canadian average over the same period is a loss of 26% of employment, and other mature economies—such as France, the Netherlands, and the United Kingdom—have experienced similar declines. However, several positive outliers exist, as shown in Figure 1. Notably, US employment in the manufacturing sector has decreased just 8% over that same period, and Germany's just 4%. And as noted earlier, the US and the UK have each experienced significant employment gains since 2011.

Figure 1: MANUFACTURING EMPLOYMENT IN SELECT ECONOMIES

Region	2011-2014	2004-2011
Ontario	-3%	-43%
Canada	-1%	-33%
United States	5%	-15%
Germany	2%	-4%
United Kingdom	5%	-35%
Netherlands	0%	-38%
Australia	-2%	-10%
France	-5%	-20%
Japan	-2%	-13%



Data sources: Organisation for Economic Co-operation and Development and Statistics Canada.

Assessing why Ontario's manufacturing sector has underperformed against these global peers is evidently complex. And while the underlying investment and productivity issues are of evident concern to policy-makers at all levels of government, they remain difficult to address with blunt policy measures. Nevertheless, the following analysis seeks to inform the development of appropriately targeted policy remedies with a quantitative analysis of growth sectors within Ontario's manufacturing economy, and a subsequent qualitative analysis of the challenges facing these upstart manufacturers. Of particular interest in this research is how new technologies—such as (but not limited to) 3D printing, robotics, and nanotechnology—could provide significant opportunities for growth and competitiveness.

Some may question the focus on manufacturing in the context of a broader strategy to create jobs and economic opportunity in Ontario. The narrative of manufacturing's decline is a popular one. However, as the following analysis will show, a more nuanced study of the sector's evolution brings to light several positive trends. A review of the demography of high-growth firms and of Canada's fastest growing firms also highlights a strong manufacturing presence. This growth, according to multiple sources, is also likely to contribute more to the broader economy thanks to a higher economic multiplier. The US Bureau of Economic Analysis finds that every dollar in final sales of manufactured products supports US$1.40 in output from other sectors of the economy. Statistics Canada finds a broadly similar manufacturing sector multiplier of CAD$1.74.

Finally, and less easily measured, is the role of manufacturing in design and innovation. As Harvard Business School professors David Pisano and Willy Shih find in their research,

> Once manufacturing is outsourced, process-engineering expertise cannot be maintained, since it depends on daily interactions with manufacturing. Without process-engineering capabilities, companies find it increasingly difficult to conduct advanced research on next-generation process technologies. Without the ability to develop such new processes, they find they can no longer develop new products. In the long-term then, an economy that lacks an infrastructure for advanced process engineering and manufacturing will lose its ability to innovate. (Pisano and Shih 2009)

In short, the view that a jurisdiction can specialize only in high-value research and development, and forget about manufacturing, ignores the complex nature of innovation. And, as innovation capacity is increasingly dispersed around the globe, retaining a variety of the elements that feed it will be increasingly important to long-run competitiveness and economic prosperity.

In this context, public support for the manufacturing sector has merit. However, this support cannot ignore the reality that vast swaths of the sector are proving uncompetitive. Those that show signs of life, if not signs of real sustained success, must be better understood and, where appropriate, better supported.

This project provides an analytical base for understanding which manufacturing sub-sectors in Ontario are potentially worthy of such attention. It begins with a quantitative analysis of the evolution of the most successful firms in the province, denoted here as billion-dollar firms. It then provides an analysis of current trends in the Ontario's manufacturing sector, as well as within sub-sectors. This analysis feeds a qualitative review of how emerging technologies offer manufacturers new tools in their search for sustained competitiveness. This potential is subsequently evaluated against the insights collected from leading Ontario firms in growing manufacturing sub-sectors. The project concludes with a series of actionable policy actions priorities aimed at supporting existing areas of strength in the manufacturing sector, as well as actions directed towards the development of novel ones.

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Section 1: The Population of Mega-Large Firms in Ontario

Billion-Dollar Firms

While contemporary economic policy is focused heavily on the development of entrepreneurial start-ups, evidence suggests that progress along the commercialization path to high-growth status is far more important. And, if sustained, that high growth will lead to additions to Canada's cohort of "billion-dollar firms"—those with annual revenues in excess of CAD$1 billion. For the purpose of this analysis, publicly traded foreign subsidiaries are not included.

This segment of billion-dollar firms is not particularly large. Drawing from the DEEP Centre's 2014 study on Canada's Billion Dollar Firms: Contributions, Challenges and Opportunities, just 169 publicly traded firms qualified as of year-end 2012. Accounting for privately held companies in the same cohort raises this figure by 136.[1] However, the number of fully independent, Canadian-owned private entities is much smaller at just 19.[2] A total of 188 Canadian-owned, billion-dollar firms are subsequently treated as the billion-dollar sample. By comparing this sample to the 2004 sample of similarly defined firms, we find an overall positive view of the development of Canada's billion-dollar cohort. In particular, there is a healthy evolution of firms from below the billion-dollar threshold, with a significant percentage of mid-range firms either positioned to enter the billion-dollar cohort or providing attractive acquisition targets. The growth of the overall cohort, however, is driven largely by the development of mega-large resource firms. Adjusting this sample for more recent declines in oil prices and subsequent resource-related revenues, we see a significant adjustment to this sample. What is clear across Canada, however, is a significant decline in the number of mega-large manufacturing firms, and churn as opposed to growth in knowledge-intensive sectors of the economy such as health care and high technology.

In Ontario, the overall cohort of billion-dollar firms consists of 64 firms, including 59 publicly traded and 5 privately held firms. These firms are concentrated in financial services (14), consumer retail and wholesale (9), and manufacturing (7).

Among the publicly traded cohort, these Ontario-based firms employ over 1,072,964 worldwide, and approximately 643,124 in Canada. A province-specific employment number is not available. These employment numbers represent significant growth from 2007. Worldwide employment for these Ontario headquartered, publicly traded firms amount to 894,677 in 2007, with 600,914 of those jobs provided in Canada. The percentage of total employment based in Canada for these firms has declined from 67% in 2007 to 60% in 2012.

Tracking back to 2004, Ontario hosted 60 domestic billion-dollar firms, including 56 publicly traded and 4 privately held firms. Significant changes over the 2004–2012 period include the subtraction of 4 financial services

1 Comparative figures for 2004 are inflation adjusted.

2 Of 136 privately held billion dollar firms: 65 are foreign subsidiaries, 49 are domestic subsidiaries, 19 are independent private entities, and 4 are municipal/public utility entities.

companies, owing largely to consolidation, the more than doubling of the consumer retail and wholesale cohort, a significant reduction in the number of large manufacturing entities, and significant growth in the number of large engineering and construction firms. The sectoral composition, and evolution, of these Ontario-based billion-dollar firms is as follows:

Table 1: THE EVOLUTION OF ONTARIO'S BILLION DOLLAR COHORT

Industry	Number of Billion-Dollar Firms 2013	Number of Billion-Dollar Firms 2004	Change, 2004–2013	Number of Firms Acquired
Financial Services	14	18	–4	2
Consumer Retail and Wholesale	9	4	+5	0
Manufacturing	7	11	–4	3
Food & Beverage Production	6	5	+1	1
Metals and Mining	5	5	-	3
Energy and Utilities	4	3	+1	0
Professional Services	4	3	+1	1
Technology	3	2	+1	1
Engineering and Construction	5	2	+3	0
Media and Broadcast	2	3	–1	1
Real Estate	2	2	—	1
Health	1	1	—	0
Telecommunications	2	1	+1	0
Total Firms	**64**	**60**	**+4**	**13**

An analysis of these cohorts show that of the 60 firms present in 2004, 16 changed ownership structures through acquisition, 3 were demoted from the category, and 3 filed for bankruptcy. The remaining 37 firms remain in the category in the 2012 cohort. Ownership changes were equally distributed across sectors—with acquisitions impacting 4 financial services firms, 3 manufacturing firms, 3 metals and mining firms, 2 food and beverage firms, 1 technology firm, 1 real estate, and 1 media firm. Bankruptcies affected 2 manufacturing and 1 technology firm.

Mid-Range Firms

Equally important to understanding the evolution of Ontario's cohort of largest firms is the demographic of firms that may be on their way to billion-dollar status. We define these mid-range firms as publicly traded (on the TSX) and privately held firms with revenues between CAD$500–999 million. Comparative figures for 2004 are inflation adjusted.

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In 2013, Ontario hosted 37 mid-range firms versus 37 mid-range firms in the 2004 cohort. The primary changes by sector, as shown in the table below, include a significant decline in the size of the manufacturing cohort by 6 firms, and of the consumer retail and wholesale cohort by 2 firms. Net additions are concentrated in the real estate sector, where the cohort has added 5 firms. Among manufacturing firms, transactions are responsible for the disappearance of 3 firms from the 2004 cohort, changes in ownership structured (privatization) affected 2 manufacturing firms, while 1 manufacturing firm graduated to the billion-dollar revenue cohort. Including food and beverage, acquisitions are seen to impact a total of 5 firms in the broader manufacturing sector.

Significant growth is seen in the real estate sector, and, to a lesser degree, in the transportation and metals and mining sector. In real estate, the growth of the cohort is driven largely by same-sector acquisitions and industry consolidation.

Table 2: THE EVOLUTION OF ONTARIO'S MID-RANGE COHORT

Industry	Number of Mid-Range Firms 2013	Number of Mid-Range Firms 2004	Change, 2004–2013	Number of Firms Acquired
Financial Services	4	3	+1	—
Consumer Retail and Wholesale	1	3	–2	—
Manufacturing	4	9	–5	3
Food and Beverage Production	2	3	–1	2
Metals and Mining	5	3	+2	1
Energy and Utilities	2	1	+1	—
Professional Services	5	5	—	1
Technology	3	2	+1	1
Engineering and Construction	–	1	–1	—
Media and Broadcast	2	2	—	1
Real Estate	7	2	+5	—
Health	—	2	–2	—
Telecommunications	—	1	–1	1
Transportation	2	—	+2	—
Total Firms	**37**	**37**	**—**	**10**

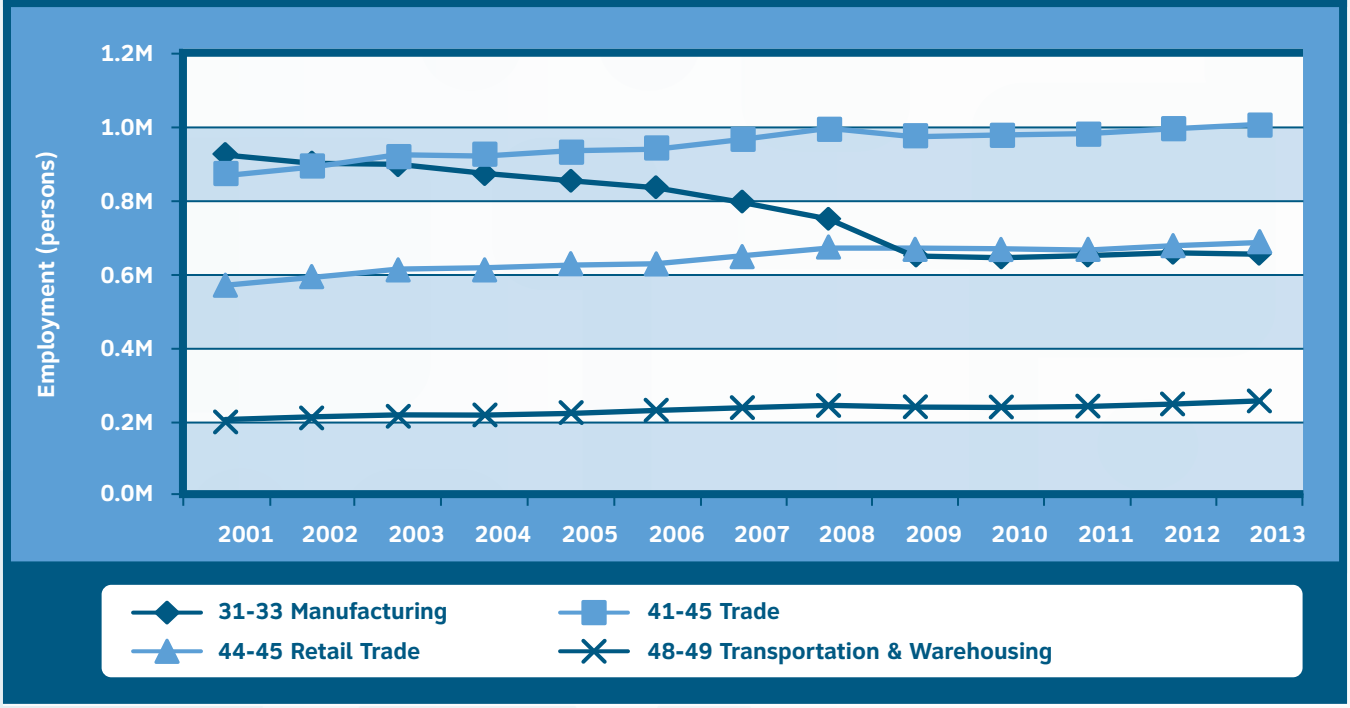
Across both the billion-dollar and mid-range cohorts, Ontario's manufacturing sector shows the most significant decline. Nine firms in the sector, or just shy of 50% of the total 2004 cohort, were either acquired or demoted by 2012. While ownership changes do not equate directly to a declining footprint, the changes in ownership seen across this sector merit further analysis as to whether they are driven by status as either attractive growth opportunities or weak consolidation efforts. Related to the manufacturing sector but held apart in this analysis, the food and beverage sector shows resilience with no net change in the total cohort (billion-dollar and mid-range) of firms active in Ontario. Among technology sector firms, a net addition of two firms in the CAD$500 million and up category indicates a relative degree of strength. Conversely, a decline of two firms in this demographic among health-related firms (life sciences and pharmaceutical) highlights an area of concern.

The evolution presented above emphasizes but one view of the performance of these components of the Ontario economy. While valuable, these insights need to be contextualized using both macro- and micro-level data to produce a more holistic picture of the evolution of the Ontario economy, as well as specific sectors therein. In particular, given the changes seen among manufacturing companies in the above analysis, the following section introduces an aggregate view of the sector's performance and evolution.

Section 2: Today's Manufacturing Landscape in Ontario

The decline of Ontario's manufacturing sector has become near gospel. Yet a more granular analysis of the sector's performance highlights a far more nuanced perspective on the sector's evolution. To be sure, employment in the sector has decreased significantly over the past decade (see Figure 2). While the dramatic decreases in manufacturing employment seen over the 2004–2010 period have been replaced by (what in relative terms is) short-term stability, trends towards automation and increased global competition will continue to put downward pressure on labour demand in Ontario. As the following analysis shows, labour demand remains weak at best, even in the sub-sectors experiencing sales growth.

Figure 2: EMPLOYMENT TRENDS IN ONTARIO'S KEY SECTORS

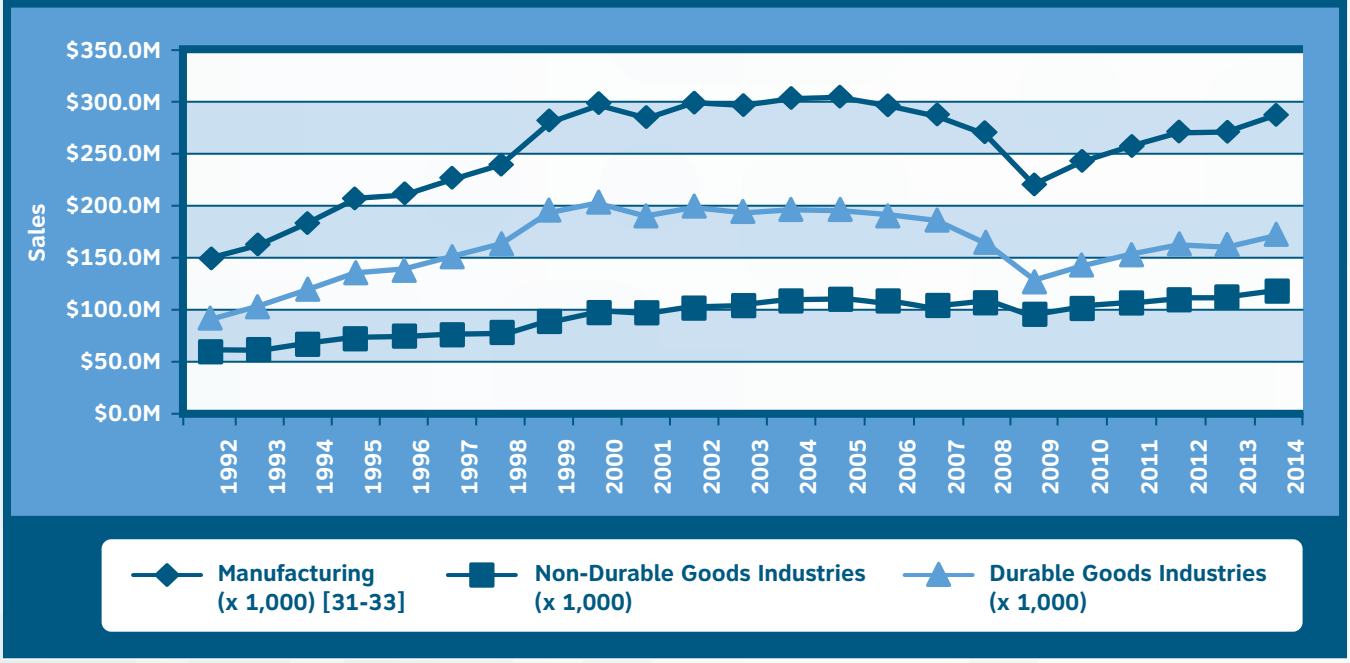


Employment, however, is by no means the best measure to judge the sector's health. The decreasing labour intensity of manufacturing production leaves sales data a far better judge of competitiveness.

While far from impressive, the manufacturing sector has seen revenues rebound from their 2009 lows with average annualized growth of 1.56%. This growth has allowed aggregate sector revenue to approach 2004/2005 peak levels. Accounting for differences between durable and non-durable manufacturing provides a potentially

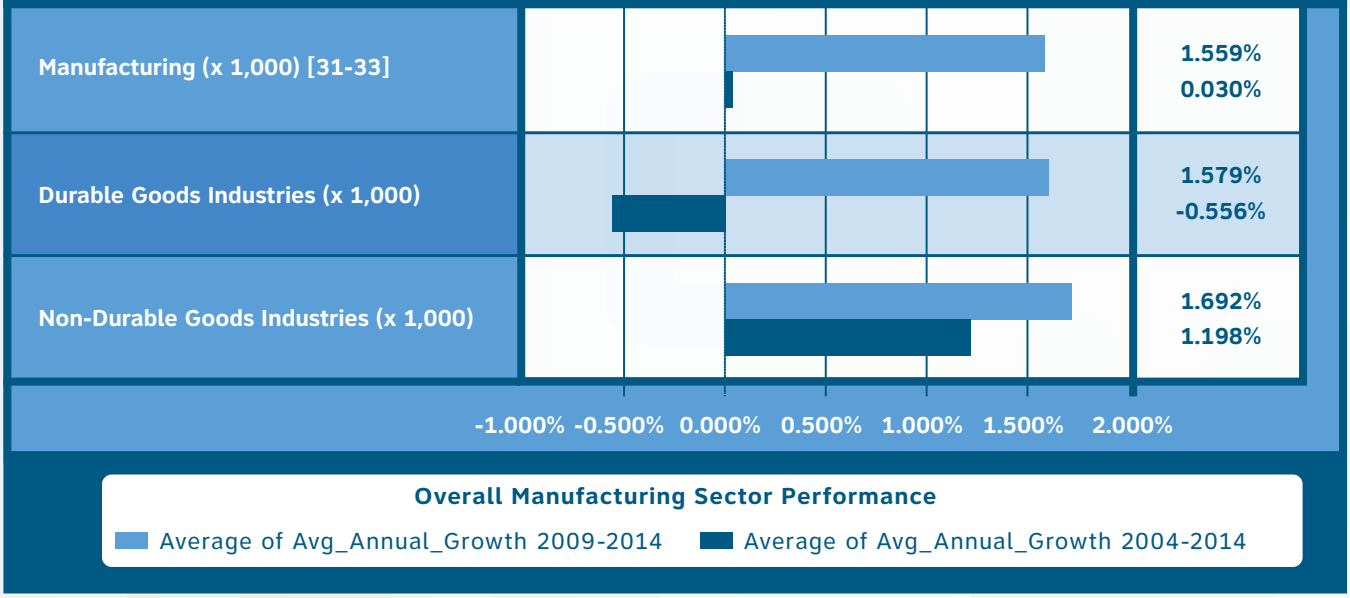
more telling story (see Figure 3). While durable goods manufacturers experienced significant declines in revenue between 2005 and 2009, and have yet to rebound to pre-crisis levels, non-durable goods manufacturers have seen aggregate revenues continue to grow slowly since 2000. Over the 2004–2014 period, durable goods industries saw average annualized growth rates of –0.6%. In comparison, non-durable goods industries grew at an average annual rate of 1.2%. While such growth is minimal, in relative terms it represents a silver lining in the broader manufacturing sector's fortunes.

Figure 3: REVENUE TRENDS IN ONTARIO'S MANUFACTURING SECTORS



Evidently, aggregate sector performance obscures a great deal of helpful detail. Our analysis thus extends to North American Industry Classification System Level 3 and 4 codes to better understand sub-sector performance among Ontario's population of manufacturers. Using Level 3 codes and defining exceptional performance at an interval of +/– 3% average annual growth over the period 2009–2014, we find just 5 qualifying sub-sectors, including 4 with +3% average annual growth rates. Moving further to Level 4 codes, 18 qualifying outliers are found with greater than 3% average growth rates (see Appendix). All but two of these growth outliers are concentrated either in food, beverage, transportation equipment, or highly technical manufacturing processes (semiconductor, magnetic and optical media, and miscellaneous).

Figure 4: ONTARIO MANUFACTURING SECTOR PERFORMANCE



To be sure, these sub-sectors and outliers represent just a small share of the over 6,000 Ontario-based manufacturers, processors, and producers classified by Industry Canada. However, the significant growth seen in these sectors makes them worthy of attention based on the premise that policy-makers will have more success catalyzing growth in jobs and economic opportunity by supporting sectors with momentum than by seeking to renew or revitalize declining sectors.

The following two sections of the report provide an analysis of the factors that will shape the future success of manufacturing in Ontario. Section 3 examines the emergence of new technologies that will shape the nature of innovation and competition in high-potential manufacturing sectors, while potentially giving rise to entirely new growth opportunities. Section 4 provides an analysis of the current dynamics driving the growth of firms in a number of the sub-sectors identified above, including strategic choices related to technologies, exports, and training. Together, the analysis of emerging technologies and competitive strategies provides the basis for a series of actionable priorities that are designed to support the growth of firms in these sectors and beyond. These priorities are presented in the concluding section of this report.

Section 3: New Technologies and Their Transformational Potential in Manufacturing

New technologies and technological processes—including, but not limited to, 3D printing, nanotechnologies, and robotics—are at the heart of a massive revolution of manufacturing capability and competitive advantage. These novel technologies offer potentially game-changing capabilities to firms able to leverage and exploit their features. Akin to the disruptive power of the Internet, these technologies encompass both the potential to disrupt patterns of global economic activity and of long-standing competitive advantage, as well as to provide significant opportunity for renewal among incumbent firms.

In the context of re-energizing Ontario's manufacturing sector, it is vital to understand both the technologies that will give rise to new competitive opportunities and challenges for Ontario-based firms and the policy strategies that other jurisdictions are deploying to give their domestic firms an edge in a rapidly changing manufacturing environment. The analysis begins with a look at the manufacturing-specific policies and programs in place in China, Germany, India, Sweden, the United Kingdom, and the United States.

The Competitive Landscape

Exploiting the potential of new technologies is key to future competitive advantage in the manufacturing industry. As firms in other jurisdictions race ahead, too many of Canada's manufacturing firms are falling behind in the global charge to modernize manufacturing operations. Given the unfortunate pattern of underinvestment that characterizes the Canadian industry, getting domestic manufacturers to adopt new technologies is an imperative that all levels of government in Canada must help meet. Indeed, the growing first-mover advantages rapidly accruing elsewhere necessitate a coordinated Canadian response.

The United States provides one such example where policy-makers and other stakeholders have been pressed into action. In 2012, President Barack Obama announced the first round of technologies identified by the newly formed American Manufacturing Partnership (AMP) as the key to revitalizing the manufacturing sector in the US. This process, and the investments promised to follow, represents what the Obama administration has termed a "full court press to increase U.S. competitiveness for advanced manufacturing" (White House 2014). The AMP was established in 2011 as a means of bringing together industry, academic, and government partners to help craft a National Advanced Manufacturing Strategy. The AMP process saw 11 manufacturing technology areas (MTAs) identified as vital to advanced manufacturing and worthy of specific attention for increased funding initiatives:

1. Advanced sensing, measurement, and process control (smart manufacturing or advanced automation).
2. Advanced material design and synthesis (including nano-materials, meta-materials, metals, coatings, ceramics).
3. Information technologies, including visualization and digital manufacturing.
4. Sustainable manufacturing.
5. Nano-manufacturing (includes micro feature manufacturing).
6. Flexible electronics.
7. Biomanufacturing and bioinformatics, including proteomics and genomics.
8. Additive manufacturing.
9. Advanced manufacturing equipment (including testing).
10. Industrial robotics.
11. Advanced forming and joining/bonding technologies.

Throughout 2013 and 2014, the 11 MTAs were prioritized on the basis of four factors:

- Industry and/or market pull;
- Cross-cutting impact on sectors;
- US security or competitiveness implications; and
- Leveraging US strengths.

The resulting AMP 2.0 MTAs are:

1. Advanced materials design, synthesis, and processing.
2. Advanced sensing, measurement, and process control.
3. Visualization, informatics, and digital manufacturing.

The AMP process is broader than just the identification of core technologies. Rather, the initiative is focused on satisfying three complementary pillars: (1) enabling innovation through key technologies, (2) securing the talent pipeline, and (3) improving the business climate (White House 2012).

These targeted efforts placed on key technologies are far from unique. The UK government has identified manufacturing and associated industries as a key plank in its Industrial Strategy program. Building on the 2013 "Eight Great Technologies" exercise that identified eight technologies "where the UK can lead the world," a series of sector-specific initiatives have sought to highlight leading technologies and their potential role in the long-term sustainability of those sectors (Government of the United Kingdom 2013a).[3] Within this broader technological framework, aerospace, automotive, agricultural technology, life sciences, and offshore wind have been identified as key strategic sectors for support.

In the automotive sector, a strategy document released by Automotive Council UK identifies the need for strategic development across five key technology areas: 1) internal combustion engines; 2) electric machines and power electronics; 3) lightweight vehicle and power train structures; 4) intelligent mobility; and 5) energy storage and energy management. The Council has subsequently developed a series of key technology road maps in these and other areas (Automotive Council UK 2013).

In aerospace, government, academic, and industry partners have come together to create the Aerospace Technology Institute, focused on the development of "the high value, technologically sophisticated parts of the aircraft where the UK can maintain a sustainable competitive advantage" (Government of the United Kingdom 2013b). Key areas of focus for the institute include emerging technologies in: 1) future propulsion; 2) highly integrated aircraft structures and systems; 3) electric aircraft; 4) connected and intelligent aircraft; and 5) integrated design and high-value manufacturing.

For life sciences, the UK government has established a National Biologics Manufacturing Centre (NBMC), intended to "support the growth of the UK's biologics industry with open access facilities to support the development and commercialisation of biologic products and process technologies" (Centre for Process Innovation 2014). The NBMC is based within the UK's Centre for Process Innovation, itself apart of the country's High Value Manufacturing Catapult (HVMC). The HVMC is composed of a network of seven strategically focused innovation centres, including the Advanced Forming Research Centre, the Advanced Manufacturing Research Centre, the Centre for Process Innovation, the Manufacturing Technology Centre, the National Composites Centre, the Nuclear Advanced Manufacturing Research Centre, and the Warwick Manufacturing Group.

Program support for advanced manufacturing in key sectors and technologies also includes the UK's Advanced Manufacturing Supply Chain Initiative, established in December 2011, with the goal of supporting innovative projects in areas where the UK holds a key competitive advantage. Funded technologies to date include particle-based and composite materials, printable materials, and advanced electromagnetic technology.

3 The eight technologies are big data and energy-efficient computing, satellites and commercial applications of space, robotics and autonomous systems, synthetic biology, regenerative medicine, agri-science, advanced materials and nanotechnology, and energy and its storage.

The German government, in contrast, is focused on maintaining and advancing the country's advantage in high-value manufacturing through a focus on cyber-physical systems. In this context, Germany's Industrie 4.0 strategy is intended to build on the country's leadership in the area of embedded systems and establish it as the "lead provider and market for cyber physical systems and advanced manufacturing solutions" (German Trade and Investment 2014). As the strategy document notes:

> As part of the country's INDUSTRIE 4.0 project, Germany aims to be the lead provider of cyber-physical systems by 2020. In marked contrast to many other industrialized nations, Germany has maintained a stable manufacturing labor force while integrating new technological developments into industrial products and processes at an early stage. A bridge between the real and virtual worlds is being created with the digital refining of everything from production facilities and industrial products to everyday products with integrated storage and communication capabilities, radio sensors and intelligent software systems. Boundaries between the real and virtual worlds are collapsing to create an Internet of Things. Germany's superior embedded system and cyber-physical systems know-how represents a major opportunity for industry in Germany to help shape the fourth industrial revolution. (ibid.)

The German government and industry are thus seeking to support the continued development of "smart factories" and "smart production" as part of the strategy to maintain and increase the competitiveness of German manufacturing across a variety of sub-sectors. The Siemens AG plant located in Arburg is an early example of this approach, as is the recently established "artificially intelligent" production system in Kaiserslautern. One component of this strategy is Autonomics 4.0, which focuses on priority technology areas such as "developing the next evolutionary steps for machines, service robots, and other systems able to deal with complex tasks autonomously as the transition from ICT-based control mechanisms to autonomously acting components and systems ushers in a new age in which efficiency, cost effectiveness, and quality increase in new and flexible production infrastructures" (German Trade and Investment 2014). In addition, the German government is funding a variety of projects for basic research, feasibility, and application through consortiums of academic and industry partners.

In Sweden, the government's Made in Sweden 2030 agenda has been established with the ostensible goal of establishing Sweden as "the primary choice for developing and producing advanced products and services." The report continues:

> Manufacturing companies are characterized by innovative product and production system development, as well as by excellent leadership. Swedish manufacturing industry is a forerunner in producing customized, high-end industrial services. Sweden's globally competitive position in 2030 is based on the strategic, long-term efforts that began in the early 2000, leading to increased focus on research, innovation and education in production. In addition, the strong ties between industry, academia and research institutes constitute essential and unique assets to strengthen Sweden's competitiveness. (Vinnova 2013)

The plan subsequently identifies six key areas vital to strengthen Sweden's position as a leader in industrial production by 2030: 1) environmentally sustainable production; 2) flexible manufacturing processes; 3) virtual production development and stimulation; 4) human-centred production systems; 5) product and production-based services; and 6) integrated product and production development. Within these areas, key technologies—such as additive manufacturing processes, 3D printing, and ICT systems—are identified as particularly important for development. At the broader European level, the European Commission has identified a series of key enabling technologies as part of its Horizon 2020 initiative, including: 1) micro-nanoelectronics; 2) nanotechnology; 3) photonics; 4) advanced materials; 5) industrial biotechnology; and 6) advanced manufacturing and processing technology (European Commission, n.d.).

Advanced manufacturing and key technology development has also emerged as a major area of emphasis in emerging market countries. In China, concerns about low-cost competition from other jurisdictions and concomitant desire to move up global value chains have led to a focus on upgrading the country's manufacturing base via a focus on quality and innovation. As part of this effort, the government has launched its Made in China 2025 program, which identifies 10 priority sectors of focus: 1) new information technology; 2) numerical control tools and robotics; 3) aerospace equipment; 4) ocean engineering equipment and high-tech ships; 5) railway equipment; 6) energy saving and new energy vehicles; 7) power equipment; 8) new materials; 9) biological medicine and medical devices; and 10) agricultural machinery. While adopting a broad approach, much of the activity across these sub-sectors is focused on reducing China's reliance on foreign technology and addressing concerns tied to rising labour costs. In ICT, for example, the plan will focus on fostering the development of microchip production domestically to offset the country's reliance on imports (Yuan 2015). To this end, China has created an investment fund worth approximately US$20 billion to finance the development of integrated circuits (Jin 2014).

In a somewhat similar vein, the Indian government's Make in India initiative is intended to foster growth in the sector, transforming India into a "global manufacturing hub" (The Hindu 2015). Much of the initiative is focused on attracting FDI through promotion, infrastructure investment, and streamlining regulatory processes. The initiative identifies a series of key focus areas for policy, including: 1) employment-intensive industries (textiles and garments, leather and footwear, gems and jewellery, and food processing); 2) capital goods industries (machine tools, heavy electrical equipment, heavy transport, and earthmoving and mining equipment); 3) strategically significant industries (aerospace, shipping, IT hardware and electronics, telecommunications equipment, defence, and solar energy); and 4) industries where India is viewed as having an existing competitive advantage (automobiles, pharmaceuticals, and medical equipment). The sectors identified in the initiative are consistent those previously highlighted in the 2011 National Manufacturing Plan, which points to the need for sector-specific policies in these key areas (Government of India 2011).

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Emerging Technologies and Opportunities

A focus on promoting the development and adoption of new technologies is a consistent element in the policies and programs that comparable jurisdictions have implemented to bolster their manufacturing sectors. The following section presents a review of three novel technology families identified as priorities in each of the jurisdictions above, and which offer significant application in manufacturing in Ontario. They each build on pockets of academic and industrial expertise and, if properly nurtured, can help redefine and renew advanced manufacturing in Ontario.

3D Printing

Additive manufacturing, or 3D printing, is a robotic printing process that prints or layers material of various kinds to produce a three-dimensional object. Not long ago the process had limited use, given both its novelty and the high price tag that accompanied this hardware. However, as prices for 3D printers have declined precipitously, from $20,000 per unit to less than $2,500, the potential application as a desktop tool for designers and producers is immense. And while this consumer price deflation brings the technology to a mass audience, there is equal potential for large-scale manufacturers to use it to design and develop new products.

The disruptive potential of 3D printing in manufacturing is recognized by many. As President Obama noted in his 2013 State of the Union Address, "A once-shuttered warehouse is now a state-of-the art lab where new workers are mastering the 3-D printing that has the potential to revolutionize the way we make almost everything."[4] This potential role in a manufacturing renewal is based on two complementary aspects. First is the use of 3D printing in the development of prototypes and other design functions requiring rapid, iterative work. Second is the actual production of low-volume products that require specialized features contemporary manufacturing technologies are unable to create.

Take Nike, for example. The global footwear giant used 3D printing to develop its Vapor Laser Talon football cleat. The new technology allowed the company to rapidly prototype a model "in hours, as opposed to months." Then, while traditional manufacturing processes were incompatible with the shape of the shoe, 3D printing allowed the company to rapidly produce what was previously impossible. Shane Kohatsu, Nike Director of Footwear Innovation, notes that "3D printing again allowed us to test, iterate and create shapes not possible with traditional manufacturing processes, which in turn allowed us to push the limits of innovation faster" (Nike 2014).

Plastics, however, offer only limited functionality. Other materials—notably metals, ceramics, and biomaterials—offer a far more exponential curve and are part of a second, more sophisticated wave of 3D printing application. These advances, alongside ongoing innovation in micro-electronics (see following section on nanotechnology), offer the potential to make such technologies mainstream.

4 See *www.whitehouse.gov/state-of-the-union-2013*

The technology's application in fields as diverse as regenerative medicine, prosthetics and implants, high-end architectural construction, and specialized parts manufacturing is immense. Nike's use of the technology is one such example. NASA's use of the technology in a field in which Ontario seeks competitive advantage, food and food processing, is equally instructive. In 2013, NASA awarded a US$125,000 grant to Austin, Texas-based Systems & Materials Research Corporation to help develop a printing application for food products, in particular a 3D printed pizza for consumption by astronauts in space. And while the direct output of this research may be focused on NASA's extraterrestrial activities, it's not difficult to see how such a technology could be applied in both industrial and residential settings to satisfy customized and personalized tastes. A more refined example of this potential is the CocoJet printer, developed by 3D Systems with Hershey Chocolate. The printer allows for the creation of customized chocolate designs in any imaginable shape or form. While far from revolutionary, these process innovations offer short-term market-capture opportunities. Again, it's not difficult to foresee how other food processors and packagers could use such technologies to develop niche products with global appeal.

While larger and richer firms will be able to better absorb the resource implications of investment in and utilization of 3D printing, others, notably SMEs, can take advantage of a growing number of 3D print platforms. In Ontario, Uxbridge-based Agile Manufacturing offers the country's largest array of 3D printers for use by outside firms and is one of a growing number of firms that provide services related to 3D design, rapid prototyping, and laser scanning for reverse engineering in a variety of nylon polymers, metals, and other composite materials. The company produces everything from custom-detailed musical instruments to components for sophisticated health-care products. Similar services are increasingly offered across the province through both private set-ups like Agile, or semi-public ones offered through post-secondary institutions.

Ensuring that SMEs across a range of sectors—from health care to food—have access to a suitable array of such services will be key. The development of a network of public access facilities that supplement those detailed above will also be key. Silicon Valley-based TechShop offers an instructive example. Opened in 2006, TechShop offers subscription-based access to a wide array of industrial tools and technologies in eight American cities, with two more in planning. Operating somewhat like business incubators, participants are offered programming to suit the stage of their idea or product, and can draw on experienced users and mentors to help refine them. Evidently, the major drawback of the TechShop model is its cost. With annual membership fees ranging from US$1,000 to $1,695, the facilities are beyond the reach of early stage companies and individual enthusiasts. To be sure, the costs of equipping these facilities with staff and equipment justifies those costs. However, building a pipeline of talent and new ideas would benefit significantly from near open access to learning and tinkering with these new technologies. Collaborative models leveraging public and private insight and financing, akin to ICT-focused business incubators, should be seen as an ideal route to developing a wide funnel of 3D talent and related products.

Ontario's comparative advantage in agricultural production, and strong manufacturing base in food and food processing, makes this technology a natural complement in Ontario factories and laboratories. Similarly building on existing competencies in health-related fields, as well as related service sectors, offers significant market potential. Capturing the potential of these technologies, however, will require building an ecosystem of research and development around source materials to ensure domestic users have some form of competitive advantage. Similarly, ensuring the rapid development of a trained and able labour force through both distributed initiatives like TechShop and university- and college-based pipeline development efforts will be vital to ensuring that Ontario-based firms have a talent pool to draw from.

Nanotechnologies

In 2012, Research in Motion co-founder Mike Lazaridis invested CAD$100 million in the Waterloo Institute for Nanotechnology, hosted by the University of Waterloo. The move cemented Ontario's competitive position in an emerging, yet still tangential, industrial technology. Evidently, understanding the potential application of a technology that operates at a scale measured as one-billionth of a metre (or a million times smaller than the length of an ant) isn't simple. Yet, it's this complexity that positions nanotechnology as able to smash orthodox thinking around technological limits, and offer a transformative medium potentially as disruptive as the Internet. In so doing, the technology holds significant potential to redefine manufacturing and a series of sub-sectors within it.

The nascent field of nanomanufacturing, defined as the application of nanomaterials in manufacturing processes, promises "stronger, lighter, more durable, water-repellent, anti-reflective, self-cleaning, ultraviolet- or infrared-resistant, antifog, antimicrobial, scratch-resistant, or electrically conductive" materials, according to the US National Nanotechnology Initiative (NNI). Globally, the market potential for new nanotechnologies is estimated to reach $64 billion by 2019 (BCC Research 2014).

According to the NNI, nanomanufactured applications currently in commercial use or advanced research and include (but are not limited to):

- Nanoscale polymers added to automobile bumpers for increased strength at reduced weight;
- Nanoscale fabrics and treatments applied to surfaces to prevent microbial growth;
- Nanosensors in packaged food product to detect spoilage or contamination;
- Nanoscale fuel additives and improved catalytic converters for cleaner exhaust and extended range;
- Nanoscale transistors that are faster, more powerful, and increasingly energy efficient;
- Nanoscale additives to low-grade raw petroleum to improve fuel efficiency and processing; and
- Nanoparticles for environmental remediation, including absorption of industrial water pollutants.

The implications in manufacturing are significant. Take, for example, the research being conducted through US Department of Agriculture appropriations from the NNI. A focus on food and agri-food includes research on "processing technologies to produce healthy, value-added foods from specialty crops, including applications of methylcellulose and chitosan nanoparticles in edible films; Imaging technology for food safety and security, including use of Raman scattering with silver nanorods or use of nanoscale peptides and DNA aptamers to detect food-borne pathogens and toxins; Novel methods for manufacturing of bioproducts from agricultural feedstocks, including blowspinning and electro-spinning of biopolymers to produce nanocomposites, nanofoams, nanofibers, microemulsions, and hydrogels" (NNI 2014). The US Navy's development of thinfilm electronic systems that provide for unheard of flexibility and durability, and the US Department of Defense's development of carbon nanotubes that produce similarly unique strength and weight-related properties (with significant interest from aerospace players such as Airbus, Boeing, Bombardier, and Embraer) offer immense industrial and commercial potential.

A 2014 report by Nano Ontario, the province's nanotechnology industry association, identifies 103 Ontario-based companies engaged in the development or utilization of nanotechnologies. Thirty percent of this population is identified as working in the field of industrial coatings, and 20% in environmental applications. Other Ontario-based activities include chemical delivery systems, automotive coatings, medical devices, and clinical diagnostics. The distribution of companies by size includes 49% SMEs, 34% large companies, and 17% start-ups (Nano Ontario 2014).

Leading Ontario-based companies include: Iridian Spectral Technologies, which uses nanomaterials for application in the telecommunications, spectroscopy, and the entertainment industry (filter wheels, glasses for 3D cinema); Nepean-based Ranovus develops nano-enabled semiconductor and photonics for the telecommunications and data management sectors; and from the laboratories at the University of Toronto, researchers have developed Cellax, a nanoparticle drug that could offer a more effective and less intrusive alternative to contemporary chemotherapy treatments.

Building on these early gains will require significant support. Lazaridis' investment in Waterloo aside, investment in Canada has been at an order of magnitude smaller than what has been invested in the US. According to Natural Resources Canada, combined federal and provincial funding for nanotechnology research has reached CAD$640 million over the past decade. This includes $24 million in annual funding for the National Institute for Nanotechnology in Edmonton, Alberta. In Ontario, the Environmental Commissioner of Ontario finds that the Ministry of Research and Innovation has provided $63 million in funding to nanotechnology-related projects.

In contrast, since 2001, the United States' NNI has received over US$21 billion in public support for research and technology development, including over $1.5 billion in 2015 budget appropriations (NNI 2014). In 2014, just shy of US$40 million was allocated to signature initiatives focused on nanomanufacturing. These public

investments are matched by public-private initiatives, such as the New York Power Electronics Manufacturing Consortium (NYPEMC). Announced in June 2014, the NYPEMC brings together funding from the State of New York and six companies spearheaded by General Electric. The program will be hosted by the State University of New York College of Nanoscale Science and Engineering in Albany. While the State of New York is contributing upwards of US$135 million towards the effort, the remaining $365 million comes from participating companies. The agreement allows participating companies, as well as qualifying SMEs, to use the university's nanotechnology research and laboratory facilities. The thrust of the program is focused on the development of nanomaterials and micro-semiconductors for use in the energy, health, and aerospace sectors.

While NYPEMC is focused on developing close anchor and SME ties with research institutions, similar collaborative ventures are less visible in Canada. Leading academic institutions like the University of Waterloo offer opportunities for industry collaboration; however, the outcomes of such collaborations are still unclear. Funding for industry-academia partnerships in this field must be increased. Developing a collaborative relationship with Ontario manufacturers to allow for the transmission and licensing of these technologies into corporate labs and into both consumer and industrial products is necessary next step.

As with 3D printing, the development of a deep pipeline of talent will be necessary to allow for the diffusion of this technology across sectors. The University of Waterloo graduated its first cohort of undergraduate nanotechnology engineers in June 2010. The depth of experience is subsequently limited and attempts must be made to provide pathways for this talent into incumbent firms through focused Mitacs-type industry-academia relationships.

Finally, while the National Institute for Nanotechnology in Edmonton is the de facto host for major research and collaborations in Canadian nanotechnology, its distance from Ontario leaves space for the development of a similarly broad research and application focused organization in Ontario. Building upon the expertise in nanotechnology present at the Waterloo Institute for Nanotechnology and in materials and composites at the University of Western makes southwestern Ontario a natural host for the development of an Ontario nanotech cluster.

Robotics

While robots have long been a part of advanced manufacturing, the competency of robots continues to advance at a rapid pace while the associated costs decline precipitously. Thanks to computer vision and machine-learning algorithms, robots, once consigned to carefully controlled tasks, can now function more like human workers. And due to cheap sensors and chips, they're getting more powerful per dollar. The combined impact of declining costs and increasing competency will have revolutionary implications for manufacturers everywhere.

While the Canadarm has long stood as Canada's key contribution to the field of robotics, newcomers such as Clearpath Robotics signal a new era in Canadian robotics that promises more nimble, commercially oriented applications. The Kitchener-based company develops robotic applications for use in the air, water, and factories, and rugged and non-rugged applications on the ground. Their clients include Honda, Intel, Dow, and others like them. And their creations stand to join, and perhaps work alongside, the estimated 1.5 million robots working in factories across the globe.

In the US, PriceWaterhouseCoopers and the Manufacturing Institute estimate that there are over 180,000 industrial robots hard at work in factories.[4] China, however, has leapfrogged mature industrial markets to become the world's leading user of industrial robots with over 200,000 in place as of late 2014, according to the International Federation of Robotics. Globally, the auto industry is the largest host to industrial robots, accounting for nearly 40% of the global supply. The electronics industry is a distant second-place host, capturing 20%, followed by metal and machinery (9%), rubber and plastics (7%), and food and beverage (4%). Data from the US market highlights interesting sectoral shifts in the use of robotics technologies. In 2005, 69% of robots in use in the US were in automotive-related facilities. In 2013, this share has declined to 56%, while food and beverage usage has jumped from 3% to 7%, and the life sciences from 2% to 6%.

The most popular industrial applications are for materials handling, welding, assembly, dispensing, and processing. However, as noted by the Manufacturing Institute in a 2014 report on robotics, the increasingly "near-human" features of contemporary robotics technologies has meant previously impossible tasks such as picking and packaging, testing or inspecting products, or assembling minute electronics are now fully within the realm of robot capacity.

Growth in the market for robotics, and the simultaneous development of Internet of Things applications that promise to connect everything, is likely a primary driver for Google's aggressive foray into robotics. In 2013 alone, the company acquired eight robotics companies for an estimated US$100 million. Exploiting the potential of these technologies will require a focus on a rescaling of robots to meet the needs and limitation of SMEs. While larger industrial employers can absorb the costs and large-volume production runs that conventional robots require, a next generation of more customizable and more easily programmable robots will open the door for a broader base of industrial users.

As it stands currently, a survey of 120 manufacturers conducted by PWC and the Manufacturing Institute in 2014 highlights the growing industrial popularity of robotics technologies:

- 59% of manufacturers are currently using some sort of robotics technology;
- 68% of manufacturers plan to invest in robotics technology over the next 3 years; and
- 27% listed "not having a need" as the biggest limitation for not adopting robotics in the next 3–5 years.

4 See *www.themanufacturinginstitute.org/News-Articles/2014/10/01-Robotics-Report.aspx*

Increasingly advanced automation and robotics technologies highlight the existing tension between technological advance and the demand for labour in sectors that adopt them. Thus, while the optimism surrounding the reshoring of manufacturing in the North America is understandable, it is unlikely that this reshoring will have anywhere near the hoped-for impact on employment, thanks to the growing adoption of robots. Moreover, where reshoring does lead to permanent employment growth, the manufacturing jobs created are likely to be very different than those in decades past, with an increased aptitude for technology and design among the skills that employers will require. Interviews with executives conducted for this project indicate the development of a skills disconnect with respect to such new technologies. While the closure of manufacturing facilities across the province has created a pool of available labour, the subsequent ability to train and integrate this labour pool on new technologies and processes is challenging and costly. Larger firms with higher levels of labour demand are better able to deploy resources towards these challenges, while SMEs are stressed to do so and look to new graduates to fill these roles. While the sample interviewed is insufficient to make broad conclusions, it does point to the need to remain engaged with employers as to ongoing retraining efforts and the appropriateness of funding for skills updates and retraining.

Canadian employers and employees face two equally challenging trends as a result. Not only will increased automation place domestic workers at a disadvantage, but below-par productivity levels in Canadian and Ontario manufacturing facilities relative in US and Mexican firms will leave them increasingly unable to win new contracts. The need to update existing technologies and processes is subsequently a significant, if not top, priority for all orders of government in Canada. And while the aforementioned tension between robotics and labour may seem to make investment a poor choice, the reality of today's global manufacturing economy is, simply, invest or perish. Maintaining competitiveness and existing manufacturing employment at stable, if not perhaps slightly decreasing levels, will require additional investment. Choosing to forego these investments will mean the disappearance of this sector entirely. Choosing to invest, on the other hand, will at least give manufacturers the opportunity to compete for business. At the same time, both public and private stakeholders must move ahead with training, reskilling, and other labour-market initiatives aimed at ensuring that those firms who do invest in advanced robotics and automation technologies have the skilled labour necessary to exploit their potential.

Across each of these technological fields, leadership and competitiveness in Ontario will build on established competencies in both academic and industrial application of these technologies. Moreover, they will each also benefit from complementary clusters of expertise, such as the nascent Internet of Things cluster emerging in Kitchener-Waterloo (Bellemare 2015). This new field of machine-to-machine communication will enable new forms of data collection and subsequent process and product improvements across nearly all manufacturing fields. Capturing these benefits, however, will require investments of both financial resources and time. Increased engagement with both post-secondary research organizations, as well as the start-up communities that host and facilitate the development of these new technologies, will be key.

Section 4: Insights from Industry Leaders

Given the diverse and complex challenges ahead, there will be no silver bullet solutions for reinvigorating Ontario's manufacturing sector. The sector cannot expect government to provide all of the answers. Nor can it rely on a devalued Canadian dollar to boost its fortunes. Rather, as a series of research reports have indicated, the sector needs multifaceted solutions for boosting competitiveness.

Existing research on the challenges facing Ontario and Canadian manufacturers has focused largely on the business environment and regulatory issues. The Mowat Centre's 2014 report, *Ontario Made: Rethinking Manufacturing in the 21st Century*, highlights a series of important issues related to the competitiveness of the Ontario manufacturing sector (Oschinski, Chan and Kobrinsky 2014). However, the role of new technologies and the potential they offer were largely omitted from the analysis. Similarly, the Ivey Business School and Lawrence National Centre for Policy and Management's 2014 report, *The Future of Canadian Manufacturing: Learning from Leading Firms,* focuses largely on regulatory, trade, and coordination issues (Ivey and Lawrence National Centre 2014).

While in both cases the insights and recommendations are helpful, they allocate insufficient attention to the primary driver of competitiveness and innovation—investment and research into new technologies. The omission is surprising, given that technological advances such as robotics, 3D printing, and nanotechnology are redefining the very nature of manufacturing and, like the Internet, are already giving rise to powerful new competitors that could disrupt and perhaps even displace large swaths of the conventional manufacturing sector. No amount of regulatory tinkering will be sufficient to hold these forces at bay. Indeed, only by adopting these new technologies and investing in transformational processes can Ontario-based manufacturers expect to capture market share and shore-up their competitiveness. In short, manufacturers must innovate and adapt to survive.

The case for technological investment is all the more urgent given that Ontario firms, notably manufacturing firms, significantly underinvest in new technologies when compared with their competitors in other jurisdictions. According to research conducted by Ontario's Jobs and Prosperity Council, Ontario manufacturers spend less than 60% of what their American counterparts do on non-residential fixed assets (Ontario 2012). And while a large share of them are investing in automation, this remains at levels insufficient to produce sector-wide growth.

Where investments in automation are being made, they are driven at least in part by workforce challenges (BDO 2014).[5] Across Ontario and Canada, manufacturing performance is constricted in a significant manner by a lack of skilled labour. According to the 2014 survey of Canadian manufacturers, conducted on behalf of CME, attracting and retaining skilled workers remains the primary challenge facing manufacturers. Over half of those surveyed noted that they already face workforce shortages. And while such labour demand should drive labour costs up, this inflationary pressure is identified by 38% as a subsequent competitive challenge (ibid.).

Our own work on labour market challenges in Southwest Ontario surfaced broadly similar findings (DEEP Centre 2015). Manufacturers interviewed as part of the project overwhelmingly indicated skilled labour shortages in manufacturing as a major impediment to ongoing growth. While regionally specific issues are certainly a factor in creating these shortages, more generalized increases in labour demand among competitive manufacturing companies is also a driving factor. As the 2014 CME manufacturers survey indicates, over 45% of those surveyed foresee 1–10% increases in their workforce over the next three years. Over 10% anticipate a greater than 10% increase in the size of their labour force (BDO 2014).[5]

Given these challenges, how are successful Ontario manufacturers seeking to boost their competitiveness? And are new technologies and investments in capital-intensive tools and processes part of the answer? To test this hypothesis, we examined the performance of firms in manufacturing sub-sectors experiencing revenue growth that counters the usual "manufacturing decline" narrative. In motor vehicle parts, food manufacturing, and a bucket of highly technical fields—including semiconductor, magnetic and optical media, and engineered technologies—growth patterns over the 2009–2014 period highlight pockets of sustained success. This progress has come despite currency movements and a global competitive environment that has muted growth across other a majority of the province's sectors. Interviews with executives at 12 leading Ontario manufacturers help shed light on the factors most likely to contribute to a vibrant manufacturing sector in Ontario, and particularly on the role of technology adoption in driving long-term competitiveness. These firms were selected for analysis because of their classification in manufacturing sub-sectors experiencing significant growth (see the quantitative analysis provided in Section 2). In each of those sub-sectors, a variety of publicly and privately held companies were sampled, including both large firms and SMEs.

Insights from the interviews highlight both the challenges and opportunities available to firms in these manufacturing sub-sectors. They also highlight a series of potential complementary roles for public agencies, be it in the attraction of foreign investment, co-investing in new technologies, or in the development of a skilled labour pool.

5 According to the 2014 Canadian Manufacturers and Exporters (CME) survey, 40% of respondents are investing in automation to overcome their workforce challenges, and 34% expect to continue doing so in the years to come (BDO 2014).

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Insights from Ontario's Auto Parts Industry Leaders

That Ontario-based automotive factories have captured just US$750 million of over US$10 billion in new global automotive investments is the surest sign of an industry whose fate in the province is cloudy at best. Growth, both in terms of production facilities and consumer markets, is clearly outside of the province, and increasingly far from it. Mexico's capture of US$7 billion in new facilities and the rapid maturation of China's automotive market are two relevant examples of this shift in both the production and consumer landscape. Within North America, Canada's share of vehicle production slumped to its lowest level since 1987, at just 14%. Compare this to Mexico, which has seen its share of North American production increase from 3% to 20% over the same period (Keenan 2015a).

Yet despite these trends, employment and sales growth in Ontario's auto parts sector remains modestly positive. Ontario remains home to 12 major automotive production plants, approximately 350 automotive parts suppliers, and over 300 tool, die, and mould makers. The industry employs over 100,000 people and, as noted in Section 2, the sector's performance is a positive outlier amidst generally declining employment and revenue figures across the province's manufacturing sector.

The ongoing importance of the sector is without question. What remains to be seen is how Ontario auto parts suppliers react in order to remain relevant in an evolving global automotive picture? What types of investments and relationships will they build to remain on the lead technological edge? To answer these questions, the DEEP Centre spoke to senior executives at three Ontario-based auto parts manufacturers. This sample included Aurora-headquartered Magna, Waterloo-based Ultra Manufacturing, and London-based Canada Tubeform. Together, they provide a broad perspective on the challenges facing the industry in Ontario, as well as the steps taken or planned by these players in order to remain competitive in an increasingly competitive space.

Three distinct themes emerge from these conversations. The first is the need to better coordinate engagement with global automakers to encourage and incent investment in the province. Second is the adoption of a systems-based approach to innovation and technological change. Third is ongoing challenges related to Ontario's manufacturing labour force.

As Scott Paradise, Magna's Vice-President of Marketing and Business Development for the Americas, noted in a recent interview, "If you can attract the auto makers, you're going to attract us and every other supplier" (Keenan 2015b). This comment frames both the opportunity and challenge for Ontario auto parts suppliers and their policy stakeholders. Mexico's aforementioned ability to attract those original equipment manufacturers (OEMs) has Ontario-based suppliers being forced to, at the very least, consider following this activity south. Christopher Campbell, Founder and President of Canada Tubeform, notes, "All of my customers have a large presence in Mexico and without exception they all want to build down there with them." As one senior manager at one major automotive company noted, "growth markets are not here. We're at a saturation point in Ontario, so building and growing our business here requires a push to land more OEMs." While Ontario's auto parts industry

has seen employment and sales grow, this is a product of contracts with defined expiry dates. Renewing these engagements, and developing new ones, is integral to maintaining these employment levels. As Joe D'Angelo, Founder and President of Waterloo-based Ultra Manufacturing, notes, "we need to maintain and get new anchor customers. We exist because of a regional hub. But without new anchors there will be no new companies like us."

Canada's, and Ontario's, failure to land new OEM investment is blamed in part on the lack of coordination among policy-makers at different levels of government. The subsequent development of a Canadian automotive investment board as suggested in 2014 by the Canadian Automotive Partnership Council—an advisory group composed of industry executives, Ontario, Quebec, and federal government officials and representatives from the Unifor union—is broadly seen as a potential solution. Yet any such steering committee will have to realize that the successful attraction of OEMs is premised on an ability to outbid other jurisdictions with subsidies.

Without such new investment, exporting parts to growing automotive hubs in Mexico and other locations will take on added importance for Ontario-based auto parts companies. However, several barriers continue to inhibit an export-driven path to growth. In particular, as OEMs move to order-specific sequencing, suppliers must be able to guarantee on-time delivery. Such guarantees are difficult to make, according to our interviewees, thanks to increasingly spurious delays at border crossings. Thus, proximity matters, both for the flow of goods, as well as for the back and forth flow of people and ideas.

Landing new OEM investments is understandably seen as priority one across the industry; however, investing in innovation is arguably just as important when it comes to ensuring that Ontario-based suppliers have something distinctive to sell into automotive growth markets, be they in Mexico or Asia. Building a next generation of component parts is key to this challenge and is at the heart of the strategies espoused by each company we spoke to. D'Angelo notes simply, "For our survival we have to come up with ideas that others can't see. You need to push and create a company culture to achieve that. And you're going to fail while doing so. But if you're not failing, it's a sign that you're not pushing hard enough to succeed and innovate."

Approaches to operationalizing this culture of innovation differ across companies of different sizes. Magna is Canada's third-largest corporate spender on research and development, having allocated over CAD$575 million to such efforts in 2013.This scale allows for the promotion of innovation via both closed and open approaches. Internal or closed innovation is focused on traditional research and development activities, married with active engagement with all staff on the overarching question of "What should a car be able to do?" With open innovation, on the other hand, companies seek to acquire new ideas and innovations through collaboration and co-development partnerships with customers, suppliers, third-party contractors, business accelerators, and even freelance contributors.

Magna's internal or closed processes mesh with an open innovation strategy that looks to engage outside expertise on the company's technology needs. This hunt includes engagement with one of the world's most celebrated start-up assistance organizations, TechStars. Through the TechStars Mobility program in Detroit, Magna

and others like Ford, Verizon, and Honda work with chosen start-ups focused on the development of solutions applicable to the movement of people and goods. Magna's involvement includes the provision of funding, as well as the participation of senior Magna leaders, such as Chief Technology Officer Swamy Kotagiri, as mentors. Canadian start-up assistance organizations do not feature prominently in the company's engagement strategy as the majority are software- and application-focused, as opposed to the hardware or process focus that a major manufacturer looks for.

For Magna, and others across the industry, this open innovation strategy also includes relationships with local post-secondary institutions. However, finding alignment between the earlier stage technological ideation happening in universities and the shorter-term needs of a company makes coordination a complex process. Moreover, smaller firms note a more difficult time accessing post-secondary expertise. "I wouldn't know where to start," noted one senior executive. Building more visibility into the related research interests and the problem-orientation of faculty through the development of a social network-like platform for the auto parts or automotive industry would be a valuable addition to help address these barriers. Centres of automotive excellence developed at Ontario universities and colleges such as the University of Waterloo's WatCar or the Automotive Centre of Excellence at the University of Ontario Institute of Technology offer promise; however, there is little concrete indication of the immediate commercial impact of these centres. New initiatives such as the Problem Lab, currently in development at the University of Waterloo, may potentially solve part of the coordination challenge between these public and private actors. Akin to InnoCentive's crowdsourced solution platform, the Problem Lab will solicit challenges and intractable problems from firms to be shared among students and faculty who will be encouraged to form groups to tackle them.

As it relates to the adoption of new technologies, one executive noted that while the business case for many new technologies such as 3D printing and robotics had yet to be clearly demonstrated, the only way for companies to understand their potential and discover new applications is to experiment with them directly. Adopting 3D printing technology, in this instance, has allowed for the development of new component parts in a significantly faster manner than previously possible. Between 3D printing and new robotics technologies, the executive noted an ability to create bold pioneering designs that more often than not are where the company earns its greatest revenue from. Similarly, aggressive investment in robotics and related automated technologies has allowed for the development of zero-defect production processes across Canada Tubeform's domestic production facilities. This compares very favourably to upwards of a 20% defect rate seen in labour intensive processes still the norm in Mexico. Ongoing investments in sensing and imaging technologies may further differentiate high-quality processes among these producers.

These investments speak to the equal importance of process-related technologies and the design of lean manufacturing processes. One executive adds, "Building sustainable margins requires a marriage of a German approach to investment into capital and technology with a Japanese approach to process management." This Canadian marriage of the two approaches also relies heavily on investment in experimentation and the devel-

opment of an understanding of the industrial properties of new materials. Campbell notes, "The arrival of new advanced strength steel products and the potential application of new nano-materials requires an added level of expertise and knowledge in our factories. We need to invest in this capacity and this is where we have a significant competitive advantage."

Magna has grown its footprint despite the post-2007 downturn in the Canadian market, which saw the disappearance of many tier II and tier III suppliers. Those that survived, however, have grown thanks to the further consolidation of the market. Magna, for example, has seen its plant size grow and its Ontario labour force grow by 25% since 2010. This process of consolidation is mirrored across the industry. As one industry executive notes, "You're not relevant until you are big. And you need scale to compete." Cost pressures, and thus margin pressures, are "relentless" according to several executives interviewed. How to protect, if not increase, research and development budgets given these pressures is a significant concern for several of the executives we spoke to. Policy initiatives aimed at encouraging and facilitating innovation-related investments are a necessary target. Adding to these pressures, increased competition from European, Chinese, and South Korean manufacturers was noted as a significant incentive to scale up given the likely further pressure on margins that will result. Executives anticipate that these pressures will grow given the recently completed trade agreements with South Korea and the European Union. Senior executives at several of the firms interviewed for this project note a need for government support, especially for SMEs, as it relates to understanding and exploiting the opportunities that such agreements provide.

Finally, investments in new technologies and new production facilities will mean little without the skilled talent base to operationalize them. Executives interviewed for this work, as well as for other DEEP Centre research projects, consistently expressed significant concern about the availability of a skilled manufacturing labour force. While pockets of high unemployment in manufacturing clusters exist across the province, there remain significant disconnects between the skill sets available and those in demand by leading manufacturers. Across the pool of executives interviewed for this project, investments in and reform of secondary education mathematics and technology-related curriculum was called out as a priority. Building capacity in these fields is a precondition for the sectors' short- and long-term success. While the firms interviewed each have significant internal training program, they note that the pool of potential candidates is relatively limited and the competition for them intense. Building a robust pipeline of talent for the industry must be a top priority for stakeholders at every order of government. As will be expanded upon in Section 5, a series of short- and medium-term initiatives can and should be implemented in order to tackle this gap.

Ultimately, while Mexico's rise in the automotive sector and its related supply chain is often pointed to as the product of low wages, these low wages are increasingly accompanied by very productive labour. Keeping Ontario-based auto parts suppliers competitive and sustainable will require aggressive investments in both open and closed innovation, and in the development of a labour pool that can effectively exploit and operationalize these investments.

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Insights from Ontario's Food Manufacturing Industry Leaders

If Ontario's auto parts industry represents a cloudy future, the future of the province's food manufacturing industry is far brighter. As noted by Food and Beverage Ontario (FBO), over the period of 2007–2012, the value of the sector's production has risen 11% and, as highlighted in Section 2, employment in the sector grew by 4% over the 2010–2012 period. Exports have also risen from $6.8 billion in 2010 to $7.6 billion in 2012. And while Ontario's food and beverage trade balance has worsened, a deflating Canadian dollar and ongoing investments in innovative products could position domestic producers to displace imports and gain additional traction in key international markets.

The sector includes over 3,000 food and beverage processors, employing over 100,000 Ontario residents (FBO 2015). Ninety percent of these companies employ less than 100 employees. As part of this project, we spoke with senior executives at Maple Leaf Foods, Sofina Foods, and Dare Foods Ltd. While these firms represent the far smaller share of large firms in the sector, they represent a trio of firms whose impressive growth is an example of the opportunities available in the sector. Moreover, companies of their size and scale also represent the most significant investors in new technologies and new processes in the industry. As Al Brezina, FBO Vice President of Research and Innovation for, notes, "Ontario food processing SMEs are very lean, and struggle to invest given the size of their margins. Most innovation is subsequently driven by larger processors." This represents both an opportunity and a challenge for the future of Ontario's food processing industry—both of which are explored in more detail as follows.

Several key themes surface as consistent across these conversations. First is the necessity of investments in new technologies and processes. These, however, are made difficult by increasingly stifling margin pressure driven by retail consolidation and rising input prices. Innovation in this manufacturing sub-sector is also driven primarily through internal processes, with far less "open innovation"-type engagement with business incubators or other third-party groups. Finally, like in auto parts, accessing sufficient skilled labour remains a significant challenge for the industry, one that current post-secondary programming seems insufficient to address.

Before exploring these themes further, however, it is worth highlighting a comment on the impact of the quickly depreciating value of the Canadian dollar. While many hope or believe that this trend will produce immediate gains for Ontario manufacturers, these exchange rate dynamics play but a small part in their future sustainability according to manufacturing executives. As Colin Farnum, Senior Director Innovation and New Technologies at Maple Leaf Foods, explains, "the current foreign exchange situation gives us breathing space, but winning new markets and product areas is ultimately about meeting consumer demands with innovative new products."

The ability to confidently invest in developing new products and, in turn, the adoption of new technologies is premised on building an awareness of cutting edge products, processes, and technologies around the world. Farnum explains, "we look around the world—in both the private and public spheres—to find technologies that can take us to the next level. This means looking at other industries and the process technologies they use to maximize efficiency, as well as looking at new technologies, and seeing how we might apply them to existing portfolios of food products." While this approach is quite orthodox, others in the sector are far more focused on "sticking their knitting" and building in an incremental fashion. Toine Stolze, Director of International Sales and Co-Manufacturing at Kitchener-based Dare Foods Ltd., notes that the food processing industry is quite conservative when it comes to exporting and flexibility. This is driven in part by tight margins and in part by proximity to a large market that has long had significant room for any product. Stolze compares this to his previous experience in Holland where the small size of the domestic market and a fragmented neighbourhood forced a far more flexible and export-oriented approach.

In Ontario, and according to the executives interviewed, the cost pressures that inhibit investments in innovation have been accelerated by ongoing consolidation in the Ontario and Canadian retail consumer market. The subsequent inability to recover research and development and other innovation-related investments makes furthering the sector's competitiveness uncertain. As one executive noted, "you need transformational products to win new markets and to meet the cost recovery demands of the necessary investments involved in building them. However, our margins are increasingly limiting our ability to make those initial investments. We're stuck within this tension."

Technologies of interest include robotics and automated process for production line efficiency, vision systems, and other optical technologies for quality control and energy systems. The latter, in particular, is of interest to several of those interviewed. Food processing involves high thermal loads for both heating and cooling. Finding new ways of more efficiently applying heating and cooling, and lessening the need for conduction in those processes, offers significant opportunities for collaboration among industry and other academic and third-party actors. Other technologies, notably 3D printing, are seen more as sources of product innovation for retailers, restaurants, and others closer to the final consumer. For food manufacturers, however, it would be short-sighted to ignore the growing market for organic printed materials. Nutella has enjoyed a significant brand visibility thanks to its role as one of the first "printed" food products. While the impact on the bottom line may be limited, the marketing value of this engagement may prove to be significant in the long term.

A higher priority than investment in new technologies is an ongoing quest for scale as a response to margin pressure. In so doing, however, tension exists between the desire to achieve scale and a need to remain flexible to access new markets and new product opportunities. As one executive noted, "while scale is important, the major driver of success going forward is going to be product differentiation. The real competitive advantage in that race will be to food manufacturers who can shift quickly to meet emerging and nascent demand."

Doing so effectively will require added visibility into those international markets, as well as visibility into the local sources of innovation and product components that will enable differentiation. Unfortunately, building supply relationships with the small- and medium-sized companies that represent 90% of the over 3,000 food and beverage process in the province is seen as quite challenging. The majority of these potential suppliers of product and technology lack visibility. And while each of the firms interviewed for this project noted ongoing attempts to increase their visibility, rapid market entries and exits make the development of a dynamic ecosystem map a real priority. This issue of visibility applies equally to efforts to engage with Ontario post-secondary institutions. While several Ontario colleges and universities run programs aimed at developing Ontario's food manufacturing labour force, connections on research are far less well developed. In both cases, systematic efforts to build awareness of capacity and specialization across the province would be a welcome step in facilitating the success of both small and micro-sized producers and the medium and large ones who are often their lead customers.

While the consolidation of the domestic retail market that has brought significant margin pressure, it also brings an increased level of standardization to regulatory and food safety requirements. And while this entails added costs, it also raises the bar for Ontario food processors and may lend itself to the further development of a "Made in Ontario" brand equated to food safety and food quality for both domestic and export markets. Capturing exporting opportunities for food products in growth markets such as Asia and the Middle East will require a differentiator that currently is missing for Ontario and Canadian food products. While Australia markets its meat products with the "True Aussie" brand, there exists no equivalent for Ontario or Canadian products. Such branding would also help as new trade agreements open up new opportunities and new competitive challenges in Europe and Asia for Ontario food processors. Al Brezina from FBO notes that "domestic food manufacturers, notably the small and medium sized ones, are going to need help to take advantage of agreements such as the Comprehensive Economic Trade Agreement [CETA]. While there's significant opportunity, the regulatory and linguistic frameworks will make providing them with support and guidance essential to benefitting from the deal."

The aforementioned positive benefits of safety and regulatory upgrading are balanced by the additional pressure such moves will put on small and micro-sized players in the industry. Across interviews it was acknowledged that such shifts alongside retailer consolidation would make it increasingly difficult for small food processors and manufacturers to survive. Policy designed to assist such players, notably as it relates to ongoing training and management development, should be a public and private-sector priority. So too should a modernization of federal regulation of new food technologies and new food ingredients. Brezina notes that, as it stands, "old food labelling rules get in the way of producers' ability to market and sell products that the market wants."

Finally, and as seen in the auto parts sector, a lack of skilled labour will hamper the sector's ability to grow. Executives interviewed noted an overall "very weak" supply of skilled labour, observing deficiencies in the availability and pipeline of labour with advanced scientific and mathematical skills. In addition, perceptions of the food manufacturing industry as "low value" direct graduates from academic programs away from the front

line of processing and into laboratories for research. While this fills a long-term need, it amplifies the need to further develop a positive brand for the industry and the variety of high-value employment possibilities in it. This is broadly true across the manufacturing industry. However, stakeholders interviewed for this project noted the acute need to address the brand of food manufacturing. Perceived by many as low value, its role in satisfying the hunger of millions should be seen as nothing short of high value.

While many in the industry are focused on scale and price as a means of immediate survival, for those interviewed it's clear that "price won't win in the long term." Rather, investments into research and development, management capacity, supply chain visibility, export assistance, and labour development are necessary to help ensure that the green shoots of growth in Ontario's food manufacturing industry are allowed to flourish.

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Insights from Ontario's Speciality Technical Manufacturing Industry Leaders

While Ontario's auto parts and food manufacturing sectors both offer opportunities for ongoing success, neither have the exponential potential of novel highly engineered manufacturing subfields such as those concentrated on semiconductors, optical, navigational, and other technical fields. As will be highlighted, successful manufacturing companies in these fields have each carved out high-margin niches in high-technology manufacturing sub-sectors. They've done so by marrying the engineering and technological talent usually destined for ICT and other high-tech sectors with in-demand product designs whose markets are instantly global.

Senior executives from five firms were interviewed for this portion of the project. The firms include Waterloo-based Aeryon Labs; Kitchener-based Angstrom Engineering, Christie Digital, and Thalmic Labs; and Mississauga-based Temporal Power. Each represents a high-growth Ontario manufacturer in a leading high-tech sub-sector. The sample includes several manufacturing firms with very recent growth, notably Aeryon, Thalmic, and Temporal Power. Others, like Christie Digital, are far larger and more established. While their growth paths vary, each holds potential to emerge as one of Canada's next major manufacturing giants. The insights that emerge as to how they promote innovation—as well as issues related to labour, government support, and offshoring—provide a lens into the challenges facing this new breed of Ontario manufacturer, as well as the opportunities available to them to continue their upward momentum. Ultimately, each of these companies represents a new generation of manufacturing company that combines design, production, and software capabilities into the fulfilment of a niche or high-value market.

Waterloo-based Aeryon Labs is a great example of this new type of company. Founded in 2007, the unmanned aerial vehicle or drone manufacturer has doubled in size over the past calendar year and now houses 120 employees in a 40,000 square foot facility. Aeryon's place at the leading edge of technological innovation initially required a significant focus on educating potential customers on the use of their products. However, the success of early adopters has proven to be effective marketing in the attraction of potential clients in new fields. "We're in a real expansionary phase of how and where this technology can be applied," says Founder and President Dave Kroestch.

A few kilometres away, 60-person Thalmic Labs is at the front of the pack in the wearables space, having produced the popular Myo watch. The company is now feverishly working on its next products and the evolution of gesture control technologies.

Christie Digital represents the evolution of the iconic Electrohome brand. Now owned by Tokyo-based Ushio Corporation, the company has over 700 staff at its Kitchener facilities. Vice President of Research and Operations Ihor Stech notes that the company's largest costs are in the design and development of new products. The company employs 270 engineers who are focused on "pushing the edges of physics" to enable brighter, lighter, and quieter projectors and screen displays.

With 25 employees, including 10 engineers, Mississauga-based Temporal Power has positioned itself as a leading manufacturer of the energy storage products that are necessary for the fulfillment of the renewable energy promise. According to Aaron Lampe, Temporal's Vice President of Sales and Operations, the company is aiming to double its employee count and force itself out of its current 25,000 square foot location within the next 3 to 4 years.

And finally, while the companies listed so far each produce an end consumer or business product, Kitchener-based Angstrom Engineering manufactures thinfilm coating machines for academic and corporate research labs. Their technology is central to the rapidly expanding field of nano-enabled products and micro-electronics. Andrew Campbell, Angstrom's Vice President of Sales and Business Development, notes that "we're at the heart of advances in nanotechnology and the application of thinfilm coatings to a range of semiconductors. We provide the machines that enable industries from food to renewable energy to health to take advantage of the potential of nanotechnology." The company has seen its sales grow 20% per year over the last three years, and has doubled its employee count to 35 employees. This growth has come alongside a push to look beyond the US as the company's key export market. While the US represented over 90% of the company's revenue a decade ago, sales outreach in Asia, Russia, and Latin America has seen this US share decrease to just 40%.

Coincidentally, this sample of companies is primarily rooted west of the Greater Toronto Area, in and around Kitchener-Waterloo. The reasons for this are many, but key is the University of Waterloo's engineering programs. David Kroestch notes that Aeryon was started in the Waterloo area because of the proximity to the University of Waterloo and its famed engineering and co-op programs. Ihor Stech of Christie Digital has the same opinion of the region's labour supply. "If we were starting today from scratch, we'd still choose to locate in this area. We're within an hour and a half of eight universities and several colleges with key research and engineering capabilities." Here the focus isn't on labour for production, but rather labour for engineering and research. Stech notes that in industries where the opposite is true, for example in the automotive sector, long-term competitiveness will be difficult to achieve. Rather, Ontario can win, he believes, in industries where the labour component is comprised mainly of designers, engineers, and product managers able to integrate it into a final product.

Stech notes that Christie Digital was an early adopter of technologies such as 3D printing out of necessity rather than curiosity. "We couldn't wait three or four weeks to get a prototype. When you're working towards a defined product launch date, [you] need to be able to produce multiple generations of prototypes quickly and iteratively." The company has now moved from using such technology for just rapid prototyping to broader applications including the production of small, flexible components.

The company's approach to innovation is also focused on external partnerships with groups such as Communitech and the Centre for Smart Manufacturing at Conestoga College. In the latter case, funding from the Canada Foundation for Innovation has allowed Christie and Waterloo-based DifTek Lasers to partner with the college and its students to develop a new manufacturing process to lower the rate of defects in television screens powered

by organic light emitting diodes. Should the partnership result in a scalable process, the returns to both the partner organizations and Ontario's economy could be significant.

Temporal Power's growth is the product of a relationship just like this. Through an evolving partnership with Hydro One, Temporal has seen its unproven technology become a going, and growing, concern. The relationship started as a joint study, hosted by Ryerson University, about the potential of Temporal's flywheel technology. It progressed to a joint research project between Temporal and Hydro One, followed by testing at Temporal's facility, and now a grid-connected project. Intellectual property developed through the partnership is co-owned. Lampe describes this anchor relationship as integral to the company's growth: "without this we never would have got off the ground. [Hydro One was] willing to work with us very early in the process. This helped refine our technology and the design of our product." The benefits evidently flow both ways. Lampe adds that Hydro One "was looking to modernize and saw us as a potential means of doing do. Without this relationship, our path and progress would be very different, far less advanced, and I'd imagine Hydro One would have missed out as well." Lampe adds that while there are challenges for a start-up manufacturer in working with a major anchor customer like Hydro One, "what are the alternatives?" The high cost of hardware and manufacturing start-ups means developing faster partnership and client relationships are necessary to promote even short-run sustainability.

For Angstrom Engineering, bridging this customer-investment gap has been aided by contracts with leading universities who have acted as lead clients for new Angstrom machinery. Facilitated by NSERC Engage grants, serial dating between Angstrom and academic researchers has spawned several projects, notably a relationship with the University of Guelph related to the application of thinfilm for plant growth. This initial research relationship has evolved into a series of product orders and further work with the European Space Agency and corporate giant Syngenta. Perhaps more importantly, this type of engagement with academic researchers positions Angstrom at the cutting edge of nano-related research in a variety of fields without having to independently invest in each. While this approach is not applicable to all manufacturers, it highlights one of the primary benefits of more intense industry-academic engagement.

Across this sample of companies, they each benefitted from BlackBerry/Research in Motion's decline and the subsequent availability of highly skilled, highly technical manufacturing talent. At Aeryon, much of the company's manufacturing and sales workforce has come from BlackBerry. Kroestch notes, "they brought in and trained top talent focused on high-tech quality and prototyping. We're ultimately not that different than they were. We're about wireless, battery power, and overcoming big engineering challenges. That aligns with exactly the labour and approach to manufacturing that what we need." At Kitchener-based Thalmic Labs, much of the company's manufacturing and supply chain expertise is ex-BlackBerry staff. Vice President of Manufacturing David Perston is one of them. He joined the manufacturing start-up in 2014 in part because of the complementarity between his past work on Blackberry's mobile products and the novel ones being planned at Thalmic.

While BlackBerry pushed most of its manufacturing out of the province, Kroestch believes that "while high-volume, low-margin business will most likely continue to migrate out of the region, there remains a real place for low-volume, high-value work in Ontario." As sales have risen, the company has moved from building a "craft" product to a lean manufacturing process that takes advantage of a local supplier base that has, in part, upgraded their capabilities to meet the demands of new manufacturers like Aeryon. Perston agrees, noting that outsourcing production to China or Mexico works for a stable product with high volumes. However, by keeping production local or in-house, the company remains closer to the customer, which allows for much faster iterative design and prototyping to address problems. Lampe from Temporal Power notes that one of their biggest competitive advantages is the ability to source locally from high-skilled precision machine shops that have reoriented their capacities from automotive and heavy manufacturing to the more customized and flexible demands of companies like his. Lampe adds, "There's now, perhaps unfortunately, loads of this high-skill, high-cost capacity available within a 100 kilometre radius of us. This means we don't have to invest by ourselves in this capacity and can instead invest in other, higher-margin and higher-priority aspects of our technology."

Keeping production in Ontario, and keeping their organizations competitive, is increasingly stressed by the rise of high-value manufacturing in Mexico and throughout Asia. Kroestch notes that "manufacturing in Asia isn't just about cheap." Rather, in some fields, notably carbon fibre technologies and manufactured components, they're at the leading edge. Stech notes that the quality they see in China is on par with their Ontario facilities. The company's decision to locate production in China hasn't been focused on wages. Rather, it's about overcoming significant barriers to trade, such as tariffs on imported high-tech products, as well as being able to tap into significant production capacity.

Supporting domestic firms in this competition will be key moving forward. While Aeryon has benefitted from government funding programs such as Scientific Research and Experimental Development (SR&ED), the Industrial Research Assistance Program (IRAP), and the Ontario Centres of Excellence, the focus of such funding programs is largely on start-ups. Kroestch notes, "much of the assistance falls off a cliff once you start making money. It means there's lots of help to build a start-up, but far less to help develop that start-up into a great company." Perston agrees, noting that the capital expenditures that are most important to a quickly expanding manufacturer like Thalmic aren't eligible for SR&ED support, despite their integral place in the innovation process. The challenge for such small manufacturers is being able to eke out sufficient margins to invest in ongoing research and product development. Perston notes that this is a challenge for hardware start-ups, but ultimately an imperative in building a sustainable company. Stech adds that government policy has an integral role to play in helping to support companies who have the potential to scale, but need assistance in bringing their innovations or technologies to market. Supporting such home-grown players isn't just good politics, according to Stech. Rather, he argues that such manufacturers are far more likely to stay and grow in Ontario given their decision-making centres are all local. "If you have a decision-making point outside, then you don't have the same perspective on where to locate production or growth. Within multinationals, sites will compete against each other to host the parent company's next project with little advantage beyond cost and subsidies for any one location."

Across the firms engaged for this project, it's clear that a perception exists that government support available to them in Canada lags far behind what their competitors receive abroad. One executive interviewed, for example, notes that "there are orders of magnitude difference between what our competitors in the US get from government versus what we're able to." And while the executive notes that this lack of support puts even more pressure on the firm to invest heavily in driving their technological advantage, their ability to do so is quite limited at this stage of their development. Unfortunately, and like others in these still-emerging technologically advanced manufacturing sub-sectors, SR&ED funding has been difficult to access because the official definitions of "technologies" and "technological uncertainty" poorly reflect emergent fields. Provincial advocacy on behalf of such firms to federal granting agencies and funding organizations should immediately be scaled up.

It's clear from these examples that a new breed of high-tech manufacturing company can succeed in Ontario. From start-ups like Temporal and Thalmic Labs to established heavyweights like Christie Digital, Ontario has a unique set of assets related to design, engineering, and highly technical production that makes it a logical place to build next-generation manufacturing companies. Yet for these companies to thrive, and for the green shoots of growth in these highly technical sub-sectors to flourish, a concerted policy focus on their development will be necessary. The final section of this report concludes with an overview of the key insights presented so far, and presents a series of priority areas for action related to how policy-makers might further support the growth of the three manufacturing fields included herein.

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Conclusion

There's no simple formula to supporting the growth of the next generation of Ontario-grown billion-dollar companies, especially for those whose activities are centred on manufacturing. Over the period 2004–2014, the demographic of billion-dollar revenue firms in Ontario's manufacturing sector declined by 35%, and the number of Ontario-based manufacturers with revenues in the CAD$500 million to $999 million range declined by over 50%. This performance among Ontario's largest manufacturers is reflective of the industry's evolution over the past decade. Over the period 2001–2011, the sector shed over 300,000 jobs, with few positive stories emerging to change this narrative.

This project has sought to investigate these trends. Through a dual quantitative and qualitative analysis it has focused on discovering where, if anywhere, Ontario's manufacturing sector might be showing signs of life. And subsequently, amidst these many negative trends, a series of positive stories emerge. Three broad manufacturing sub-sectors have consistently outpaced Ontario's manufacturing index. In auto parts, food processing, and a broadly defined speciality technical manufacturing sub-sector, growth in both employment and revenue is far outstripping the rest of the industry.

The reasons for these green shoots are diverse. Interviews with senior executives in leading Ontario firms suggest that technological adoption and a constant drive to innovate are the key catalysts for growth. In auto parts, the major North American and Japanese OEMs have pushed tier I and tier II suppliers located in Ontario to innovate and reduce costs. While many in the industry have proven unable to compete, those with unique core competencies are flourishing. In food processing and food manufacturing, similar retail pressure is forcing a focus on innovation and efficiency among suppliers, while the search for new markets and the desire to protect existing ones only add to the pressure. And in the broadly defined speciality technical field, satisfying niche consumer markets with high-value, technology-enabled production that exploits Ontario's high-skill, highly technical labour force is proving the most exciting of all.

This optimism, however, must be balanced with a series of ongoing challenges that may mitigate the potential of these industries. In auto parts, the gravitational pull of Mexico and its increasingly high-quality, lower-cost labour pool, as well as the more generalized competitive subsidization of OEM location selection, means Ontario must land future OEM contracts or risk the disappearance of its deep network of parts suppliers. In food manufacturing, retail consolidation has meant the rapid disappearance of the margins necessary to invest in innovation and research. Increased competition resulting from CETA with the European Union will further squeeze Ontario producers. And among generally less mature speciality technical manufacturers, the scale of support received by international competitors, and ongoing tariff and non-tariff barriers to trade, will challenge the growth of Ontario's most promising manufacturing sub-sector.

Overcoming these challenges will require the support of government. The research conducted for this project leads to the following actionable priorities. In some cases, the research points to the need for actions targeted at a specific sub-sector, in others the research points to broad, horizontal priorities that are likely to benefit all.

1. **Attract New OEM Auto Mandates to Ontario:** While the competitive subsidization of OEM location contracts is anathema to many, the potential relocation of existing OEM operations south of the border, once current contracts expire, would be disastrous. Their departure would not just mean the loss of those direct jobs. Rather, it would lead to a rapid exodus, if not disappearance, of the suppliers who serve them. While exports could conceivably help replace this reliance on domestic OEM production, the increasingly specialized sequencing of products is making proximity matter more than ever in this industry. Coordination and commitment across levels of government is a necessary first step in achieving this goal.

2. **Better Prepare Domestic SMEs for Opportunities Abroad:** Recent trade agreements with South Korea and the European Union offer significant potential for increased exports for Ontario producers. However, taking advantage of this potential will require significant support to ensure regulatory, legal, and linguistic hurdles do not stifle the willingness and risk tolerance of would-be exporters. Support for internationalization could take several forms. For example, the province could work with soft landing programs such as the Canadian Technology Accelerator initiative—run by the Trade Commissioner Service of the Department of Foreign Affairs, Trade and Development—to develop soft landing programs and in-market boot camps dedicated to manufacturing-related SMEs seeking to establish connections in Europe and the United States. Meaningful trips to the US could be organized for as little as 48 hours, if the programming was well-structured, while trips to key European hubs might require a week or more. An online export-readiness curriculum could also be developed to help manufacturing SMEs identify and exploit international opportunities. Such a curriculum could be developed and delivered in concert with key stakeholders such as the Business Development Bank of Canada, Export Development Canada, IRAP, provincial and regional economic development agencies, as well as industry associations and universities. A robust export-readiness curriculum would guide firms through the process of conducting international market research and provide guidance on tax, HR, and legal implications of operating abroad. Most importantly, it should ensure that Ontario-based manufacturers are highly strategic in selecting the specific markets, sub-sectors, and opportunities most likely to advance their company's growth.

3. **Build Manufacturing-Oriented Activity into Ontario's High School Curriculum:** Across sub-sectors, the availability and quality of the manufacturing labour pool is impeding growth, creativity, and ultimately long-term competitiveness of Ontario's manufacturing sector. While the speciality technical firms highlighted herein each benefit from high-skill engineering and mechatronics graduates, in other fields the supply of high-skill labour is far from sufficient. Existing college and other post-secondary programs are proving unable to develop a robust enough pipeline of skilled talent. Several European jurisdictions have sought to address similar

challenges by creating "Fab Lab" manufacturing facilities in high schools and community centres to build a broader and more technically adept pipeline of future labour. These centres allow youth to experiment and learn with technical tools and technologies, including robotics and 3D printing. Further integrating the access to such centres across Ontario—and further broadening the technologies included therein to cover a variety of industries, including both highly technical and highly specialized (such as food production)—will be key to ensuring the development of a skilled labour force for Ontario's manufacturing growth industries. As Charles Mire, Co-Founder and CEO of Kitchener-based 3D printer manufacturer Structur3d.io, notes, these facilities will act as the "libraries of technical knowledge for the 21st century." We certainly agree.

4. **Sponsor the Development of Manufacturing Incubators:** With the vast majority of Ontario's business incubators and accelerators focused on digital technology and health IT, there is comparatively little dedicated and specialized support available for start-ups in the manufacturing sector. While domains such as robotics, 3D printing, and nanotechnology are ripe for innovation, firms seeking to get started in these emergent fields need access to expensive tools, highly specialized expertise, and richer funding sources than those that are readily available in most existing incubators and accelerators. Specialized incubators would be especially helpful in sectors like food processing, where the margin pressure facing Ontario food manufacturers limits their willingness to invest in future innovation and product development. In collaboration with incumbent firms, food processing incubators should be established alongside a variety of academic partners to take advantage of Ontario's diverse population and proximity to agricultural output.

5. **Upgrade Research and Development Support for Ontario's Advanced Manufacturers:** The biggest source of funds for specialized technical manufacturers in Ontario are federal funds via SR&ED, IRAP, and other national granting agencies. In many cases, however, the definitions used to judge the merit of applications have not kept pace with technological change. Given the scope of support given by competing jurisdictions, Ontario must ensure a level playing field by working closely with federal partners to ensure that procedural rigidity does not stifle the growth of Ontario's next generation of manufacturing firms.

6. **Facilitate the Increased Visibility of Supplier and Researcher Capabilities:** While large firms are easily able to attract the interest of would-be suppliers and more able to allocate staff to finding relevant researchers, manufacturing-related SMEs struggle to do both. The development of vendor-driven online supply chain networks, and researcher-driven academic research networks, would significantly improve the visibility and ease with which SMEs can access both. The University of Waterloo's forthcoming Problem Lab is a model very much worth studying.

7. **Support for Capital Expenditures and New Investment:** The 2012 federal budget announced that expenditures of a capital nature made after 2013 no longer qualify for SR&ED tax incentives. This change was made despite, or perhaps because of, the dismal investment in innovation and technology track record in the manufacturing industry. However, as noted herein, this change has significant repercussions for Ontario manufacturers whose ability to innovate and produce is tied to investments in capital machinery. Advanced manufacturers in new and growing fields as those detailed herein should be promoted and supported as effectively as possible. Ontario should advocate loudly for either the reinstatement of SR&ED provisions for eligible capital expenditures, or for the reallocation of previous SR&ED capital-related appropriations to either a capital investment fund or research and development fund for manufacturers, as recommended by CME. While either SR&ED-related action depends on the cooperation of the federal government, the development of a provincial-specific tax credit or investment incentive for eligible capital expenditures would mitigate the effects of the 2012 budget change and should be investigated. No matter the source or form of such assistance, is it imperative that such support be based on strict criteria related to technological advancement, research and development, and new product design.

8. **Develop a New Ontario-Wide Advanced Manufacturing Strategy:** Across the comparative jurisdictions studied in this report, each has an explicit advanced manufacturing strategy that directs that jurisdiction's policies and investments. Ontario should adopt this strategy by developing a public-private consortium of government, industry, and academic stakeholders who will work over the short and medium term to identify key emerging and enabling technologies that will structure further investment and partnership collaboration. The three emerging technology areas outlined here—3D printing, nanotechnologies, and robotics—can serve as one initial input into this process. Once key technology areas concordant with Ontario's competitive advantages in manufacturing have been identified and agreed upon by the stakeholder groups, the process should move towards establishing public-private partnership arrangements to facilitate research and commercialization activity in these areas, including the scaling-up of funding and investment.

9. **Sponsor Open-Innovation Approaches to New Technology and New Solution Development:** Working with the province's emerging network of advanced manufacturing research centres, as well as with related industry players, the province should act to facilitate and encourage open innovation approaches for new technology and solution development. This approach could include the creation of an annual manufacturing innovation contest focused on key strategic technology areas, which could be hosted rotationally at advanced manufacturing research hubs within the province and in partnership with industry. Technology focus areas could be selected by a representative group of academic and industry officials on the basis of ongoing technological developments and private sector demand. In addition to encouraging open innovation among the province's manufacturing firms, this type of annual event could help build the type of robust tripartite networks between industry, government, and research organizations necessary to foster processes of collaboration and continuous innovation.

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There's no doubt that Ontario's manufacturing industry has and will continue to face significant challenges. The ongoing processes of industrial upgrading seen in emerging economies, as well as technological evolution around the globe, will only hasten the need for Ontario firms to upgrade, reinvest, and reinvent themselves to match these competitive pressures. As this report highlights, in a series of manufacturing sub-sectors, Ontario firms are showing they can compete and they can win. However, as exogenous competitive pressures grow, it is in the Government of Ontario's best interest to work as closely as possible with industry to ensure the opportunities that new markets and new technologies offer are not stifled by the new challenges they bring. The insights included herein are meant to highlight starting points for how policy-makers in Ontario might choose to do so.

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Appendix: Data

Table 6: POSITIVE SALES GROWTH OUTLIERS

(+3% average annual growth), 2009–2014

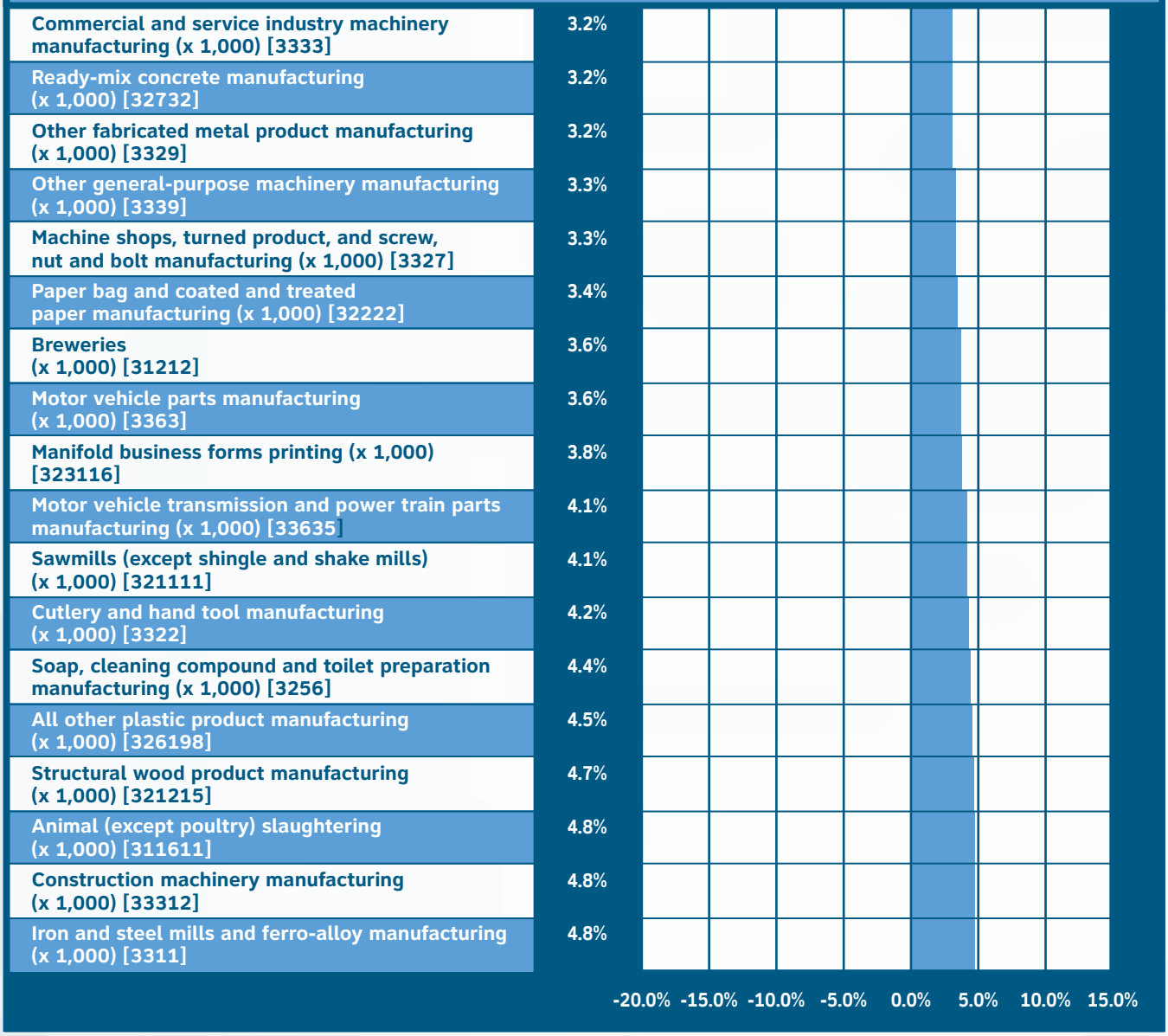

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Table 6: POSITIVE SALES GROWTH OUTLIERS (continued 2 of 3)

(+3% average annual growth), 2009–2014

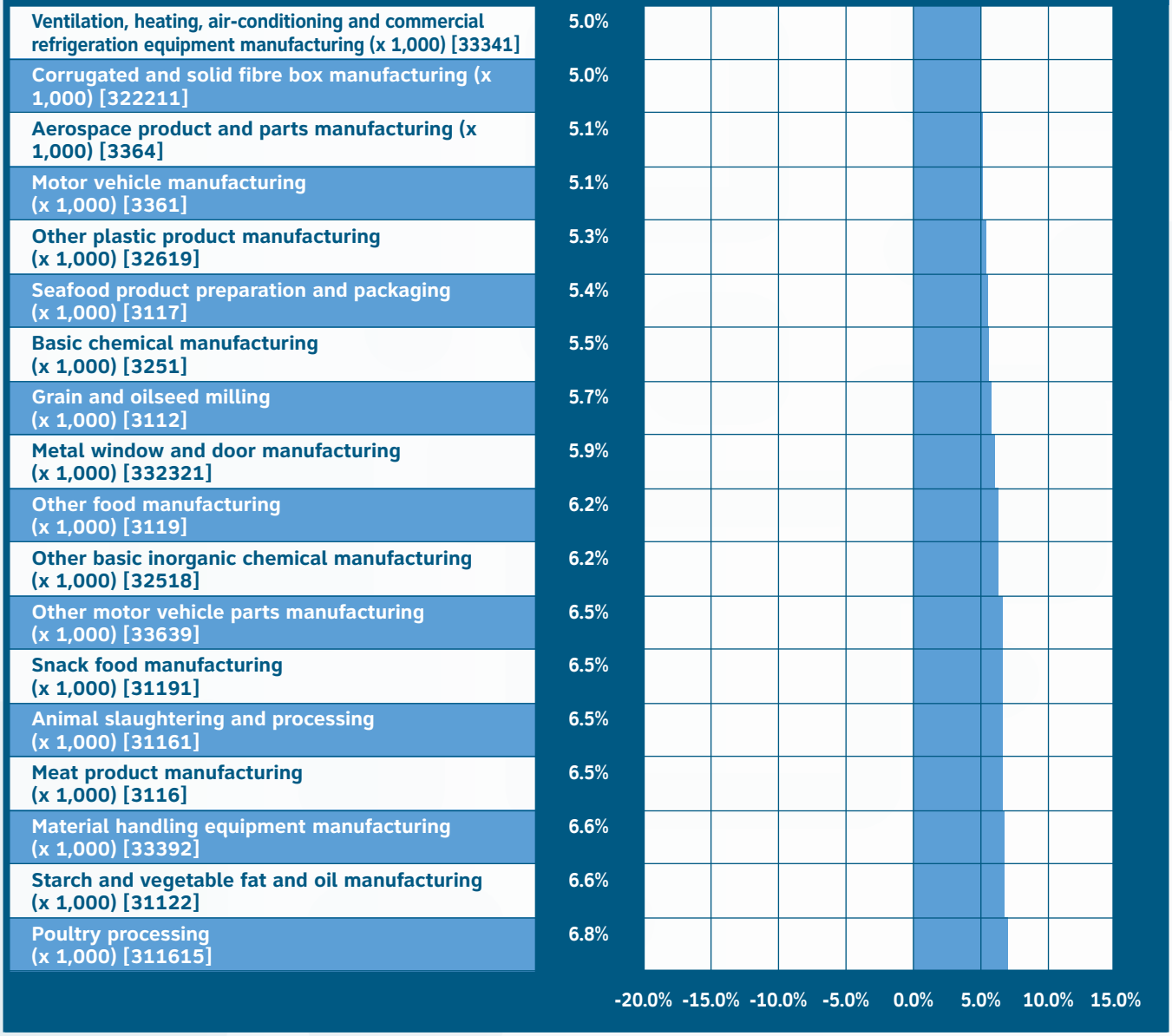

Table 6: POSITIVE SALES GROWTH OUTLIERS (continued 3 of 3)

(+3% average annual growth), 2009–2014

Mattress manufacturing (x 1,000) [33791]	6.9%
Motor vehicle metal stamping (x 1,000) [33637]	7.0%
Other miscellaneous manufacturing (x 1,000) [3399]	7.1%
Motor vehicle plastic parts manufacturing (x 1,000) [326193]	7.6%
Motor vehicle body manufacturing (x 1,000) [336211]	8.0%
Medical equipment and supplies manufacturing (x 1,000) [3391]	8.0%
Industrial machinery manufacturing (x 1,000) [3332]	8.1%
Rendering and meat processing from carcasses (x 1,000) [311614]	8.2%
Animal food manufacturing (x 1,000) [3111]	8.3%
Semiconductor and other electronic component manufacturing (x 1,000) [3344]	8.6%
Other basic organic chemical manufacturing (x 1,000) [32519]	9.2%
Motor vehicle steering and suspension components (except spring) manufacturing (x 1,000) [33633]	9.8%
All other food manufacturing (x 1,000) [31199]	10.6%
Dairy product manufacturing (x 1,000) [3115]	11.4%
Plastic plumbing fixture manufacturing (x 1,000) [326191]	11.4%
Toilet preparation manufacturing (x 1,000) [32562]	11.6%
Manufacturing and reproducing magnetic and optical media (x 1,000) [33461]	12.3%

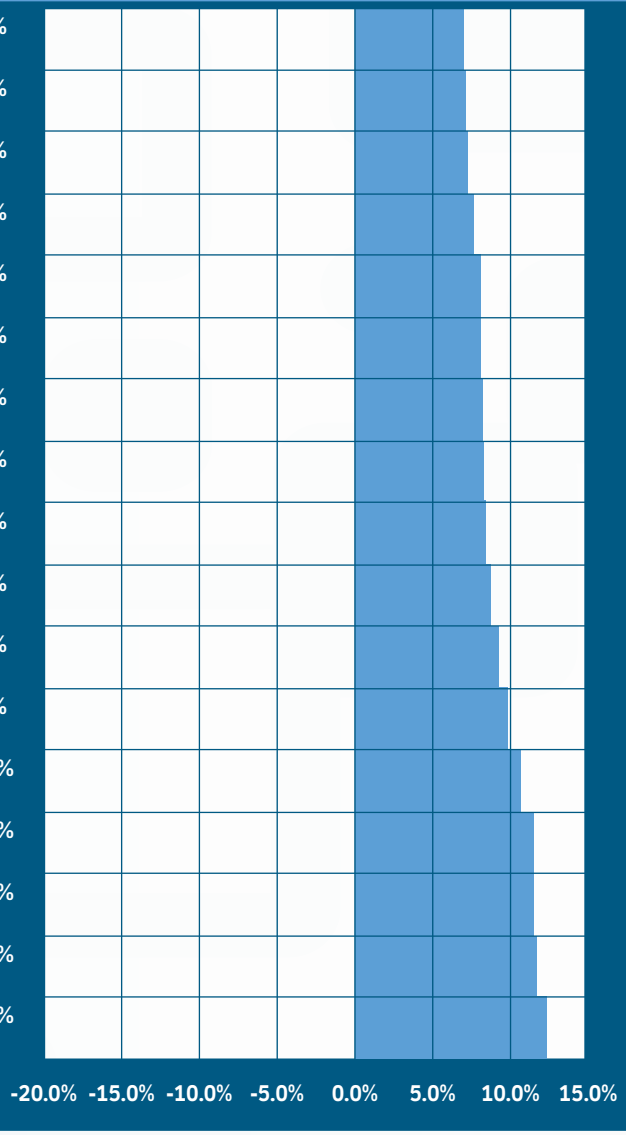

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Table 7: EMPLOYMENT GROWTH OUTLIERS

(+/–3% average annual growth), 2009–2014

3152 Cut and sew clothing manufacturing	-11.5%
3212 Veneer, plywood and engineered wood product manufacturing	-11.1%
3326 Spring and wire product manufacturing	-10.0%
315 Clothing manufacturing	-9.9%
3325 Hardware manufacturing	-9.7%
3162 Footwear manufacturing	-9.3%
3274 Lime and gypsum product manufacturing	-8.5%
3343 Audio and video equipment manufacturing	-8.3%
3342 Communications equipment manufacturing	-8.1%
3341 Computer and peripheral equipment manufacturing	-8.1%
3221 Pulp, paper and paperboard mills	-7.6%
3379 Other furniture-related product manufacturing	-7.6%
3117 Seafood product preparation and packaging	-7.4%
3351 Electric lighting equipment manufacturing	-7.2%
3352 Household appliance manufacturing	-7.0%
322 Paper manufacturing	-6.5%
3328 Coating, engraving, cold and heat treating and allied activities	-6.5%
3211 Sawmills and wood preservation	-6.4%

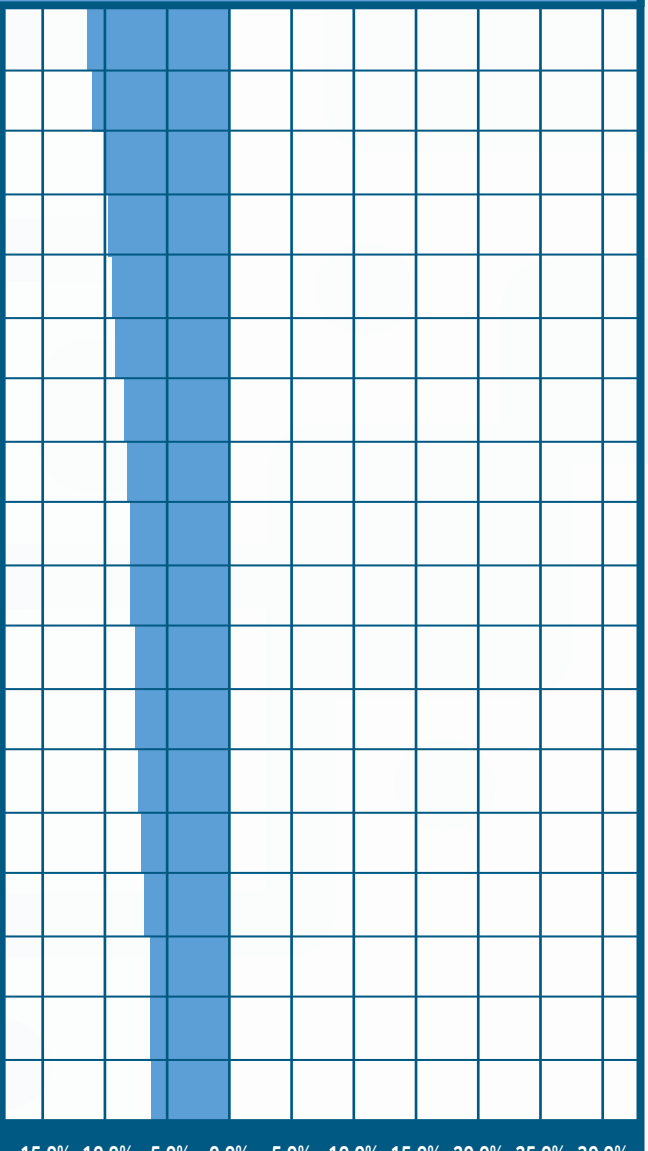

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Table 7: EMPLOYMENT GROWTH OUTLIERS (continued 2 of 3)

(+/–3% average annual growth), 2009–2014

3113 Sugar and confectionery product manufacturing	-6.0%
3222 Converted paper product manufacturing	-6.0%
334 Computer and electronic product manufacturing	-5.7%
3324 Boiler, tank and shipping container manufacturing	-5.7%
321 Wood product manufacturing	-5.6%
3132 Fabric mills	-5.3%
3272 Glass and glass product manufacturing	-5.0%
3262 Rubber product manufacturing	-4.7%
3141 Textile furnishings mills	-4.7%
3371 Household and institutional furniture and kitchen cabinet manufacturing	-4.3%
3359 Other electrical equipment and component manufacturing	-4.3%
3233231 Printing and related support activities	-4.2%
3255 Paint, coating and adhesive manufacturing	-4.1%
335 Electrical equipment, appliance and component manufacturing	-3.9%
3252 Resin, synthetic rubber, and artificial and synthetic fibres and filaments manufacturing	-3.8%
314 Textile product mills	-3.8%
3311 Iron and steel mills and ferro-alloy manufacturing	-3.5%
3251 Basic chemical manufacturing	-3.4%

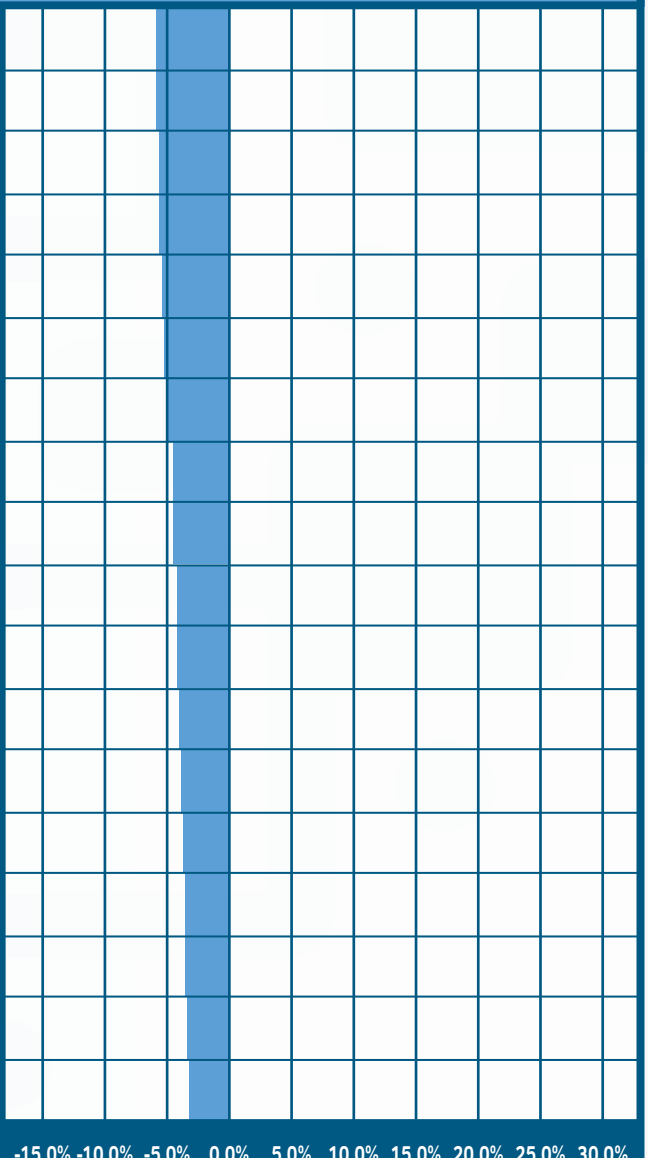

Table 7: EMPLOYMENT GROWTH OUTLIERS (continued 3 of 3)

(+/–3% average annual growth), 2009–2014

3344	Semiconductor and other electronic component manufacturing	-3.3%
3335	Metalworking machinery manufacturing	-3.3%
3219	Other wood product manufacturing	-3.2%
337	Furniture and related product manufacturing	-3.2%
3271	Clay product and refractory manufacturing	-3.2%
3363	Motor vehicle parts manufacturing	-3.2%
3149	Other textile product mills	-3.2%
3114	Fruit and vegetable preserving and specialty food manufacturing	-3.1%
3119	Other food manufacturing	3.3%
312	Beverage and tobacco product manufacturing	4.0%
3169	Other leather and allied product manufacturing	4.8%
3333	Commercial and service industry machinery manufacturing	5.1%
3365	Railroad rolling stock manufacturing	6.1%
3161	Leather and hide tanning and finishing	27.5%

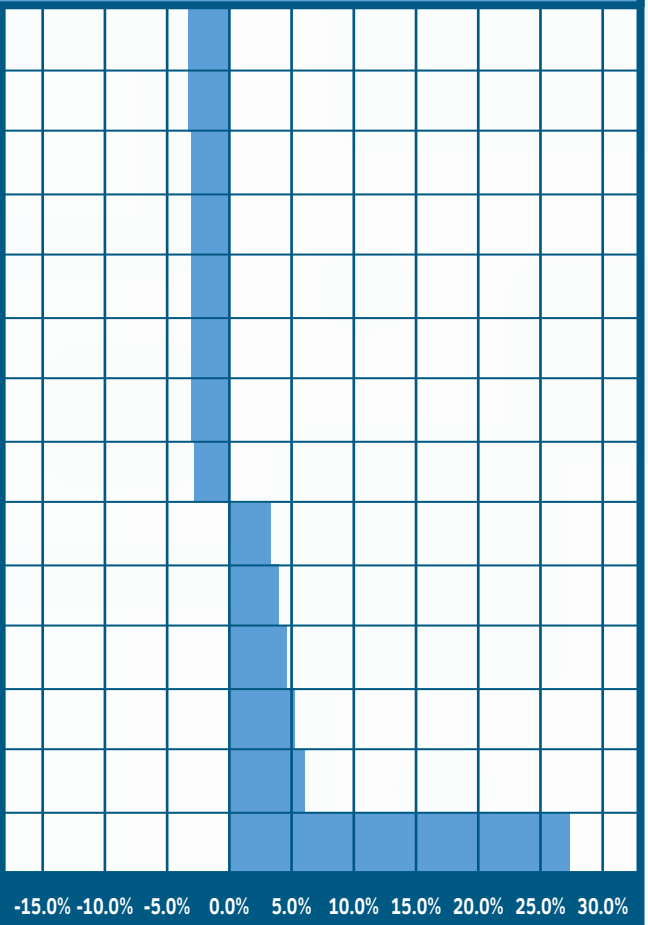

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Table 3: REVENUE BREAKDOWN OF ONTARIO-BASED MANUFACTURERS[10]

Revenue Range	Number of firms
$1–$99,000	58
$100,000–$199,000	59
$200,000–$499,000	174
$500,000–$999,000	252
$1,000,000–$4,999,999	1,129
$5,000,000–$9,999,999	524
$10,000,000–$24,999,999	463
$25,000,000–$50,000,000	231
$50,000,000+	312
Total	**3,202**

Table 4: EMPLOYEE BREAKDOWN OF ONTARIO-BASED MANUFACTURERS

Employee Range	Number of firms
1–10	973
11–50	1,796
51–100	592
101–250	399
251–499	152
500–1,000	64
1,000+	63
Total	**4,039**

10 All table data from Industry Canada's "Canadian Company Profiles," www.ic.gc.ca/app/ccc/srch/cccSrch.do?lang=eng&prtl=1&tagid=&profileId=&rstBtn.x=.

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Table 5: SECTOR INTEREST BREAKDOWN OF ONTARIO-BASED MANUFACTURERS

Employee Range	Number of firms
Aerospace	372
Agriculture	239
Automotive	448
Construction	386
Consumer Products	373
Culture	63
Defence	374
Electrical Related	245
Environment	341
Fisheries	122
Food and Beverage Manufacturing	230
Forestry	200
Furniture and Wood Product Manufacturing	155
Information Technology and Telecom	329
Medical/Biotech/Chemical	352
Mining/Petroleum/Gas	374
Plastics and Rubber Products	207
Primary and Fabricated Metal	181
Pulp and Paper	177
Service Industry	201
Textile and Clothing	90
Tourism	88
Transportation	326
Wholesale/Retail	263
Total	**6,136**

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