Development of an Agricultural Biomaterial Industry in Ontario

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Executive Summary

The agricultural-based biomaterial industry in Ontario is investigated with an overarching goal of formulating strategies to accelerate the industry's establishment and development. The availability of current and potential biomass feedstock for use in the biomaterial sector is assessed. The current market status of selected biomaterials is analyzed, and the promising biomaterials for immediate commercial establishment in Ontario are identified. Policy instruments to promote the biomaterial industry are examined and compared with those in other jurisdictions. The influential factors in commercializing biomaterials and barriers are reviewed, and an evaluation matrix to screen the biomaterials/firms is developed. The strategic approach to accelerate the industry development is proposed with the prioritized market sectors and biomaterials.

Ontario's agricultural sector can readily meet the potential biomass demand of the emerging biomaterial industry with an estimated annual biomass supply of approximately 6 million tonnes. Miscanthus and switchgrass are proven purpose-grown biomass crops in Ontario at commercial scales, and they are potential feedstock for the emerging biomaterials industry. Approximately 3 million tonnes of purpose-grown biomass can be sustainably produced from 0.5 million acres, which is less than 6% of total cropland in Ontario, at current average yields. Additionally crop residues such as wheat straw and cornstalks could also be used as biomass feedstock, although the sustainable removal of crop residues requires further field research at present. Considering that the total amount of biocomposites produced in Europe in 2012 was 352,000 tonnes, Ontario has sufficient biomass to supply the most optimistic projected needs of a future biomaterials sector. While sufficient feedstock can be supplied within Ontario, the actual amount supplied depends on relative prices. Under current crop prices, 3 MT of biomass could be supplied for prices of biomass at least $60 to $150 per tonne depending on the current crops/residues.

Feedstock compatibility, technology maturity, profitability, economic development potential, competition with substitutes, regulatory and institutional support and existing value chain infrastructures are the important factors determining the feasibility of a biomaterial/firm.
An evaluation matrix is developed with these factors as evaluation parameters and weightings assigned to each factor for alternative biomaterials in Ontario. Although all evaluation parameters play key roles, feedstock compatibility, profitability and ability to compete with substitutes are considered as the most critical for financial feasibility. Many jurisdictions in North America are providing financial incentives and other support to potential bioproduct firms in an effort to attract the investment and create jobs locally. This evaluation matrix offers as a tool to screen the potential biomaterial firms seeking government support.

Non-structural biocomposites and fibreboards are promising candidates for near-term commercial establishment and thus the development of an agricultural-based biomaterial industry in Ontario.
Technologies for producing non-structural biocomposites and fibreboards are well developed, and potential markets, especially automotive and construction sectors, exist locally. These biomaterials also

require more biomass feedstock than other bioproducts. Due to the bulky nature of these biomaterials and associated logistic costs, manufacturing plants that are sized for local demand could be cost competitive. In contrast, the major expansion of the bioplastics and biopolymers sectors are forecasted to occur in Asia and South America where large markets exist and competitive sugar crops are available. Bioplastics and biopolymers are therefore unlikely to be competitive in Ontario and neither are the development of biofoams and biorubbers. Structural biocomposites could be a competitive sector but further technological developments are required.

The construction/building sector is the potential leading market for agricultural biomaterials in Ontario followed by transportation/automotive sector and household/consumer sector.
The estimated annual biomass demand in the short and medium terms from the transportation/automotive and household/consumer sectors are 7,200 tonnes and 3,000 tonnes, respectively. The potential demand for biomass from biomaterials in the construction/building sector is significantly larger at 50,000 tonnes annually. Most policy instruments, especially direct market pull measures, can be effective to create the agricultural biomaterial market for the construction/building sector.

The development of an innovation ecosystem with the agricultural biomaterial manufacturing facilities as the core of the system is recommended.
The initial establishment of a few biomaterial firms is crucial in developing a functioning innovation ecosystem. Non-structural biocomposites and fibreboards targeting the construction/building sector should be considered as prioritized opportunities for immediate commercialization in Ontario. Entrepreneurs in Ontario's agricultural sector are potential manufacturers of biomaterials, and they should be provided with necessary assistance if the industry is able to take root. Given the uncertainties in competing in export markets, the strategy at the initial development stage could focus on sizing the bioproduct manufacturing facilities to meet local markets. The creation of clear directions, visions, policies, strong commitments from governments and better coordination among federal and provincial ministries/organizations are recommended to accelerate the emergence of an agricultural-based biomaterial industry in Ontario.

The creation of effective federal and provincial bioproduct development policies could assist in the emergence of an agricultural-based biomaterial industry in Ontario and Canada.
The US has the most comprehensive set of bioproduct policies but its focus is on pharmaceuticals and biofuels rather than biomaterials made from agriculturally-sourced material. In the EU, however, there is a strong focus on linking the agricultural sector to the bioproducts sector. Regardless of which the type of bioproducts emphasized, most of the policy efforts in the U.S. and EU have been targeted toward funding research and development, with the U.S. providing more resources on fostering commercialization of the bioproducts. The U.S .also has a strong federal procurement program for bioproducts (BioPreferred) that has been successful in inducing demand.

1. Introduction

This study investigates the development of an agricultural-based biomaterial industry in Ontario with an overarching goal of formulating strategies to accelerate the industry's establishment. Specific characteristics of the agricultural sector and biomaterial markets in Ontario are analyzed. In this initial section of the report, the background information for the study is given. The general purpose and specific objectives of the study are presented. The methodology of the study in achieving the objectives is outlined along with the scope of the sectors and biomaterials assessed.

1.1 Background

A number of studies (http://www.ofa.on.ca/issues/overview/biomass and Kludze et al. 2013) suggest that the agricultural sector in Ontario can sustainably produce a significant amount of biomass feedstock from both purpose-grown crops and their residues. Ontario, home to the largest automotive industry in Canada and the most populated province, is the ideal place in Canada to develop an agricultural biomaterials industry to serve the automotive, construction and the consumer products markets. The economic, social and environmental benefits associated with this emerging industry could be substantial.

A healthy biomaterials sector could provide an additional source of demand for crops grown by Ontario's agricultural producers. The diversification in the markets for their crops may reduce income variability, which has been exacerbated in recent years by the volatility in grain prices. Ontario's farmers will also be able to participate further along the supply chain, which could enhance their value-added. Purpose-grown biomass, the likely feedstock for the biomaterials industry, could also offer agricultural producers more crop choices for their land.

The manufacturing sector, which has been declining in Ontario, could benefit from the development of an agricultural biomaterials industry. Being able to locate manufacturing plants close to the feedstock source and to large final-demand markets could reduce transportation costs and enhance the financial viability of biomaterial firms. Revitalization of the manufacturing sector combined with a sustainable feedstock supply could lead to the creation of skilled jobs and development of a biomass supply chain. The investment community may subsequently also find new opportunities in the biomaterials industry in Ontario.

The development of an agricultural biomaterials industry in Ontario could bring investments to rural areas that may have positive economic and social impacts on rural communities. Due to the bulky nature of biomass, the agricultural biomaterials firms will likely locate their processing plants in rural areas close to the source of the feedstock. The creation of a new industry with the biomass supply chain could lead to the rural development opportunities. With enhanced economic activity, the outflow of youths from the rural areas could be reversed, and the income gaps between rural and urban areas could be reduced. As a source of sustainable production inputs to key manufacturing and consumer markets, the agricultural sector can play a key role in transitioning from the petroleum-based economy to a sustainable bio-based economy.

The superior properties of biomaterials derived from agricultural biomass include better insulation and lighter weight compared to conventional material. Thus, adoption of biomaterials could help the automotive industry meet higher fuel economy standards. Building materials made with biomaterials could reduce the construction cost and lower heating/cooling energy requirements. Biomaterials offer more choices to the consumers who are environmentally conscious.

The production cost of ethylene, the conventional input to produce plastic materials, declined by approximately 50% from 2005 to 2012 in North America (American Chemical Council, 2013) due to the discovery of abundant shale gas, and significantly changed the dynamics of petroleum-based materials industry. Ethylene-derived plastic materials are therefore getting relatively cheaper, posing competitive pressure on biomaterials.

The identification of niche markets and applications for agricultural biomaterials in Ontario and nearby regions is necessary in this competitive environment. This would require the understanding of the availability, cost, and distribution of agricultural biomass feedstock, market demands, competition from petroleum and forestry based products, and barriers in commercializing agricultural biomaterials.

A large numbers of agricultural biomaterials products are being developed at various universities, research institutions and start-up firms, but only a few products have commercialization potential due to the region-specific nature of biomass feedstock. The large numbers of agricultural biomaterials products under development could be screened with certain criteria, including: feedstock availability, target markets, demands for biomaterials, competition from petroleum and forestry based products.

Ontario, home of the largest automotive industry in Canada and the most populous province, is potentially a large source of consumer and industrial demand of agricultural biomaterials. With its significant agricultural resources, Ontario is well positioned to develop an agricultural biomaterials industry. Both the federal and provincial government have committed resources to the development of the agricultural biomaterial sector in Ontario; however, the commercialization of biomaterials in Ontario has been slower than expected. This suggests a review of the current status of the industry and the formulation of new strategies with a comprehensive policy framework are needed to accelerate this development.

1.2 Objectives of the Study

The purpose of the study is to formulate strategies to develop an agricultural biomaterials industry in Ontario. The specific objectives are:

- To estimate the availability, cost and geographical distribution of agricultural feedstock, for both crop residues and purpose-grown biomass
- To identify the agricultural biomaterials products and associated biomaterials firms with the most promising commercialization potential in Ontario
- To analyze the barriers to commercialization and economic feasibility of the selected agricultural biomaterials products for the Ontario automotive, construction, and consumer products markets

- To prioritize opportunities, formulate strategies and provide recommendations for all stakeholders to accelerate the development of an agricultural biomaterials industry in Ontario.

1.3 Methodology

A thorough literature and commercialization status review, communication with biomaterial firms and industry organizations, consultation with academics and industry experts, comprehensive data analysis, and the development of evaluation matrix for feedstock, markets and biomaterials firms are included in the approach methodology of the study. The research activities for each specific objective are given below.

- *To estimate the availability, cost and geographical distribution of agricultural feedstock, for both crop residues and purpose-grown biomass*

A number of studies (http://www.ofa.on.ca/issues/overview/biomass and Kludze et al. 2013) have investigated the availability of sustainable crop residue, the potential production and supply chain of purpose-grown biomass, and the use of surplus hay and pasture land for biomass production. This study compiles the findings of the previous studies, and estimates the availability of agricultural biomass feedstock for the biomaterials industry along with the infrastructure to support the pre-processing of biomass material for future use. The estimation considers the latest yield data of purpose grown biomass crops in Ontario's regions and the experiences gained in harvesting crop residues for biofuels production in nearby regions in the US. Spreadsheet models were developed to extend the work of Kludze et al (2013) and DeLaporte et al (2013) to calculate the costs of different biomass feedstock based on the most up-to-date cost figures of crop establishment, harvesting, storage, crop insurance, land and others. The study also provides geographical distribution of agricultural feedstock in Ontario regions along with the current infrastructure support.

- *To identify the agricultural biomaterials products and associated biomaterials firms with the most promising commercialization potential in Ontario*

A number of agricultural biomaterials products under development are screened considering feedstock availability, target markets, demands for biomaterials, competition from petroleum and forestry based products and technology maturity. An evaluation matrix is developed to identify the biomaterials and firms with the most promising commercialization potential in Ontario. The specific characteristics of the agricultural sector and the biomaterial markets in Ontario are examined. Input from industry experts, especially in commercialization organizations, is obtained in the development of the evaluation matrix. The weightings to the evaluation parameters are assigned with an objective of using the evaluation matrix as a general framework to determine the commercialization potential of a biomaterial firm.

- *To analyze the barriers to commercialization and economic feasibility of the selected agricultural biomaterials products for the Ontario automotive, construction, and consumer products markets*

The commercialization status of selected biomaterials in Ontario is reviewed. Biomaterial firms, industry experts, research institutions, agricultural producers, policy makers and other potential stakeholders are interviewed to identify the barriers in commercializing agricultural biomaterials in

Ontario. The biomaterial markets in the Ontario automotive, construction and consumer sectors are examined and estimated. The potential biomass demands and barriers for commercialization are analyzed considering the strengths and weaknesses of each sector. The regulatory and financing support provided by other jurisdictions to the biomaterials sector is also reviewed. The lessons learnt from an agricultural based biomaterial firm in Western Canada are also presented. The economic feasibility of alternative biomaterials is assessed given this review.

- *To prioritize opportunities, formulate strategies and provide recommendations for all stakeholders to accelerate the development of an agricultural biomaterials industry in Ontario*

The latest trends in the automotive, construction and consumer products markets are reviewed, and the potential biomaterial demands and associated biomass requirements in Ontario are estimated. The state of the biomaterial industry and the entrepreneurial activities in the agricultural sector in Ontario is assessed. The existing and required regulatory and institutional supports are described using examples of US and EU policies. By combining these findings with the results of the evaluation of agricultural biomaterials products/firms, strategies to accelerate the development of an agricultural biomaterials industry in Ontario are formulated. Recommendations to all stakeholders are provided.

1.4 Scope of the Study

The biomaterial industry is relatively broad with a significantly large numbers of potential products, ranging from biocomposite flowerpots to carbon fibre for aerospace applications. Numerous biomaterials are under development, some at the early research stage and some entering commercialization, for use in a variety of sectors. Considering the characteristics of Ontario's agricultural sector in combination with current and potential markets for biomaterials in Ontario, the scope of the study is limited to:

- bioplastics/biopolymers, biocomposite (structural), biocomposite (non-structural), fibreboards, biofoams and biorubbers as the biomaterials;
- the major crops of Ontario (corn, soybeans, wheat) and semi-commercial perennial grasses (miscanthus and switchgrass) as the biomass feedstock;
- automotive, construction and consumer products as the targets for potential biomaterial markets; and
- Ontario, Canada as the jurisdiction of focus.

2. Agricultural Biomass Feedstock

There are two potential sources of agricultural biomass feedstock: (1) crop residues and (2) dedicated biomass crops such as switch grass and miscanthus. The volume of feedstock from each of these two sources is reviewed here based on work by Kludze *et al* (2013a, 2013b) and DeLaporte *et a*l (2014).

2.1 Crop Residue as a Feedstock

Given the concentrated crop production regions in the province, crop residues from corn, wheat , and soybean are considered to be particularly promising sources of biomass feedstock. However, crop residues are important in the maintenance and protection of soil quality, which limits the amount that can be removed. In addition, there is also only so much crop residue available in a given year because these crops are grown in rotation.

Kludze et al (2013a) assess the sustainable availability and procurement cost of biomass from crop residues in common Ontario crop rotation scenarios, on a county scale. The paper estimates the quantity of crop residue that could be sustainably removed from an average farmer's field after grain harvest, at the county level, taking into account county-specific yields and sustainability constraints. Crop residue requirements to maintain soil organic carbon (SOC) and nutrient pools are higher than those required to control soil erosion; thus, the amount of residue that needs to remain on the field to maintain current soil organic matter (SOM) levels was the major consideration and focus of the study. The intent was not to provide removal estimates to specific farm locations, but to create an aggregate, county- level estimate of potentially available residues in Ontario.

Assuming Ontario conditions range between the worst-case scenario and the best-case scenario, 7053 kg to 6.2 million metric tonnes of residue could be removed annually across the province (Kludze et al 2013a). Under typical SOM formation and decomposition conditions and assuming typical corn-soybean (CS) and corn- soybean-winter wheat (CSW) rotation scenarios, about 1.1 million metric tonnes of residue could be sustainably removed each year, primarily from the major agricultural counties in this province. Actual annual removal may fall between the scenario values, depending on a variety of site-specific factors, including soil type, topography and climatic conditions. The amount that can be removed from each county varies because of the total acreage of the three crops, the average yield of each crop, and also the rotation systems that are present. The increased frequency of soybean in a rotation has the effect of reducing removal rates from other crops in the rotation. Other crop management practices such as the use of cover crops with prolific rooting systems and vegetative growth in rotations, adding animal and/or green manure or compost to field crops, and adding soil amendments can increase both the active and heavy fractions of SOM.

The break-even price for crop residues is between \$57 MT^{-1} and \$87 MT^{-1}. The break-even costs cover only production and collection costs and do not cover costs associated with risk, management and other financial considerations, such as the costs of decreased SOM resulting from excess removal. These break-even prices represent the minimum price necessary to cover all variable and fixed costs for the farmer, but they do not ensure that biomass will be supplied at these prices. The actual amount supplied for each biomass, price depends critically on the opportunity costs associated with not growing typical crops in the conventional manner.

2.2 Dedicated Biomass Crops as a Feedstock

Since the availability of crop residue biomass may be limited due to technical, economic and sustainability constraints associated with its removal under Ontario conditions, there has been growing interest in using perennial warm-season grasses (WSGs) as a renewable feedstock because of their high yield, drought tolerance (Sanderson *et al*., 2008), favorable biomass properties, and their potential to improve soil properties (Blanco-Canqui, 2010), reduce greenhouse gas (GHG) emissions relative to fossil fuels, and to serve as carbon sinks by sequestering carbon in the soil (McLaughlin and Walsh, 1998). Switchgrass and miscanthus have been identified as among the best WSG choices for low-input biomass production and the most feasible means to provide biomass for emerging bioproduct markets.

Kludze *et al* (2013b) examine Ontario land needs for miscanthus and switchgrass and the break-even point for production and collection of the two crops. It uses different land categories in Ontario to develop a scale of prime to marginal land types, which forms the basis for their estimates for biomass supply of the two biomass crops.

Kludze *et al* (2013b) estimate that almost 45M tDM of switchgrass biomass could be supplied in Ontario (see Table 2.1). Due to higher miscanthus yield, the Ontario agricultural land base could potentially supply approximately 62M tDM of miscanthus biomass (see Table 2.2). Various land use scenarios could meet or exceed a provincial biomass production target of 2 M tDM. For example, the following scenarios could be considered: (1) if switchgrass production was distributed evenly across land classification and region only 5% of all land would be required to achieve 2.1 M tDM; (2) if production was restricted to Class 5 land due to either economic or regulatory constraints, 75% of Class 5 land would need to be converted to switchgrass production to achieve the 2 M tDM target; (3) if production was restricted to the Southern region of the province as a result of market proximity and transportation costs, approximately 15% of land would be required to achieve 2 M tDM; (4) if production was restricted to the Southern region of the province as a result of market proximity and transportation costs; and (5) if production was restricted to marginal land due to either economic or regulatory constraints, only 0.63 M tDM could be produced if 100% of Class 4 and 5 land were converted to switchgrass.

Although farmers' reasons for switching from growing traditional crops to biomass crops may be diverse (e.g. environmental stewardship; wildlife habitat; use of fewer farm inputs), their acceptance of biomass crops will be influenced by the profitability of these crops relative to existing alternative land uses. However, there is currently no market price for biomass crops in Ontario. Kludze *et al* (2013b) therefore used break-even prices to consider the financial feasibility of biomass crop production. To determine the breakeven-price of growing each biomass crop, an enterprise budget was developed using local cost and yield figures in relationship to the land classes.

Table 2.1: Estimated amounts of switchgrass biomass by percentage of land class allocated to switchgrass production (tDM yr^{-1})

Land Class	*Land Planted to Switchgrass* 5%	10%	25%	60%	100%
			Southern Ontario Region		
1	92 988	185 976	464 941	1 115 858	1 859 763
2	346 002	692 003	1 730 009	4 152 021	6 920 035
3	181 957	363 913	909 781	2 183 475	3 639 126
4	15 761	31 521	78 803	189 128	315 214
5	15 730	31 459	78 647	188 753	314 588
ALL	652 436	1 304 872	3 262 181	7 829 235	13 048 726
			Western Ontario Region		
1	319 049	638 098	1 595 244	3 828 585	6 380 976
2	283 950	567 900	1 419 749	3 407 398	5 678 997
3	134 192	268 384	670 959	1 610,301	2 683 835
4	113 038	226 076	565 190	1 356 456	2 260 760
5	44 473	88 945	222 363	533 672	889 454
ALL	894 702	1 789 403	4 473 505	10 736 412	17 894 022
			Central Ontario Region		
1	62 537	125 074	521 144	1 250 745	2 084 575
2	37 049	74 097	308 738	740 971	1 234 952
3	41 949	83 898	349 576	838 982	1 398 303
4	35 277	70 553	293 970	705 529	1 175 882
5	24 026	48 051	200 214	480 513	800 855
ALL	200 837	401 673	1 673 642	4 016 740	6 694 567
			Eastern Ontario Region		
1	10 720	21 439	53 597	128 633	214 388
2	125 951	251 902	629 754	1 511 410	2 519 017
3	116 012	232 023	580 059	1 392 141	2 320 235
4	77 527	155 054	387 634	930 322	1 550 537
5	29 278	58 556	146 390	351 336	585 561
ALL	359 487	718 974	1 797 434	4 313 842	7 189 738
			Ontario Total		
1	48 5 293	970 587	2 634 926	6 323 821	10 539 702
2	792 951	1 585 902	4 088 250	9 811 800	16 353 001
3	474 109	948 218	2 510 375	6 024 899	10 041 499
4	241 602	483 204	1 325 597	3 181435	5 302 393
5	113 505	227 011	647 614	1 554 274	2 590 458
ALL	2107461	4 214 922	11 206 762	26 896 229	44 827 053

Source: Kludze et al 2013b

Table 2.2: Estimated amount of miscanthus biomass by percentage of land class allocated to miscanthus production (tDM yr^{-1})

Land Class	Land Planted to miscanthus 5%	10%	25%	60%	100%
			Southern Ontario		
1	147 984	295 968	739 920	1 775 808	2 959 679
2	550 637	1 101 274	2 753 185	6 607 645	11 012 741
3	260 718	521 435	1 303 587	3 128 608	5 214 347
4	22 265	44 530	111 326	267 181	445 302
5	21 909	43 818	109 544	262 905	438 176
ALL	1 003 513	2 007 025	5 017 562	12 042 147	20 070 245
			Western Ontario		
1	507 744	1 015 487	2 538 717	6 092 920	10 154 867
2	223 172	446 344	1 115 860	2 678 064	4 463 440
3	180 652	361 303	903 257	2 167 816	3 613 026
4	61 521	123 041	307 603	738 246	1 230 410
5	91 744	183 488	458 721	1 100 930	1 834 883
ALL	1 064 832	2 129 663	5 324 158	12 777 976	21 296 626
			Central Ontario		
1	99 524	199 047	829 363	1 990 471	3 317 451
2	58 960	117 920	491 335	1 179 203	1 965 338
3	60 107	120 214	500 892	1 202 141	2 003 569
4	49 835	99 670	415 291	996 700	1 661 166
5	33 465	66 929	278 869	669 286	1 115 476
ALL	301 890	603 780	2 515 750	6 037 801	10 063 000
			Eastern Ontario		
1	17 059	34 118	85 296	204 710	341 183
2	200 442	400 884	1 002 209	2 405 302	4 008 836
3	166 229	332 457	831 141	1 994 739	3 324 565
4	109 522	219 044	547 610	1 314 265	2 190 441
5	40 780	81 560	203 901	489 361	815 602
ALL	534 032	1 068 063	2 670 157	6 408 377	10 680 627
			Ontario Total		
1	772 310	1 544 620	4 193 296	10 063 909	16 773 180
2	1 033 211	2 066 422	5 362 589	12 870 214	21 450 355
3	667 705	1 335 409	3 538 877	8 493 304	14 155 507
4	243 143	486 285	1 381 830	3 316 392	5 527 319
5	187 898	375 795	1 051 035	2 522 482	4 204 137
ALL	2 904 266	5 808 531	15 527 627	37 266 301	62 110 498

Source: Kludze et al 2013b

Table 2.3. Break-even Prices ($/T) for Switchgrass and Miscanthus at Alternative Yields

Annual Costs	Switchgrass[1] 7 t/ha	6.3 t/ha	5.6 t/ha	Miscanthus[2] 11.24 t/ha	10.03 t/ha	8.90 t/ha	7.80 t/ha)
Establishment Costs	12.59	13.99	15.74	26.36	29.55	33.30	37.99
Fertilizer Costs	21.83	23.77	26.18	9.85	10.86	12.04	13.53
Harvesting & Storage Costs	36.98	37.68	38.57	40.78	41.35	42.05	42.88
Total Costs (Break-even prices)	71.40	75.44	80.49	76.99	81.76	87.39	94.40

Source; Kludze et al 2013b

Depending on biomass yields, Kludze *et al* (2013b) estimated the break-even price for the dedicated energy crops would range from $71.40 tDM^{-1} at 7 tDM ha^{-1} to $80.49 tDM^{-1} at 5.6 tDM ha^{-1} for switchgrass and from $76.99 tDM^{-1} at 11.24 tDM to $94.40 tDM^{-1} at 7.8 tDM ha^{-1} for miscanthus (see Table 2.3). Whether agricultural biomass can be sustainably generated in Ontario, the actual amount supplied depends on production costs, yields, opportunity costs of production, and the government's land use policy for bioenergy crop production.

DeLaporte *et al* (2014) assess the potential yields and costs of growing switchgrass and miscanthus on Ontario's land base under different climate assumptions, using a GIS-based integrated bio-physical and economic simulation model. DeLaporte *et al* (2014) find that, while switchgrass has lower yields than miscanthus, it also has lower break-even farm-gate prices due to lower establishment costs. In the base scenario, switchgrass yields between 6.3 tDM ha^{-1} and 13.3 tDM ha^{-1}, with a mean of 10.8 tDM ha^{-1} (see Figure 2.1). Miscanthus mean yields range from 9.3 tDM ha^{-1} to 22.8 tDM ha^{-1}, with a mean of 18.3 tDM ha^{-1}, nearly double the yield of switchgrass. Switchgrass break-even prices range from $54.18 tDM^{-1} to $76.38 tDM^{-1}, with an average of $58.76 tDM^{-1}. These values are lower than those of miscanthus, which ranges between $56.92 tDM^{-1} to $85.20 tDM^{-1}, with an average of $62.05 tDM^{-1}. This general result persists through three future climate scenarios. However, miscanthus yield increases at a faster rate with increased heat than does switchgrass and so the break-even prices of the two crops converge in the warmer climate scenarios. Biomass yields in the northern regions of Ontario are lower than the traditional crop-growing regions of southern Ontario but increase more quickly with climate change. Both crops show promise as biomass sources for bio-energy production, but a changing global climate, along with cultivar and planting technology developments, could affect the choice of crop grown.

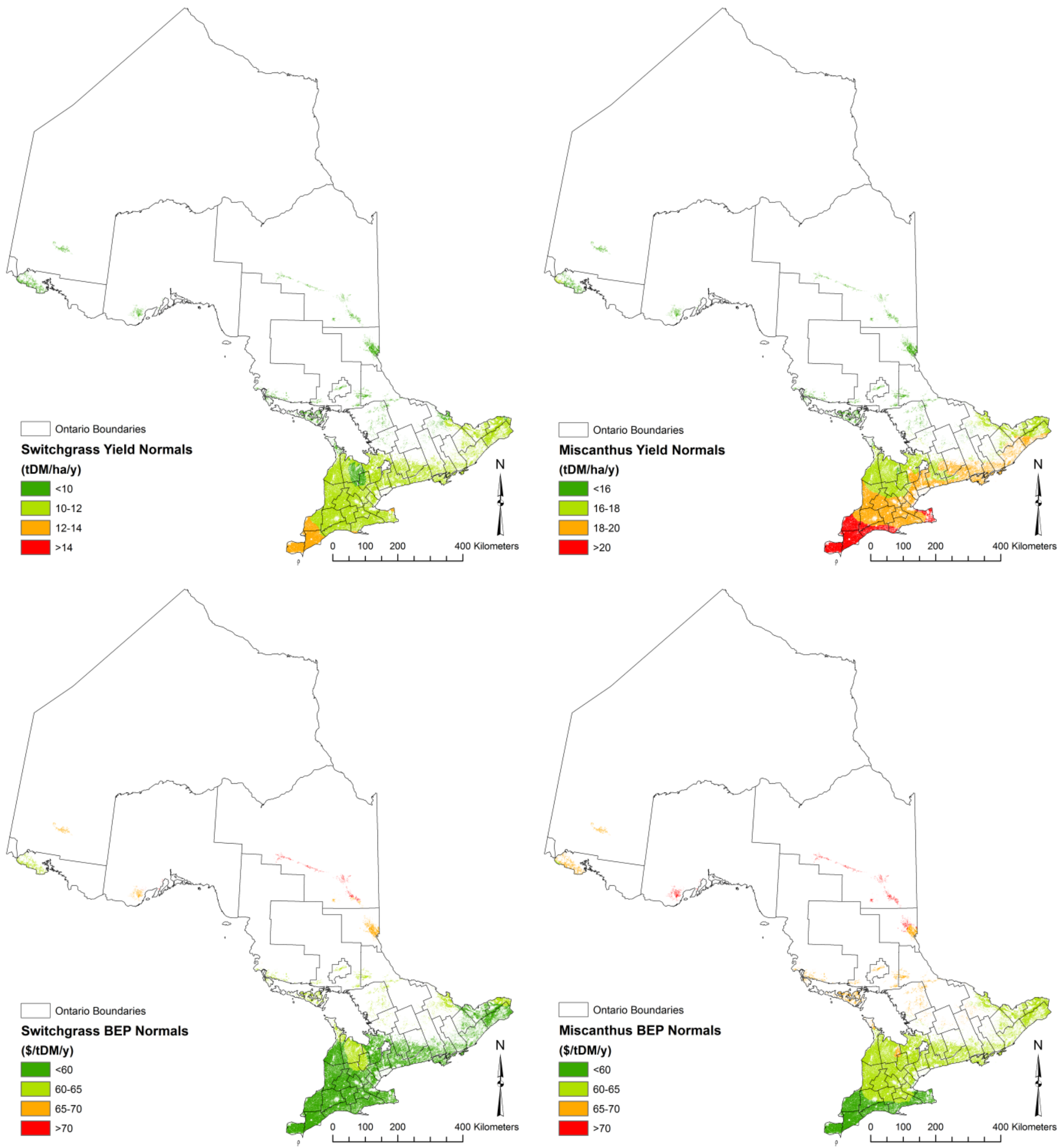

Figure 2.1: Switchgrass and miscanthus yields and break-even prices on the Ontario land base under average 1971-2000 (normal) climate conditions. (Source: DeLaporte *et al* (2014))

3. Review of Biomaterials

Before the discovery of fossil hydrocarbons, most of materials used by human were bio-based, ranging from clothing to construction to transportation applications. Biomaterials have become the subject of interest again in recent years due to their superior environmental attributes. Biomaterials, however, need to compete with fossil-based alternatives in cost and performance before they will be adopted. In this section, the potential development of biomaterials is reviewed from a technological and market perspectives. The biomaterials with the greatest commercial potential for Ontario in the medium and long term are identified.

3.1 Assessment of Technology Development Status

The five categories of biomaterials considered in this study are shown in Figure 3.1. Each type of biomaterial category is discussed in terms of the current technology and the available biomass feedstock in Ontario.

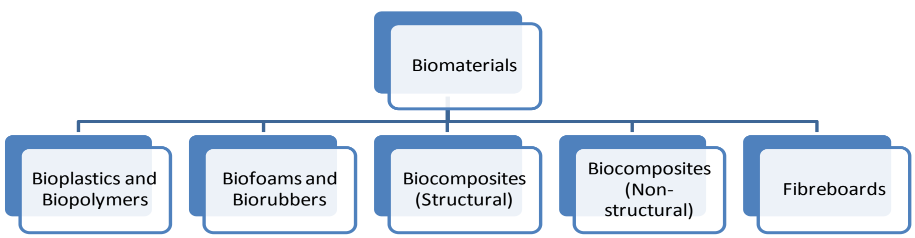

Figure 3.1 Biomaterials Considered in this Study

3.1.1 Bioplastics and Biopolymers

Bioplastics are commonly known plastic materials produced from renewable biomass feedstock. Bioplastics are technically biopolymers with a wide range of applications including beverage bottles, food packaging, containers of all shapes and sizes, garbage bags, etc. Materials considered as biopolymers in this study are all bio-based polymers other than bioplastics. Biopolymers manufactured from renewable biomass resources also have numerous applications such as adhesives, coatings, textiles, flooring and other construction materials. Bioplastics and biopolymers may or may not be biodegradable, depending on their chemical structures.

Production of bioplastics and biopolymers from starch crops and vegetable oils are technically proven. The most technically advanced bio-based plastics and polymers with significant market growth potential are Polyethylene terephthalate (PET), Polylactic acid (PLA) & PLA blends, Polyethylene (PE) and starch blends (European Bioplastics - http://en.european-bioplastics.org/; Aeschelmann et. al, 2015). A number of other biopolymers with moderate market growth potential are under development.

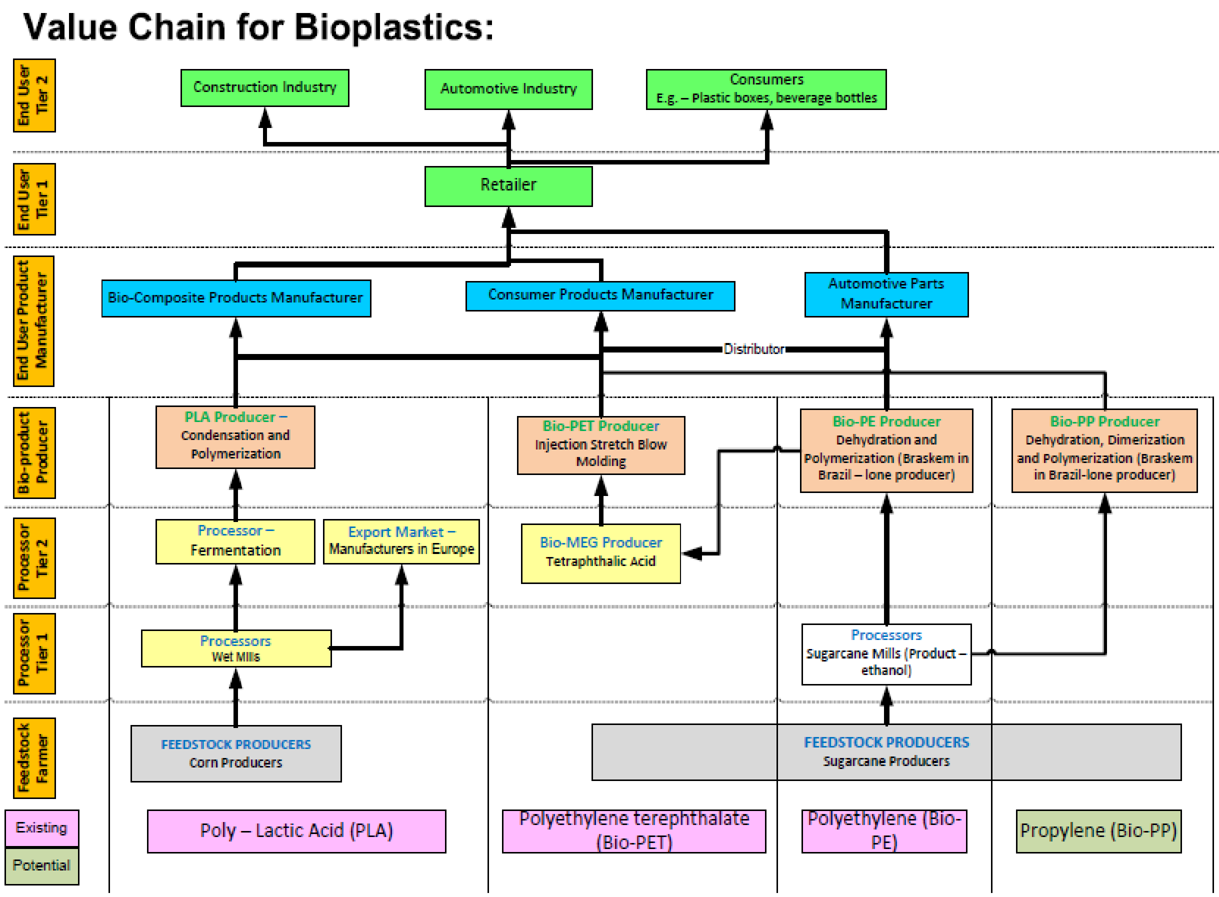

Figure 3.2 Bioplastics Value Chain

Grain corn and soybeans, Ontario's two major crops, could be used as biomass feedstock to produce bioplastics and biopolymers. The most common bioplastic/biopolymer process involves the extraction of sugar from the biomass (corn, sugarcane, sugar beets, etc.), fermentation to produce the desired chemical compounds or monomers, and polymerization. Two main groups of soy-based plastics, polyurethane using soy polyols and thermosets, can be produced by fairly well-developed technologies (United Soybean Board - http://soynewuses.org).

Technologies to extract sugar from cellulosic feedstock, such as miscanthus, switchgrass and crop residues, are being commercialized. Comet Biorefining recently announced plans to establish a commercial sugar plant from corn residues and wheat straw in Sarnia, Ontario (http://cometbiorefining.com/news.html). Industrial crops such as camelina, carinata, Jerusalem artichoke and cardoon are relatively new to Ontario, however, could also be potential feedstocks for bioplastics and biopolymers.

3.1.2 Biofoams and Biorubbers

Biofoams, bio-based polyurethane foams, are well-developed materials, and are currently used in several commercial products. The Woodbridge Group, a Canadian automotive supplier, is the leading developer of biofoams. Ford Motor Company has been using seat cushions with 5-10% biofoam content in selected models since 2009 (http://www.canplastics.com). Communication with Woodbridge Group personnel suggests that biofoam can include up to 40% bio-polyol in various automotive applications, including seat cushions, heat restraints, arm rests, headliners and occupant protection products. Biofoam Synbra Group from the Netherlands claims that PLA-based biofoam was successfully developed (http://www.biofoam.nl). Starch-based biofoams for packaging and insulation applications can also be manufactured using well-developed technologies. The value chain for companies producing biofoams is illustrated n Figure 3.3

There has been interest in developing new, domestic, and commercially-viable sources of natural rubber in North America in recent years. Bridgestone Corporation is the leading developer of biorubber, and established Biorubber Process Research Center in Mesa, Arizona, in 2014. The center is developing biorubber from guayule, a shrub native to the southwestern US (http://www.bridgestone-firestone.ca/eng/news/index_news.asp?id=2014/140922a). Producing biorubbers from another rubber-bearing plant called Russian Dandelion is also at the research and development stage (http://www.novabiorubber.com/).

Hundreds of different biomaterials could be potentially developed from biomass feedstock, since biomass contains similar chemical compounds seen in fossil resources. Biomaterials could be sustainable substitutes for many fossil-based materials in our everyday use. A large number of biomaterials are under development/improvement to compete with fossil-based alternatives in costs and performances. An Ontario example is Competitive Green Technologies, a Leamington company, that is developing a commercial scale process for converting biofibres into bio-black to be used as an innovative alternative material for petroleum-based carbon black. BIOBLAKR® Masterbatch is mentioned as a substitute for carbon black, and is the world’s first balck Masterbatch to use USDA-certified 99% bio-carbon (http://www.competitivegreentechnologies.com/).

Value Chain for BioFoam:

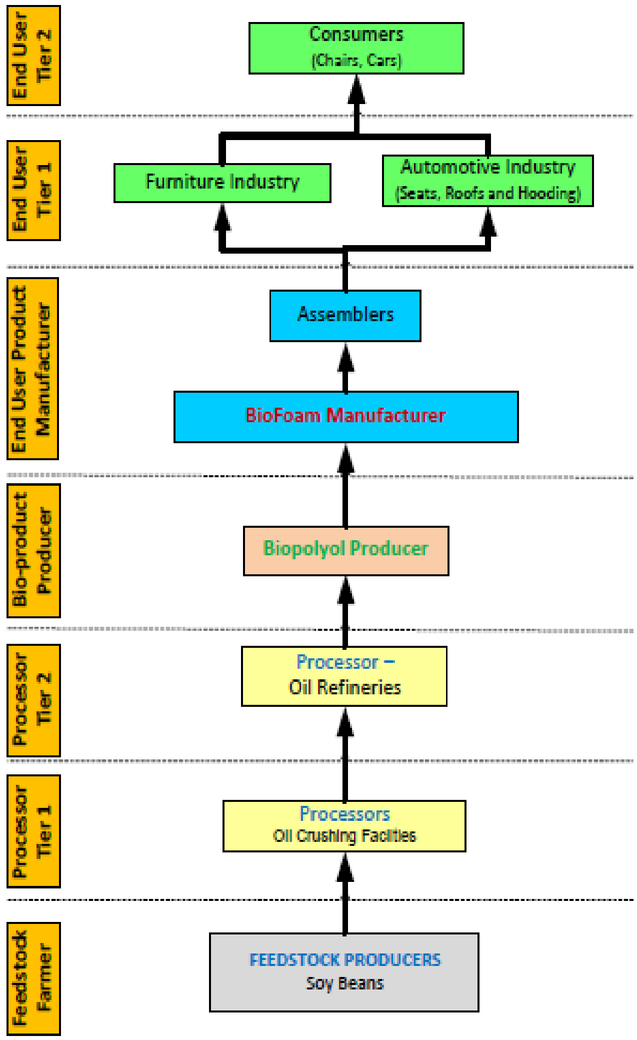

Figure 3.3 Biofoam Value Chain

3.1.3 Structural Biocomposites

A composite is made of two or more constituent materials. When combined, the composite material has properties and characteristics different from its constituents. A composite usually consists of a reinforcement phase of strong material embedded in a continuous matrix phase. Biocomposites are composite materials with one or more phase(s) made of biomass. Generally, natural biomass fibres are used as reinforcement phase in biocomposites.

Biocomposites are categorized in this study as structural or non-structural depending on their applications. Structural biocomposites are subject to considerable compressive, tensile and torsion stresses such as wind turbine blades, and automotive/aerospace body parts. Potential markets for structural biocomposites are structural applications, where composites with glassfibre reinforcement are currently used. Most of the research and development work on structural biocomposites is geared toward improving its physical properties so as to be comparable to those of glassfibre composites.

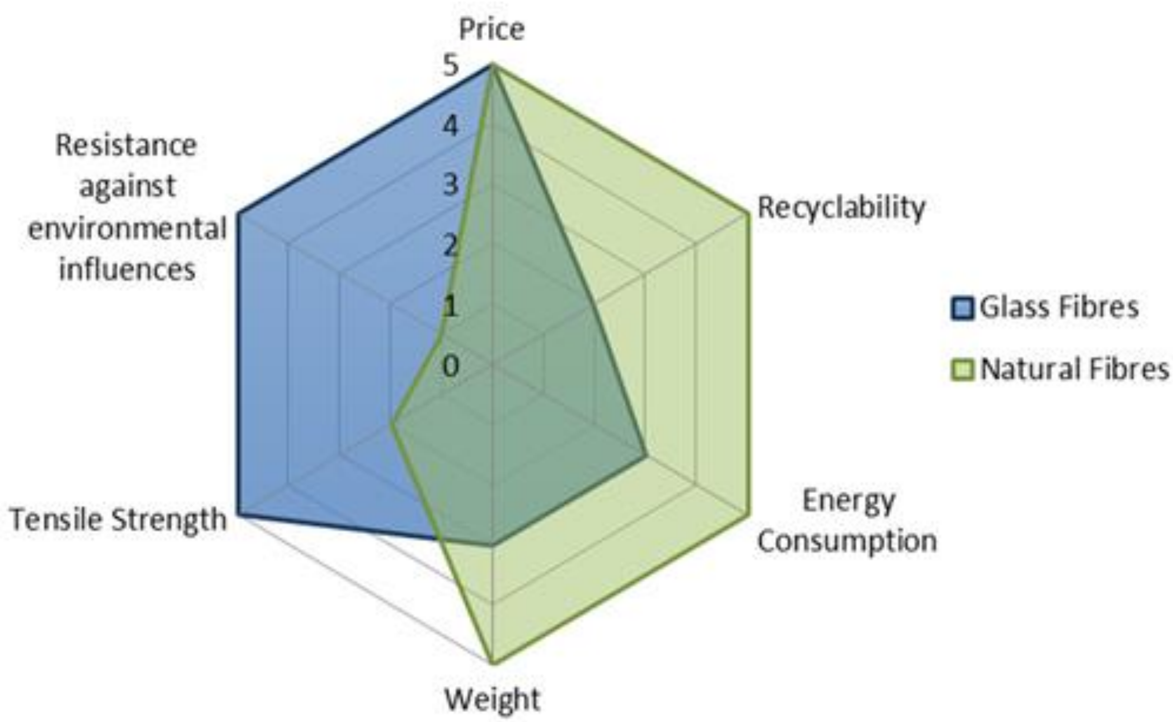

Figure 3.4 Comparisons of Natural Fibres and Glass Fibres (Source: CRC-ACS, Australia)

The relative advantages of natural fibres compared to glass fibres in composites are illustrated in Figure 3.4. The major advantages of biocomposites compared to glassfibre composites are its light weight and superior environmental attributes. However, the drawbacks of biocomposites include inferior waterproofing and thermal resistance and lower tensile strength. These deficiencies are due to flaws present in natural fibres such as growth defects, kink bands, and local strain concentrations. The shortcomings of natural fibres could be successively reduced by smaller fibre diameters from micro to nano levels as shown in Figure 3.5. Extensive research and development work is underway globally on nano-biocomposites, which have better physical properties than current micro biocomposites.

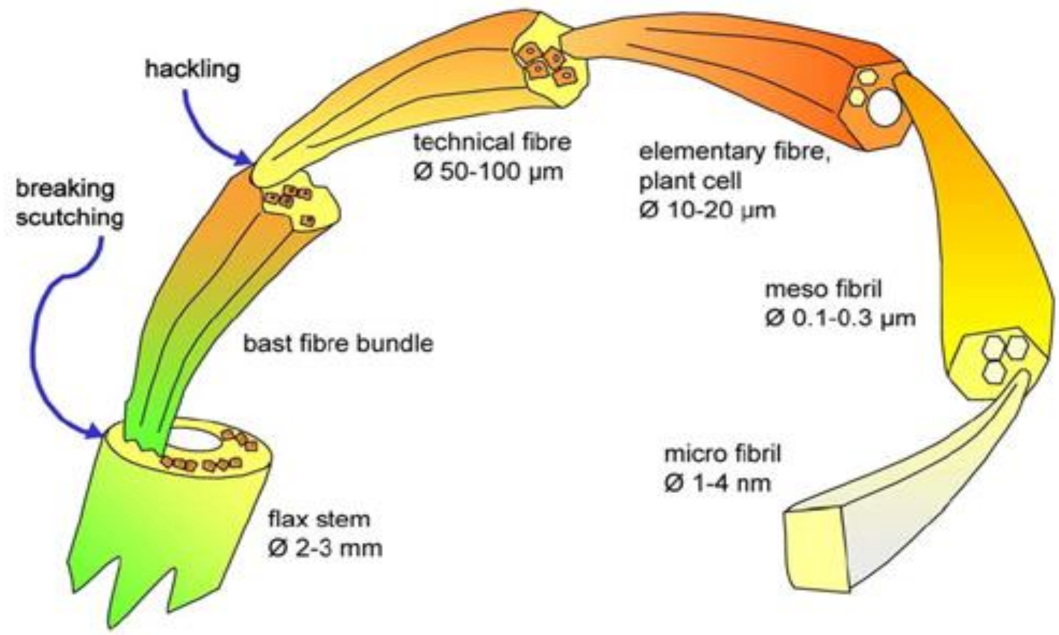

Figure 3.5 Hierarchy of Flex Fibre (Source: CRC-ACS, Australia)

The widespread use of structural biocomposites has yet to be seen. The cost and performance of structural biocomposites need to improve to compete with glassfibre composites. The most commonly used biomass reinforcements in biocomposites are hemp, flax, and kenaf (Fowler et.al, 2006). These plants are not major crops of Ontario, however, they could be grown in the province if there are demands. Further development of the production will require enhancing the production process. The value chain in Figure 3.6 indicates the need for development of other actors as well.

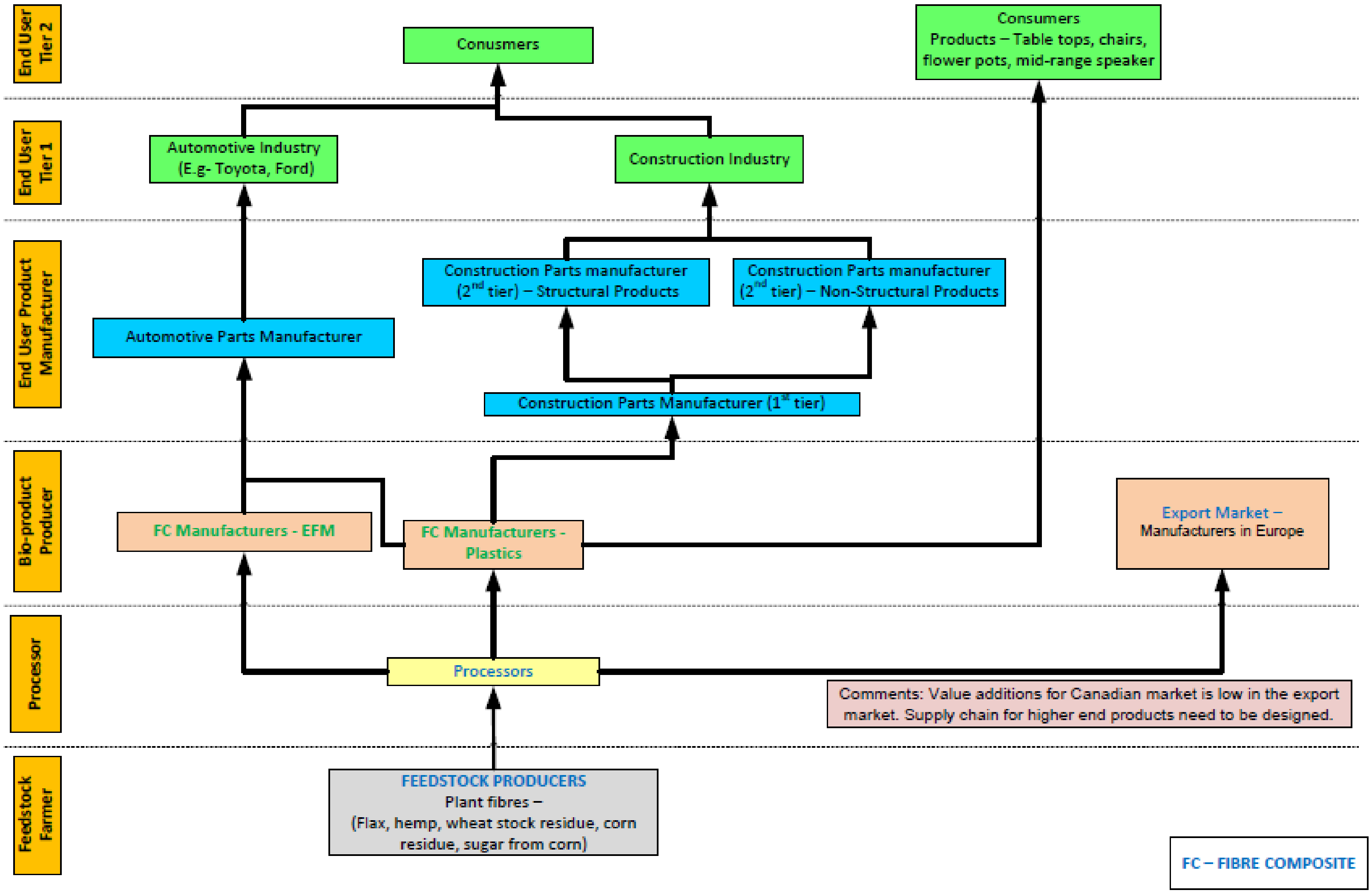

Figure 3.6 Biocomposites Value Chain

3.1.4 Non-Structural Biocomposites

Non-structural biocomposites are considered as a category in this study, since the technologies are well developed and markets are gradually expanding. Non-structural biocomposites are used in applications where performance requirements are limited. The automotive industry has been one of the major markets for non-structural biocomposites. For instance, panels and trims with low mechanical strength requirements and protected from moisture are made of biocomposites in selected models of a few auto manufacturers.

Non-structural biocomposites are usually made of biomass fibres, either wood or agricultural, and petroleum-based plastics. Technologies are being improved to increase the biomass content in the composites and to optimize the manufacturing process, especially on surface treatment and extraction techniques (personal communication with GreenCore Composites, http://www.greencorenfc.com/). Ontario's perennial crops such as miscanthus and switchgrass are potential feedstock for non-structural biocomposites. Wheat straw, a crop residue in Ontario, is currently used to make an interior non-structural biocomposite automotive part for Ford Motor Company as shown in Figure3.7.

Figure 3.7 Wheat Straw Non-Structural Biocomposites for Automotive Application (http://media.ford.com)

3.1.5 Fibreboards

Fibreboards are engineered products made of natural fibres and binding agents. Most commercial products are derived from wood fibres, however, agricultural-based fibreboards are also commercially available. Agricultural fibreboards are considered as greener replacements for wood-based low and medium density boards. Technologies to manufacture fibreboards are well-developed and mature. The areas of improvement include reduction/replacement of formaldehyde as a binding chemical agent.

Construction and furniture industries are the largest consumers of fibreboards (see Figure 3.8 for an example). The value chain of fiberboards for the construction and furniture sectors is illustrated in Figure 3.9. There are also applications in the automotive sector such as dashboard, interior compartments and door inside shell made of fibreboards. Wheat straw, cornstalks, miscanthus and switchgrass are potential Ontario's feedstock for the agricultural fibreboard industry.

Figure 3.8 Straw-Based Fibreboard in Furniture Application (www.biocom.iastate.edu)

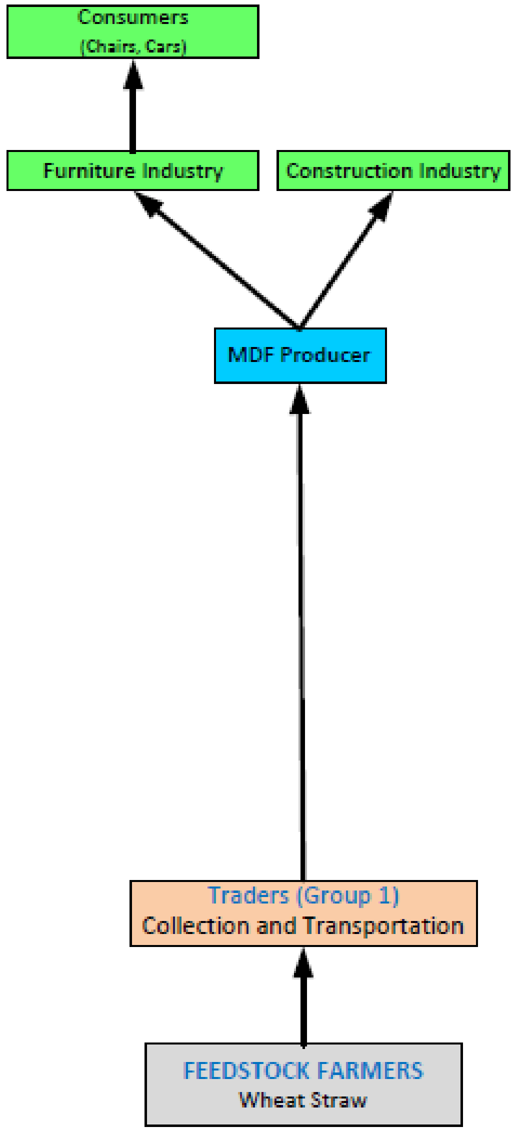

Figure 3.9 Fibreboards Value Chain

3.2 Assessment of Market Development Status

In general, market penetration of biomaterials has been limited. Although biomaterials have better environmental attributes, other parameters, especially cost, play a significant role in consumers' decision making. Regulatory supports could improve the economics and market shares of biomaterials. In most cases, companies and/or government promoting the environmental attributes have created the markets for biomaterials. Greater public concern for sustainability could enhance the market shares of biomaterials in the future. The current production levels of the 5 categories of biomaterials are discussed below.

3.2.1 Bioplastics and Biopolymers

Nova Institute estimated that the global production capacity of bioplastics and biopolymers in 2013 was 5.1 M tonnes, which represented about 2% of overall plastics and polymers production worldwide. The global production capacity of bioplastics by market segment is shown in Figure 3.10. Packaging is the largest market segment with bio-PET as the leading bioplastic. The bio-PET is mostly used for rigid packaging or bottles. This market development is largely due to the environmental initiative launched by Coca Cola. As shown in Figure 3.10, PLA and PLA blends dominate the flexible packaging, e.g. films for wrapping foods/vegetables.

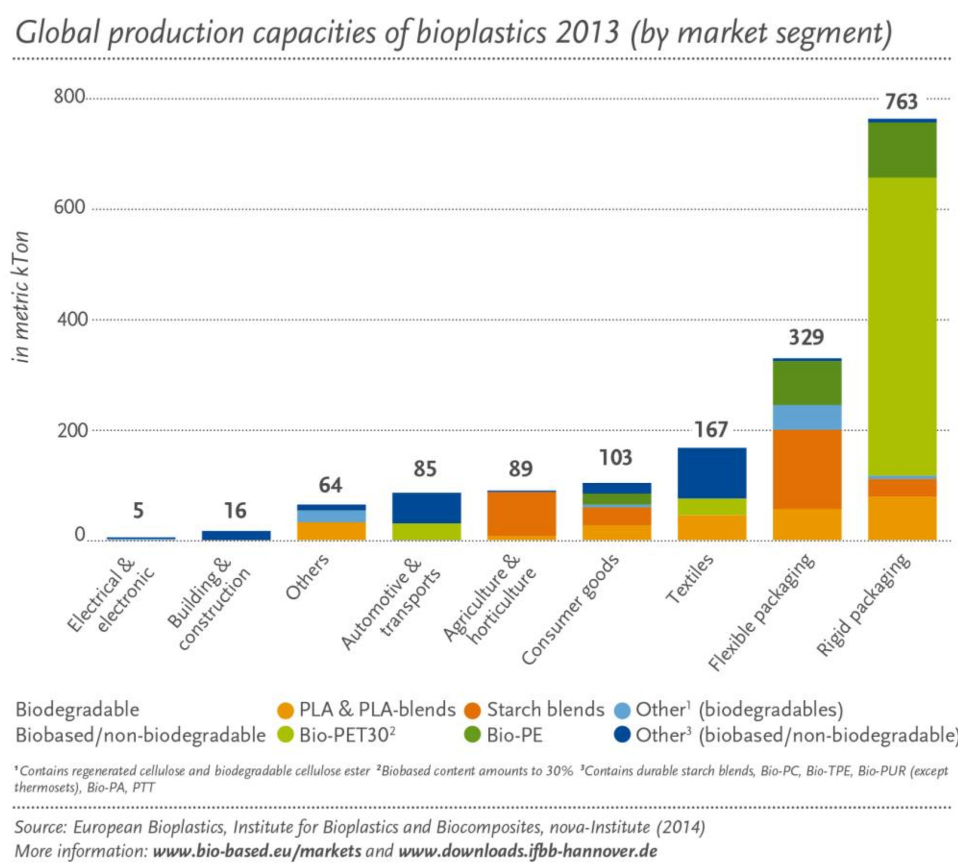

Figure 3.10 Global Production Capacities of Bioplastics by Market Segment (Source: Nova Institute)

The production capacity of North America represented 18.4% of the global total in 2013. Asia has the largest production capacity of bioplastics producing over half of the world's supply. European Bioplastics (http://en.european-bioplastics.org/) forecasted that the majority of bioplastics capacity expansion would be in Asia (See Figure 3.11) with the share of North America falling from 18.4% in 2013 to 4.3% in 2018. Although bioplastics production is expected to increase 3 fold from 2013 to 2020, the increase will largely occur from firms in Asia and South America and not North America. Nova-Institute (2015) suggests the expected rapid capacity growth in Asia in bio-based building block and polymer production is due to better access to feedstock and a favourable political framework.

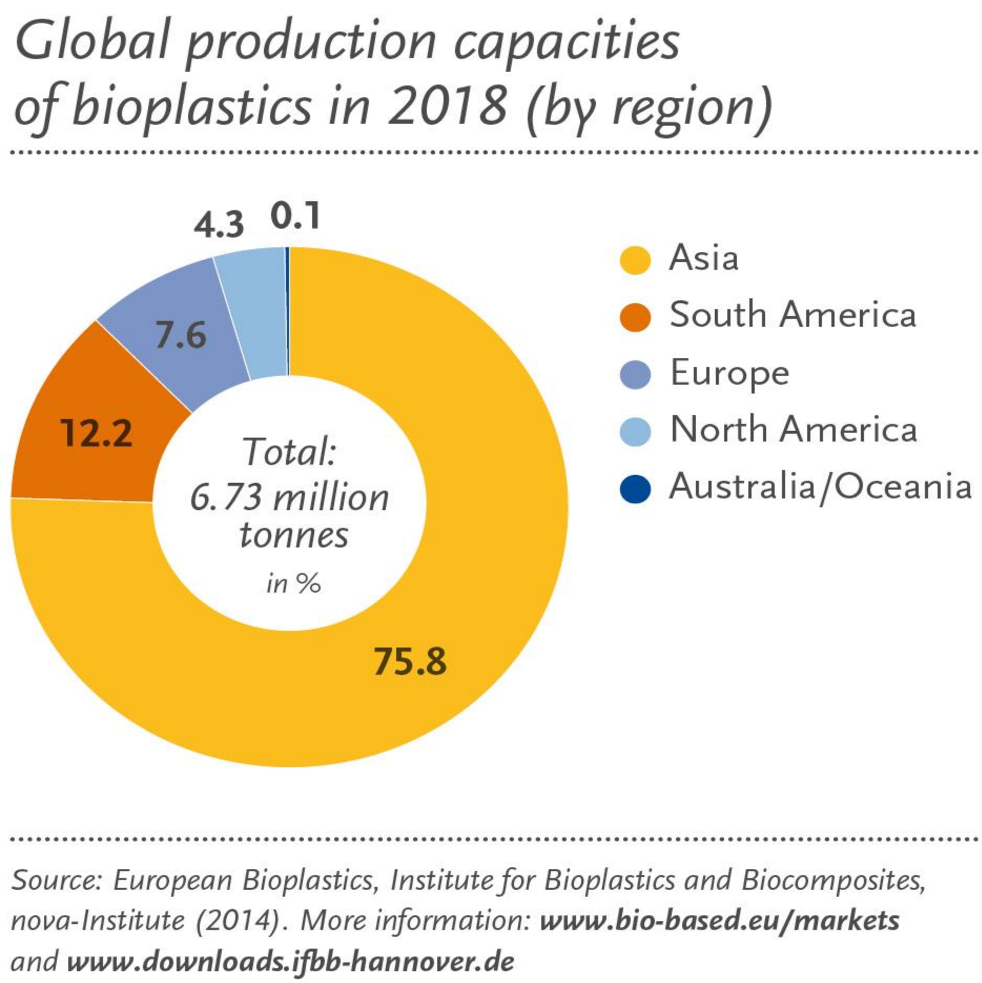

Figure 3.11 Global Production Capacities of Bioplastics in 2018 by Region (Source: European Bioplastics)

3.2.2 Biofoams and Biorubbers

Bio-based polyurethane, which could be used to produce biofoams, is one of the largest biopolymers currently produced with a global production capacity of 1.2 M tonnes in 2013 (Aeschelmann et. al, 2015). Polyurethane can be fossil-based or derived from natural oil polyols. A large numbers of products can be produced from polyurethane in several applications. Information on the total biofoams produced from bio-based polyurethane is not available, and it is likely very small. However, there is a significant potential in replacing fossil-based polyurethane/foams, since the North America polyurethane market is projected to be US$ 14.46 B by 2020. The marked demand in 1012 was 3,241 kilotons. Rigid foam was the largest product, accounting for one third of the market volume in 2013. The rigid foam market is expected to grow at a 4.3% CAGR from 2014 to 2020 (http://www.grandviewresearch.com/press-release/global-north-america-polyurethane-market). The market penetration of biofoams has been limited, likely due to the higher cost of biofoams compared to fossil-based alternatives. As mentioned earlier, Woodbridge Group has been actively developing biofoam products, especially for the automotive sector.

Synthetic rubber produced from fossil resources dominates the global rubber markets, and the industry is searching for a sustainable production system of biorubbers from alternative crops such as Russian dandelion and guayule. LANXESS, the German speciality chemicals company with a plant in Sarnia, Ontario, is the leading company in producing biorubbers and market development. The world first bio-based rubber plant of LANXESS is located in Brazil, where bio-based ethylene is produced from sugar cane for biorubber manufacturing (http://lanxess.com/en/corporate/media/press-releases/lanxess-to-produce-first-bio-based-epdm-rubber-in-the-world/). Greater market penetration of biorubbers is expected as the technology improves.

3.2.3 Biocomposites (Structural)

Improvements in cost and performance of structural biocomposites are expected within the next decade given the extensive research and development efforts underway. The current structural composite market is dominated by fibreglass composites. The global market sizes of fibreglass-dominated composite materials in different segments are given in Table 3.1 (Lucintel, 2011). The potential of structural biocomposites is, therefore, substantial if they can economically replace fibreglass composites. However, the current penetration of biocomposites in the structural materials market is very limited.

Table 3.1 Fibreglass Dominated Structural Composite Material Markets

Market Segment	***Composite Materials Market***	***Structural Materials Market (Steel, Al & Composites)***	***Composites Penetration***
Transportation	$2.7 B	$75.7 B	3.6%
Marine	$0.5 B	$0.7 B	68%
Aerospace	$2.0 B	$19.1 B	10%
Pipe & tank	$2.1 B	$29.6 B	7%
Construction	$3.1 B	$78 B	4%
Wind Energy	$2.0 B	$5.4 B	38%
Consumer Goods	$1.1 B	$7.7 B	14%

Source: Lucintel, 2011

3.2.4 Biocomposites (Non-Structural)

Biocomposites are gaining market shares in applications where performance requirements are not demanding. Europe has been the leading region in promoting biocomposites, and the production of biocomposites in 2012 is given for the European Union (EU) in Table 3.2 (Carus et. al, 2015). Most of the biocomposites made in the EU are non-structural with some semi-structural. Total production of biocomposites in 2012 was 352,000 tonnes, which represents about 15% of total composite material production in the EU. Wood-plastics composites dominated the biocomposite market in with approximately 74% market share. Fibres used in wood-plastics composites are sourced from the forestry biomass. Natural fibre composites are made from agricultural and other plant fibres such as hemp, flex, jute, kenaf, rice husk, and straw.

Table 3.2 Biocomposite Production in European Union in 2012

Biocomposites	***Production (tonnes)***
Wood-Plastic Composites (WPC)	*260,000*
Decking	174,000
Automotive	60,000
Siding and Fencing	16,000
Technical Applications	5,000
Furniture	2,500
Consumer Goods	2,500
Natural Fibre Composites (NFC)	*92,000*
Automotive	90,000
Others	2,000
Total Volume Biocomposites (WPC and NFC)	*352,000*

Source: Carus, et. al, 2015

The major market of non-wood natural fibre composites in the EU is the automotive sector as seen in Table 3.2. Total vehicle production in European Union in 2011 was approximately 18 million. Therefore, about 5 kg of non-wood natural fibre composites (approximately 50% fibre) per vehicle was used in European Union in 2012. The German automotive industry has the highest use of natural fibre at 3.6 kg per vehicle (Carus et. al, 2015). Assuming the total annual vehicle production in Ontario is 2 millions, the potential annual biomass demand is 7,200 tonnes, if the average biomaterial usage is similar to that of Germany. This demand could be supplied by approximately 1,000 acres of miscanthus or 1,500 acres of switchgrass.

Another large market for biocomposites in the EU is the construction sector; mainly decking, siding and fencing. The use of agricultural fibres in the construction sector has been very limited, although agricultural fibres offer better insulation and light weight advantages. Non-structural biocomposites are gaining market shares in construction and automotive sectors but current market penetration is limited.

3.2.5 Fibreboards

Fibreboard markets are well-established with construction and furniture industries as major consumers, and currently dominated by wood-based products. Particle board and Medium Density Fiberboard (MDF) are likely candidates to be replaced by agricultural fibreboards in selected applications.

Total production of particle boards and MDF in North America in 2012 was 5.37 M m^3 and 3.66 M m^3, respectively (UNECE and FAO, 2013). The market penetration of agricultural fibreboards seems minimal with some headway in niche applications such as furniture and interior decoration. The capacity utilization of particle board and MDF in North America was 58.7% and 76.4%, respectively, and this leads to price pressure on alternatives such as agricultural fibreboards. The prices of particle boards and MDF in North America are compared with other fibreboards in Figure 3.12.

A few manufacturers offer agricultural fibreboards, mostly with wheat straw, commercially as the technologies and industrial standards are well-developed. If 20% of fibreboard used in Ontario is replaced with agricultural fibreboard, the biomass demand will be approximately 50,000 tonnes annually

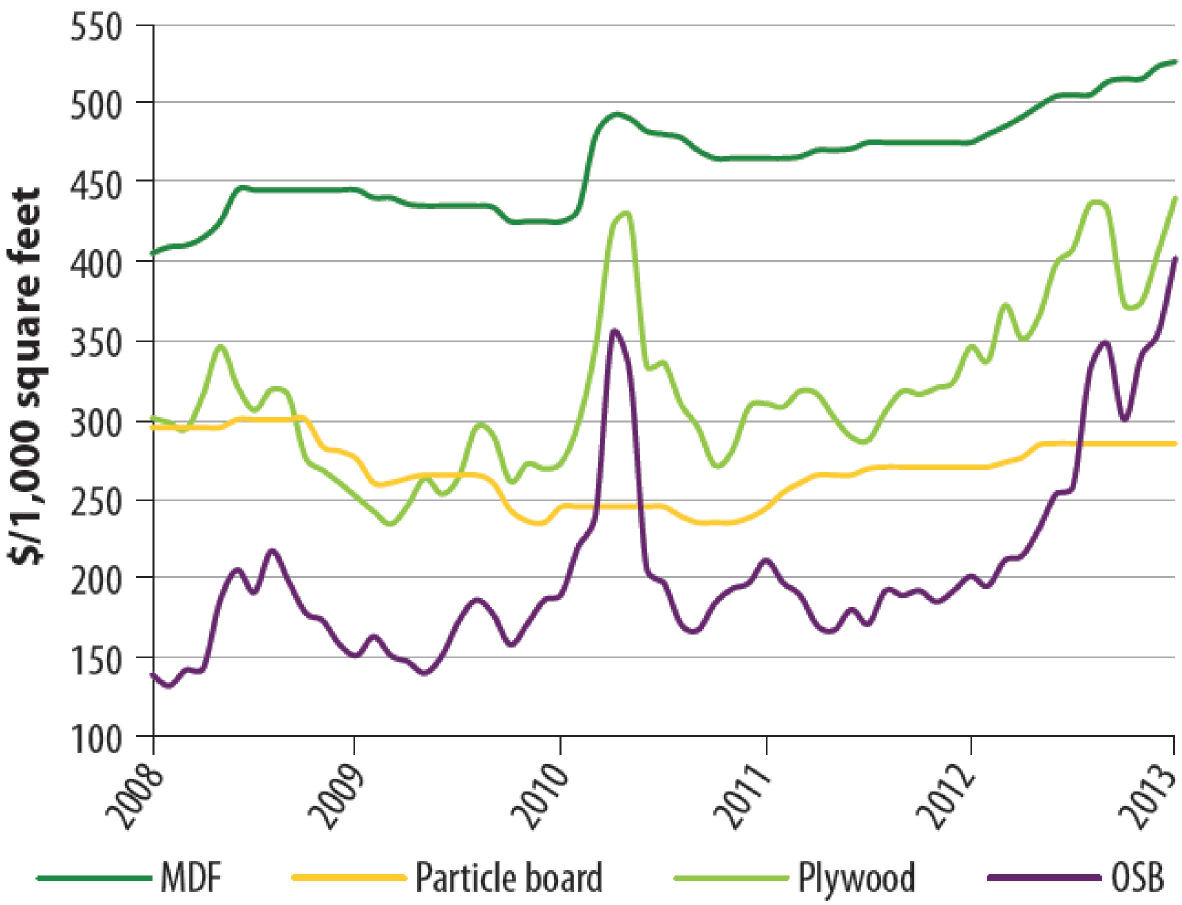

Figure 3.12 Comparison of Fibreboard Prices in North America (UNECE and FAO, 2015)

3.3 Identification of Biomaterials for Ontario

The selected biomaterial categories are reviewed from technology and market development perspectives. The biomaterial firms look for a competitive edge of the jurisdiction to locate their manufacturing plants. The production over capacity of a particular biomaterial product in other jurisdiction sometimes reduces the competitive edge of geographical location. The logistic costs of feedstock and final products, availability of feedstock at competitive price, the existence of industry clusters in other regions, and regulatory supports are also influential factors. The technology and market development of biomaterials reviewed in this study are summarized and scored in Table 3.3.

Table 3.3 Summary of Development Statuses with Competitive Edge Prospective in Ontario

Biomaterials	*Technology Development Status*	*Market Development Status*	*Competitive Edge of Manufacturing Plant in Ontario*	*Total Score*
Bioplastics and Biopolymers	3	2	1	6
Biofoams and Biorubbers	3	2	2	7
Biocomposites (Structural)	2	1	1	4
Biocomposites (Non-Structural)	4	2	3	9
Fibreboards	4	2	3	9

1 – Least favourable; 5 - Most favourable

Bioplastics and biopolymers can be produced with fairly mature technologies. Although their market penetration is limited at present, the growth in market share is expected to be significant in coming decades. However, the major expansion in the production of bioplastics and biopolymers is forecasted to occur in Asia and South America where large markets exist and competitive sugar crops are available. Bioplastics and biopolymers in Ontario is likely to have limited competitive advantage.

The technology and market development of biofoams and biorubbers are similar to those of bioplastics and biopolymers. The existence of the automotive industry, which is a large potential consumer of biofoams and biorubbers, in Ontario increases the competitive edge of a new plant in the province. In this preliminary evaluation, structural biocomposites receive the lowest scores. In addition to their unfavourable technology and market development, the agricultural fibres used for the structural biocomposites are not grown as major crops in Ontario.

Non-structural biocomposites and fibreboards are likely candidates for commercial establishments in developing the agricultural-based biomaterial industry in Ontario. Technologies for producing non-structural biocomposites and fibreboards are well-developed, and potential markets, especially within the automotive and construction sectors, exist with greater biomass feedstock requirement. Due to the bulky nature of these biomaterials and associated logistic costs, the manufacturing plants sized for local demands could be competitive.

4. Commercialization and Barriers

Almost every jurisdiction with large agricultural resources is pursuing the development of the biomaterial industry but the commercial establishment of biomaterial manufacturing facilities are limited. In this section, factors affecting the commercialization of biomaterials are reviewed. The barriers faced by the biomaterial firms are analyzed. Based on those findings, an evaluation matrix is developed to screen the biomaterial and associated firms.

The following parameters are considered crucial in the evaluation matrix: (1) feedstock compatibility, (2) technology maturity, (3) profitability, (4) economic development potential, (5) competition with substitutes, (6) niche market existence, (7) regulatory and institutional support, and (8) existing value chain/ infrastructure. The first section describes each of these parameters and how they are evaluated to construct the evaluation matrix. The second section uses the matrix to evaluate specific biomaterials.

4.1 Factors Influencing Commercialization of Biomaterials

Commercialization, in general, can be defined as the process of introducing a product or service to the market. The success of a commercialization process will depend on the existence of consumers who are willing to pay the reasonable price for the product/service introduced. The product/service has to compete with alternatives. The reasonable price should be higher than the cost of manufacturing the product or the cost of offering the service. The price also should offer an acceptable return to capital investment required for the product/service introduced. In this context, a few influential factors biomaterial firms and investors would consider in commercializing the products are briefly discussed below.

4.1.1 Feedstock Compatibility

Section 2 established sufficient biomass from either crop residue or dedicated biomass crops could be supplied for the biomaterial industry provided the appropriate incentives are in place in Ontario. The incentives depend on the prices for the biomass, the prices for alternative uses of the land for the biomass, and the risks associated with each option.

There is not a well-defined market for dedicated biomass crops such as switchgrass or miscanthus. In addition, these are perennial crops with an establishment cost and time lag before revenues can be generated. Consequently, growers of these crops would have to be guaranteed sufficient return to offset the costs of allocating land to a crop with limited flexibility. In contrast, most farmers in Ontario typically grow corn and soybeans and wheat. The choice is what to do with the residue and involves trading off short-term returns for longer-term benefits from enhanced soil quality associated with returning the biomass back to the soil. The decision does not involve the adjustment costs as with the dedicated biomass crops and is thus less risky. Flexible long-term contracts that tie the biomass price to the major substitute commodities, such as corn, could provide a solution to the risks associated with committing to biomass production to both producers and the biomaterial firms.

The ability of Ontario to supply feedstock for the biomaterial sector is scored on the basis of 5 criteria listed in Table 4.1. Given the ability to grow dedicated biomass crops and/or use residues from existing crops, feedstock compatibility is ranked 5. The actual supply of the feedstock depends on markets being established for the biomass and not on the ability to produce the material.

Table 4.1 Scoring Criteria for Feedstock Compatibility

Feedstock Compatibility	Score
Commoditized crops/residues in Ontario	5
Un-commoditized crops/residues grown in Ontario	4
Commoditized crops/residues which could be grown in Ontario	3
Un-commoditized crops/residues which could be grown in Ontario	2
Crops/residues which need further research to be grown in Ontario	1

4.1.2 Technology Maturity

A number of biomaterial technologies are at the research and development stage. Only very a few of them will be commercialized and will be financially feasible in the long term. Some technologies work at the bench scale, however, face difficulties when they are scaled-up. Some technologies cannot handle seasonal feedstock viability, which is usual with vast amount of biomass sourced from a larger area. Some biomaterials developed have not been tested extensively in real-world applications, for instance under cyclical seasonal thermal stress. The scoring criteria for technology maturity listed in Table 4.2 reflects the potential range from the R&D stage for some products to the significant commercial sales for other bioproducts.

The maturity of the biomaterial and production technology is an influential factor for potential investors in commercialization. Investors will expect much higher return for their financial capital to offset the higher risk for biomaterials with unproven performances and/or only proven at a small scale. Partnership with and/or investment by large corporations in the biomaterial firm is usually a good indicator that there is trust in the ability of the technology to work in practice. The development of biomaterial technologies is expected to accelerate in coming decades with increased government support for research and development along with private initiatives.

Table 4.2 Scoring Criteria for Technology Maturity

Technology Maturity	Score
Commercial production with annual sale > $ 5 M	5
Commercial demonstration plants being built & offtake agreements or previously proven	4
Commercial demonstration plants being built	3
Scale-up demonstration unit in operation (>1/20 of commercial scale)	2
Research and development stage	1

4.1.3 Profitability

One of the most important factors in commercialization is whether the biomaterial firm will be profitable in a reasonable period, typically 3-5 years from the initial investment. However, the cost and price charged to consumers need to be lower compared to available substitutes. Economies of size and marginal cost of production are crucial in predicting the profitability of biomaterials.

In addition to the cost of production (see next sub-section), the price of the biomaterial will influence returns to the investor. The exclusive ownership/licensing of the technology patent and/or mandated biomaterial demand with limited supply will provide some pricing power to the biomaterial firm. The pricing power of the biomaterial firm will be reduced if barriers to entry for the biomaterial are relatively easily manageable. Competition from new comers to the industry will reduce price, and thus the profitability. The factors influencing profitability are summarized in the scoring criteria listed in Table 4.3.

Table 4.3 Scoring Criteria for Profitability

Profitability	Score
Good pricing power with expected demand growth rate >=25%	5
Good pricing power with expected demand grow rate 15 to 25%	4
Marginal pricing power and/or sensitive to feedstock (>50% of total)	3
Demand is moderately sensitive to product price	2
Limited/no pricing power	1

4.1.4 Economic Development Potential

A successful biomaterial sector could substantially contribute to the economic development of the province, especially in the rural areas. The benefits of the emerging biomaterial industry include job creation associated with value-added activities along the entire supply chain from feedstock harvest/collection to transportation to manufacturing of final biomaterial products. Due to these economic development potentials and other environmental and social benefits, governments at different levels provide financial and other supports to the biomaterial firms in establishing manufacturing facilities. The commercialization risks of biomaterials are lowered by governments' investment and support.

The POET-DSM cellulosic ethanol plant in Iowa, the USA, is an example of government providing support. The cellulosic ethanol plant, once fully operational, will produce 25 M gallons of ethanol annually from approximately 250,000 tonne of cornstalks, creating jobs in harvesting and processing biomass in the rural area. The estimated total investment of the POET-DSM plant is $ 250M, and the US Department of Energy has supported this first-of-a-kind project's engineering, construction, biomass collection, and infrastructure through approximately $100 million in cost-shared support (http://energy.gov/articles/project-liberty-biorefinery-starts-cellulosic-ethanol-production).

The federal and provincial governments in Canada also offer financial assistance to bio-based companies. The $ 135M BioAmber bio-succinic acid plant in Sarnia received $ 12M investment from the federal government (http://www.feddevontario.gc.ca/eic/site/723.nsf/eng/01752.html) and $ 15M loan from the provincial government (https://news.ontario.ca/medt/en/2015/08/bioamber-opens-new-plant-in-sarnia.html).

Table 4.4 Scoring Criteria for Economic Development Potential

Economic Development Potential	Score
New manufacturing jobs and associated supply chain in rural areas	5
Feedstock preparation jobs in rural areas with central manufacturing	4
Marginal job creation at existing facilities in rural areas	3
Marginal job creation at existing central manufacturing facilities	2
Limited/no job creation	1

4.1.5 Competition with Substitutes

Agricultural biomaterials face serious competitions from fossil-based and wood-based substitutes. The slowdown in housing sector has led to the surplus forestry resources in Canada and the US. The most intense competition is likely from plastics, especially low cost recycled plastics, and other materials derived from relatively inexpensive and abundant natural gas in North America. Figure 4.2 shows the price of natural gas in recent years in North America and the price is expected to stay low for the next couple of years. The price of oil has fallen dramatically in the last few months and is also expected to remain low due to the large supply in the midst of falling demand. In contrast, the current low prices for fossil fuels puts cost pressure on bioproducts. The role of substitutes in the potential success of a bioproduct is summarized in the scoring criteria of Table 4.5.

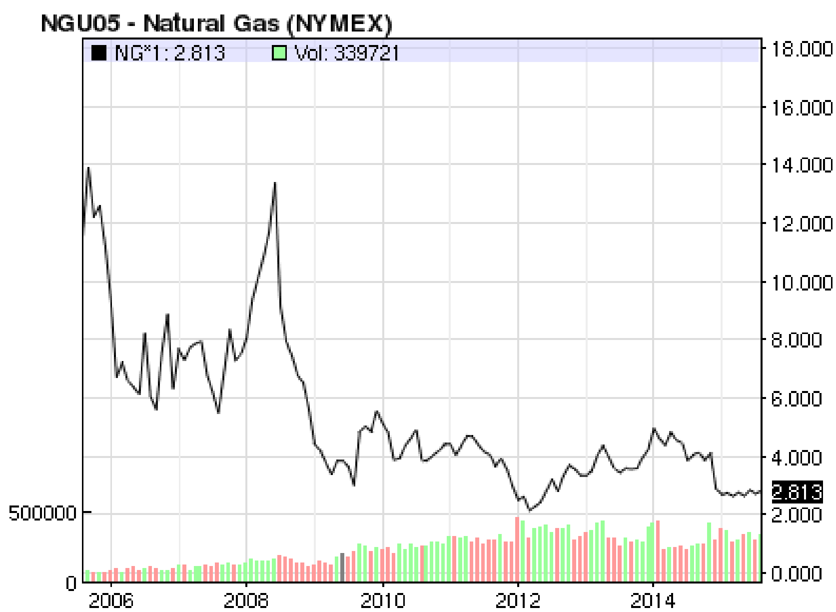

Figure 4.2 Price of Natural Gas in US $/MM Btu (http://www.nasdaq.com/markets/natural-gas.aspx)

Table 4.5 Scoring Criteria for Competition with Substitutes

Competition with Substitutes	Score
Significantly lower cost compared to substitutes (<50%)	5
Lower cost compared to substitutes (50 to 75%)	4
Comparable to the cost of substitutes	3
Comparable to the cost of substitutes at selected markets	2
Higher costs compared to substitutes	1

4.1.6 Niche Market Existence

In most cases, bioproducts are sold to niche markets rather than to commoditized markets. The niche markets are created by government mandates or the sustainability initiatives of large corporations such as Coca Cola. The expectation is that improvements in technology and economic conditions, bioproducts will eventually compete with conventional products in the commoditized markets. In contrast to commodity markets where the primary risk is associated with price, the risk with niche markets is that the demands of the consumer creating the niche can change. The potential ranking of a niche market for a given bioproduct is given in Table 4.6.

Bioproduct firms sometimes form partnerships with large international corporations to commercialize their products. The off-take agreements for the bioproducts to be produced at the commercial demonstration plants are signed, indicating existence of niche markets. Partnerships between Gevo and LANXESS for bio-isobutene and BioAmber and Mitsui Chemicals for bio-succinic acids (Jong et. al, 2014) are the examples of bioproduct start-ups capturing the niche markets created by the large corporations.

Table 4.6 Scoring Criteria for Niche Market Existence

Niche Market Existence	Score
Demand from sector(s) which is/are growing at >25% annual rate	5
Demand from sector(s) which is/are growing at 15-25% annual rate	4
Demand from major economic sector(s)	3
Demand from emerging economic sector(s)	2
Need to develop markets	1

4.1.7 Regulatory and Institutional Support

Regulatory Support

As an incubation measure, regulatory support is of critical importance in developing the bioeconomy. For example, the emergence of the ethanol industry in North America is largely due to the setting of blend mandates for the use of ethanol in gasoline. Government support in the form of mandated procurement, such as with ethanol, and public awareness programs, can create a market for biomaterials to kick-start the industry through its startup phase. The regulatory support should be eventually removed when the industry becomes self-sustainable.

Regulatory support to a particular sub-sector of the bioeconomy can be detrimental to the other sub-sectors. Nova Institute (http://www.nova-institut.de/bio/index.php) has pointed out the incentives designed for biofuels are negatively affecting the development of biochemicals and biomaterials. Wood-based fibreboard industry in a few jurisdictions in the US experienced a feedstock shortage when incentives were provided for generating electricity from forestry waste (http://www.woodbioenergymagazine.com/magazine/2015/0815/in-the-news.php). It is, therefore, crucial to create a level playing field for all sectors of bioeconomy. Regulatory barriers could lessen the feasibility of the bio-industry. For instance, the enzymes to process C5 sugars from cellulosic biomass have not been approved in Canada. The prompt review and the approval of enzymes for C5 sugars will attract cellulosic sugar/ethanol firms to Canada to establish manufacturing facilities and research and development centres. .

The regulatory system plays an important role in the ease of doing business. Government regulations can affect the opening and closing of business, the efficiency with which contracts are enforced, and the rules of administration pertaining to activities such as receiving permits for utilities. All these factors are important drivers in determining the likelihood of businesses starting and continuing (World Bank Group, 2014). Red tape in the administration process creates regulatory burdens on businesses in terms of time, costs and resources (Government of Saskatchewan). These effects tend to fall mainly on the small and medium enterprises, which can result in a loss in flexibility that is a key advantage of being small (Dammer and Carus, 2014). Canadian bioproduct firms have consistently ranked the issue of regulatory approval and the resulting higher cost and loss of timeliness as a major burden constraining their success (Sparling *et al*, 2009).

The existence of clear policies in promoting bioeconomy is another important factor the industry and potential investors consider. For example, policies and commitments of some European countries in combating climate change have attracted industries in the bioeconomy and other sustainable sectors. The emergence of the biomaterial sector in Ontario will, therefore, be aided by a clear vision for the bioeconomy by government, and supported with appropriate regulatory policies.

Financial Resources

Financial support for the biomaterial sector from the innovation process in the research and development stage to production full-scale commercial manufacturing facility can foster the sector's development. In the early stages, the majority of funding for basic and applied research and feasibility studies will likely come from governments and public institutions. In the so-called valley of death (see Figure 4.3) stage (http://www.investopedia.com/terms/d/death-valley-curve.asp), demonstration of technology should be funded through private-public partnerships. In the later stage of the innovation process where semi-commercial and commercial manufacturing facilities are established, the majority of the investment should be funded by the private sector with supporting policy and regulatory initiatives.

There are funding programs in place in Ontario and Canada for the early stages of the "valley of death". These include NSERC, SDTC, Growing Forward and FedDev grants, but there is a fragmentation of support between provincial and federal programs that could be improved. The restriction to capital tends to occur as the initiative moves towards the semi-commercial or commercial manufacturing facility stage. The investment community generally considers firms in the biomaterial sector as high risk. The setting up of facilities during the semi-commercial stage requires access to feedstock, biomass collection facilities, waste and other regulations involves significant capital, which is often not available to small and medium enterprises or start-up enterprises. Most of the bioproduct firms in Canada were identified to be small by Statistics Canada and the availability of capital was cited as a major constraint to these firms (Sparling *et al*, 2009). The dedicated capital assistance programs for commercial projects, such as the Biorefinery program in the US (http://www.rd.usda.gov/programs-services/biorefinery-renewable-chemical-and-biobased-product-manufacturing-assistance), should be developed in Canada for biomaterials/biochemicals sector. Reducing costs and promoting the sector will improve profitability, reduce risks, and thus increase the flow of capital from investors to the biomaterials sector.

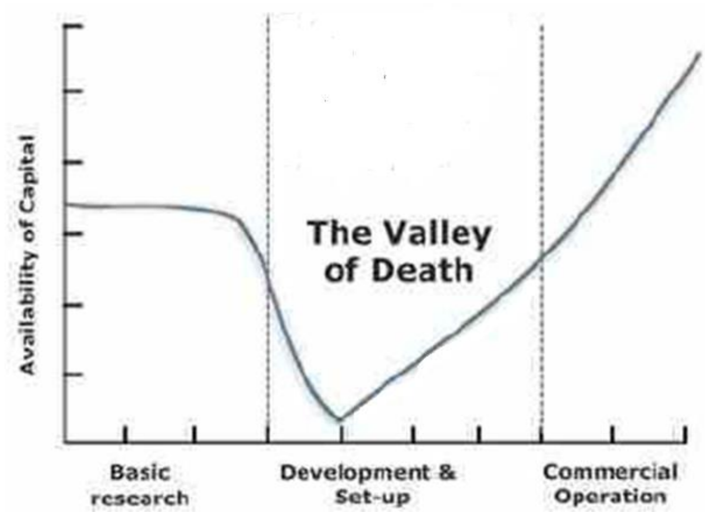

Figure 4.3: Problem of "Valley of Death" in Bioeconomy

Source: Dammer and Carus, 2014

Innovation Ecosystem

The innovation ecosystem for biomaterial industry includes academic institutions, research and development centres, business incubators, commercialization organizations, biomass suppliers, biomaterial firms, biomaterials consuming industries and sectors, government institutions and policy makers. When all these elements of the innovation ecosystem are in place and are working in synergy, the emergence and sustainability of biomaterial industry is more likely.

The lack of a strong innovation ecosystem could, therefore, be considered as a barrier or challenge to the industry establishment. The industry should be at the core of an innovation ecosystem to ensure the long-term prosperity of the sector. It will provide information and tasks to the upstream and downstream components of the innovation ecosystem. The initial establishments of a few biomaterial firms, large or small, are essential to develop a functioning innovation ecosystem. The biomaterial industry will then likely expand with continued and sustained innovations.

There are a number of components of the biomaterial innovation ecosystem in place in Ontario and Canada. The Bioproducts Discovery & Development Centre (http://www.bioproductscentre.com/), the Biomaterial A-Team (http://www.ontariobioproducts-ateam.ca/) Bioindustrial Innovation Canada (http://www.bincanada.ca/) and Ontario Biomass Producers Co-operative Inc.

(https://ontariobiomassproducersgroup.wildapricot.org/) are a few examples of innovative research centres focused on bioproducts value chain in Ontario. There are a few biomaterial firms that are selling their products commercially. For example, competitive Green Technologies (http://www.competitivegreentechnologies.com/) is one of the leading companies in the agricultural biomaterial sector in Ontario. A list of biomaterial firms in the province is given in Appendix A.

While there are some research centres and some commercialization, the innovation ecosystem is not fully developed for the bioproduct sector. Research shows that scientists in Canada lack the drive to develop products for commercialization. One of the factors could be the deficiency of investment capital for the type of R&D required for advancing the biotechnology sector (Decima Research 2006; Majumdar 2011). The total R&D spending in Canada has declined significantly from $242 million to $127 million. Moreover, bioproduct firms have allocated funds on bioproduct development and on biomass research without any focus on commercialization. This fact is exemplified as most bioproducts (polymers, bioenergy and other organic chemicals) are mostly in "R&D" and "proof of concept" phase (Sparling and Cranfield 2011). Hence, the flow of information along the value chain remains asymmetric creating the barriers for commercialization of bioproduct industry.

Table 4.7 Scoring Criteria for Regulatory and Institutional Support

Regulatory and Institutional Support	Score
Mandatory regulatory support and commercialization/R&D institutions	5
Indirect regulatory support and commercialization/R&D institutions	4
Commercialization/R&D institutions	3
Limited regulatory and institutional support	2
Need to develop R&D capacity and support mechanism	1

4.1.8 Existing Value Chain and Infrastructure

If the new bioproduct industry can be integrated into an existing value chain, infrastructure and cluster, the cost of industry establishment can be significantly reduced. The BioAmber (http://www.bio-amber.com/) bio-based succinic acid plant in Sarnia, Ontario is an example of leveraging an existing value chain. In August, 2015, BioAmber opened its $135 million plant, which will produce bio-based succinic acid from corn. The plant is located on a brown field owned by LANXESS, a speciality chemicals company. If the plant was built on a green field, the capital cost would be 25-50% higher (http://www.ivey.uwo.ca/cmsmedia/1965460/future-of-manufacting.pdf and communication with personnel from LANXESS and BioAmber). Additionally, the availability of industry experts and a skilled labour forces along with the proximity to existing petro-chemical firms (i.e. LANXESS's butyl rubber site) in Sarnia are invaluable assets to BioAmber in building and operating its plant. The established infrastructure of the ethanol industry also offers opportunities to expand into new businesses such as Dried Distiller Grains (DDGs)-based bioproducts.

The development of a new value chain for biomaterials could take time. For instances, miscanthus or switchgrass crops mature in 3-4 years from the establishment. Harvest equipment for corn stalks has been under development for a few years. If the biomaterial is made of wheat straw, most of the harvest, storage and transport components of the value chain are already in place in Ontario. However, for fibre crops such as hemp and flax, decorticating and pilot demonstration facilities, as important value chain/infrastructure components, are lacking in Ontario. As the biomaterial industry grows, the value chain will gradually become established and lower the cost of biomaterials. The ability to integrate biomaterials to be commercialized within an existing value chain and infrastructure could significantly improve the financial feasibility of the bioproduct.

Table 4.8 Scoring Criteria for Existing Value Chain/Infrastructure

Existing Value Chain/Infrastructure	Score
Able to integrate with existing value chain/infrastructure/clusters	5
Need to develop one component of value chain/infrastructure	4
Need to develop 2-3 components of value chain/infrastructure	3
Value chain/infrastructure could be developed in 5 years	2
Value chain/infrastructure development could take over 5 years	1

4.2 Evaluation of BiomaterialProducts

As discussed in Section 3 from a technology and market development perspective, non-structural biocomposites, fibreboards, and biofillers represent the most promising biomaterials for Ontario. Two examples of each are considered for evaluation using the scoring model for each of the eight factors discussed in the previous section. The two non-structural biocomposites are flowerpots from switch grass or miscanthus and car door panels from wheat straw. The two fibreboard examples are construction panels from corn stover and furniture from strawboard. Wheat straw insulation and residues as packaging materials are listed as biofillers in the evaluation. The biofillers may also be classified as biocomposites or fibreboards if they are molded into preset forms with or without other materials such as recycled paperboards. The biomaterials under bioplastics, biopolymers, biofoams, biorubbers and structural biocomposites categories are excluded in the evaluation due to its limited commercialization potential currently and/or its technical development status. The biomaterials evaluated in Table 4.9 are either being commercialized in Ontario or considered for commercialization in Ontario or other jurisdictions with similar biomass feedstock. For example, Ontario-based Competitive Green Technologies is commercializing the developing markets for non-structural biocomposites using switchgrass and miscanthus as the feedstock.

The eight factors considered important in developing a successful bioproduct are evaluated for each of the six specific examples (see Table 4.9). The eight factors ((1) feedstock compatibility, (2) technology maturity, (3) profitability, (4) economic development potential, (5) competition with substitutes, (6) niche market existence, (7) regulatory and institutional support, and (8) existing value chain/ infrastructure) are scored using a Likert-scale with 1 representing unfavourable and 5 as most favourable. Feedstock compatibility, profitability and ability to compete with substitutes are considered as the most critical for financial feasibility. Thus, the total score for each biomaterial is not the simple sum of the score for each of the 8 factors (with a maximum of 40) but a weight with a weight of 5 for feedstock compatibility, profitability and ability to compete with substitutes, 4 for technology maturity and value chain infrastructure, and 3 for the other three factors. Thus, the maximum score is 160. The higher the total score, the better the chance to commercialize the biomaterial in Ontario.

Table 4.9 Sample Evaluation of Commercialization Potential of Selected Biomaterials Based on Eight Factors

	Feedstock Compatibility	Technology Maturity	Profitability	Economic Development Potential	Competition with Substitutes	Niche Market Existence	Regulatory & Institutional Support	Existing Value Chain Infrastructure	Total Score (Max. 160)
Weighting	*5*	*4*	*5*	*3*	*5*	*3*	*3*	*4*	
Non-structurlal biocomposites (examples)									
Switchgrass/miscanthus flower pot	4	4	3	2	2	2	1	3	88
Wheatstraw car door panels	5	3	3	1	3	2	3	4	101
Fibreboard (examples)									
Corn stover construction panels	5	4	4	3	2	2	2	3	104
Strawboard/biomass crops-based furniture	5	4	3	2	3	2	2	4	105
Biofillers (examples)									
Wheatstraw/biomass crops insulation	5	3	3	2	2	3	3	4	102
Residue as packaging materials	5	3	3	3	2	3	2	3	98

5 - Most favourable

1 - Least favourable

In general, all selected materials in Table 4.9 receive high scores for feedstock compatibility and technology maturity. The lowest scores are for the competition with substitutes and niche market existence, which could be the area of focus for policy instruments. In this sample evaluation, the fibreboard materials receive the highest scores due to their relative superiorities in feedstock compatibility, technology maturity and profitability. However, their total scores compared to the maximum possible score of 160 indicate that these biomaterials need policy and other assistance in order to be successfully commercialized.

5. Industry Development Strategy

Prioritization and strategic approach are essential in accelerating the emergence of a new industry. These should be aligned with the specific characteristics of the province and the market trends. Once the industry is firmly rooted and the innovation ecosystem is in place, the expansion of industry will likely occur. In this section, the target market sectors of the biomaterials are reviewed and prioritized using the analysis of sections 3 and 4 as a foundation the assessment. The biomass supply chain is analyzed with an example of establishing a strawboard plant. The strategic approach to develop the biomaterial industry in Ontario is discussed.

5.1 Prioritization of Target Sectors in Ontario

Biomaterials can certainly replace many fossil-based materials in several market sectors. However, some sectors are more promising from biomass demand perspective and synergy with the general provincial economy. Based on recent market development trends, the focus sectors of this study are:

- transportation/automotive,
- household/consumer and
- construction/ building.

Each market sector is reviewed in order to prioritize the opportunities. The current developments are examined, and the potential demands are estimated. The major barriers to the widespread use of biomaterials in each sector are investigated, and the potential policy instruments are discussed.

5.1.1 Transportation/Automotive Sector

The transportation/automotive sector has been the target market of biomaterials in Ontario, since it is one of the pillars of the provincial economy. The Ontario BioAuto Council was the leading organization in the past decade in promoting and facilitating the greater use of biomaterials in the automotive sector in Ontario, although it is now closed. There have been other programs such as Ontario BioCar Initiative and Southwestern Ontario Bioproducts Innovation Network (SOBIN) to replace automotive parts with biomaterials. These programs are no longer active at present except Auto21 (https://www.auto21.ca), which has the broader mandate of innovation in the Canadian automotive sector.

These programs and initiatives successfully brought all stakeholders together to explore the commercialization potential of bioproducts for automotive applications. However, the market creation has been limited in Ontario, and North America in general. The European automotive sector is ahead of other regions in the world in producing bio-based automotive parts. The German automotive industry has the highest use of natural fibre at 3.6 kg per vehicle (Carus et. al, 2015). Assuming the total annual vehicle production in Ontario is 2 millions, the potential annual biomass demand is 7,200 tonnes, if the average biomaterial usage is similar to that of Germany. Approximately 1,000 acres of miscanthus or 1,500 acres of switchgrass could meet this potential demand.

The competition in North America's automotive industry is extremely tough with significant market share gains by Asian and European automakers. The relatively high cost of biomaterials has been a barrier to its widespread use for automotive parts. Additionally, the automotive industry has stringent standards on performance and consistency on parts. Biomass is perceived as a material with higher quality variance compared to fossil alternatives. Those could be the reasons that the average use of natural fibres in European Union is about 1.9 kg per vehicle, although the goal has been 10 – 15 kg per vehicle. The gradual gain of market share by biomaterials in the automotive sector is expected in coming decades as automotive suppliers such as Magna International Inc are investing in the research and development of bio-based auto parts. Since the transportation sector in Ontario contributes approximately 35% of the provincial total GHG emissions (http://eco.on.ca/wp-content/uploads/2015/07/2015-GHG.pdf), the importance of biomaterial within the transportation sector may become more important as part of the government's climate change strategy. Corporate Average Fuel Economy (CAFE) standard mandates 54.5 mpg by 2025, and lightweight auto parts including the use of natural fibres will be crucial to achieve this standard. Natural fibre composites are on average 25% stronger than wood alternatives (http://www.naturalfibersforautomotive.com/?m=201207).

There are some policy instruments/tools in place in Ontario to promote biomaterials for the automotive and other sectors considered in this study. In terms of technology/commercial push measures, biomaterial research centres and commercialization organizations are operating in the province such as Biomaterials Centres at Trent University and the University of Toronto and Auto21. For indirect market pull measures, Ontario has recently introduced carbon cap and trade plan, and knowledge transfer programs exist. However, there are no direct market pull measures to create biomaterial markets for the transportation/automotive sector. As recent major investments in the automotive sector are in Mexico, it is unlikely that Ontario would create direct market pull measures for bio-based automotive parts. Such direct market pull measures could be considered as investment-unfriendly.

The transportation/automotive sector is, therefore, a market with a small to moderate biomass demand potential. Most policy instruments, except the direct market pull measures, can be employed to promote the use of biomaterials in the sector.

5.1.2 Household/Consumer Sector

More and more environmentally conscious consumers are looking for sustainable products with similar cost and performance. A large array of biomaterials could be made for the household/consumer sector, ranging from flowerpots to coffee cups to sporting goods. Many biomaterials are under research and development or commercialization for this sector. The leading companies with reputable brand names, such as Coca-Cola Company (http://www.bioplasticsmagazine.com/en/news/meldungen/20150604_Coca-Cola.php) or LEGO Group (http://cen.acs.org/articles/93/i26/Lego-Replace-Oil-Based-Plastics.html), could introduce biomaterials into their product streams, since they have reasonable pricing power.

It is difficult to estimate the potential demand for biomaterials from the household/consumer sector, since it is a market for diverse products, and cost is usually a major factor in gaining the market share. Nova Institute (http://www.nova-institut.de/bio/index.php) estimated that a total of 120,000 tonnes of biomaterials (excluding the automotive and construction applications) were produced in the European Union in 2012; this is approximately 240 tonnes of biomaterials per 1 million people. If the same average number is applied to Ontario, the potential biomass demand from the household/consumer sector is about 3,000 tonnes annually, which can be met by less than 500 acres of miscanthus or 750 acres of switchgrass.

The market development for the household/consumer sector has been challenging for biomaterial firms. The severe competition from fossil-based alternatives in cost and performance has been the major barrier to gaining greater market shares for biomaterials. Accessing the financial resources has also been difficult for biomaterial firms since the investment flows to the industries with better attractive returns. The household/consumer sector is, therefore, a biomaterial market with small to moderate biomass demand potential. The policy tools such as carbon cap and trade plan could improve the competitiveness of biomaterials, and the greater market penetration could be seen in coming years. Carbon cap and trade will increase the cost of production for fossil-based products making biomaterials more competitive. Fuel distributors and importers are expected to pay approximately $17.33 per metric tonne of carbon, a cost that will likely get passed onto Ontario plastic manufacturers. This will increase the cost of fuel-based input relative to biomaterials.

The technology/commercialization push and indirect market pull measures exist in Ontario to promote the greater use of biomaterials in the household/consumer sector. The measures are similar to those for the automotive sector, although the automotive sector has received greater focus in Ontario. It is difficult to design the direct market pull measures for the household/consumer sector, since the products are extremely diverse. However, government procurement programs could create direct market pull measures for selected consumer biomaterials, such as office furniture.

5.1.3 Construction/Building Sector

Agricultural biomaterials offer superior properties for selected applications in construction/building sector. The prominent advantages of agricultural biomaterials include better insulation and lightweight. Ontario, as the most populated province in Canada, is the largest potential market in the country for construction biomaterials.

The construction/building sector is the largest market for the bio-composites in European Union (Carus et. al, 2015). Total production of particleboards and MDF in North America in 2012 was 5.37 M m^3 and 3.66 M m^3, respectively (UNECE and FAO, 2013). If 20% of fibreboard used in Ontario is replaced with agricultural fibreboard, the biomass demand will be approximately 50,000 tonnes annually, which would, for example, require about 7,000 acres of miscanthus or 10,500 acres of switchgrass.

Unlike the automotive sector, the construction/building sector has received limited attention from the policy makers and biomaterial industries. Although, the forestry-based biomass poses competition for the agricultural biomaterials, but agricultural biomaterials have better environmental attributes due to their shorter growing cycles compared to the forestry biomass, and nearness of the agricultural firms to the urban areas reduces logistic costs. Thus, the agricultural biomaterial has potential demand from the construction/building sector.

Direct market pull measures could be effectively designed to create agricultural biomaterial market for the sector. The measures can include greater LEED points for the use of agricultural biomaterials in the buildings, government procurement programs, and creation of building codes to promote the use of agricultural biomaterials.

Based on the analysis of this study, the target market sectors for agricultural biomaterials are ranked as follows:

- Construction/building sector
- Household/consumer sector
- Transportation/automotive sector.

The construction/building sector is the potential market with the highest agricultural biomass demand, and the direct market pull measures could be applied most effectively. The analysis of Isoboard Enterprises Inc suggests that Ontario's demand for agricultural fibreboards is likely small for a large commercial plant. This may also be true for other biomaterials. While targeting export markets outside Ontario is worth considering, higher transportation costs and tough competition would likely be encountered. The financial support and other incentives offered by the USDA and other local/federal government programs in the US for biomaterial firms to locate in the US are attractive (see Section 4.1.4 for a comparison), and may reduce competitiveness of Canadian bioproduct imports.

In order to develop domestic biomaterial production facilities with uncertainties in competing at export markets, the strategic approach could be sizing the biomaterial manufacturing facilities to meet local market demand as an initial development stage. This will allow agricultural entrepreneurs to participate in the biomaterial supply chain. Examples of such entrepreneurs in Ontario are Nott Farms (http://www.switchenergycorp.com/SwitchGrass.aspx) and Gildale Farms (http://www.gildalefarms.ca/). The advantages of these agricultural firms include lower overhead costs by integrating with their biomass production. This will likely allow them to compete with imported biomaterials.

5.2 Biomaterial Plant Sizing

The sizing of a biomaterial plant is critical in determining the financial feasibility of the plant. The most influential factors in sizing a biomaterial plant are:

- Demand from the markets intended to serve
- Transportation costs of raw biomass to the plant
- Transportation costs of manufactured biomaterials to the markets
- Ability to compete at the markets away from the plant

The transportation cost is sometimes the most determining factor in locating and sizing the biomaterial plant. The bulky nature of raw biomass often calls for the biomaterial plant to be located within 100 km of the biomass sources. The cost of transporting feedstock could be close to 50% of total feedstock cost at the manufacturing plant gate (Marchand, 2015). Most manufactured biomaterials, especially fibreboards, are also bulky. The location of the biomaterial plant, therefore, should likely be close to the markets. The sizing of the biomaterials should be limited to meet the local demand, if the ability to compete at the markets away from the plant is not strong. However, it should be noted that Over 40% of the world's MDF is now produced in China, feeding the country's rapidly growing furniture industry. In 2012, Canada produced 440,000 cubic metres of MDF—compared to U.S. production of 1.6 million cubic metres (http://www.nrcan.gc.ca/forests/industry/products-applications/15849).

The Isoboard Enterprise Inc., the strawboard producer, established in the province of Manitoba is analyzed as an example. The Isoboard plant was chosen as an example since the fibreboard and non-structural biocomposites have relatively higher potentials for greater biomass demands and represent immediate commercialization opportunities in Ontario. The strawboard plant has yet to be financially viable. The attributes of the strawboard plant are summarized in the box in Figure 5.1. (Sources: http://www.woodworkingnetwork.com/articles/isobord_enterprises_inc_-_wheat_fields_of_dreams_127688668.html, http://forestnet.com/archives/Dec_Jan_99/mill_profile.html, http://agbusinessplans.usask.ca/files/Strawtegic99/Strawtegic%20Case.doc, http://www.sustainable-future.org/futurefibers/solutions.html)

<u>Isoboard Enterprises Inc., Manitoba, Canada</u>

- Capital cost: $ 175 M
- Strawboard production capacity: 130 M sq. ft (0.75" thickness)
- Biomass feedstock at full capacity: 250,000 tonnes/year
- Feedstock cost at $70/tonne (delivered at plant's gate): $ 17.5 M/year
- Revenue at $0.40/sq. ft (delivered at customers' gate): $ 52 M/year

Figure 5.1 Attributes of Isoboard Enterprises Inc., Manitoba, Canada

If agricultural fibreboards can gain 20% of total fibreboard market in Ontario, the demand will be approximately 26 M sq. ft. The demand in Manitoba will be very likely lower than that in Ontario, considering the differences in population and economic activities. The Isoboard Enterprises plant was definitely sized for export markets outside Manitoba. The plant is located close to biomass feedstock, however, is away from major markets, including Ontario and other populated jurisdictions in the US. The transportation cost to the populated jurisdictions will likely make the strawboards less competitive with forestry-based alternatives or locally produced strawboards in those jurisdictions.

5.3 Strategic Approach for Industry Development

The existence of an innovation ecosystem is crucial in developing an industry which would survive and thrive in the long term. As discussed before, the core of the innovation ecosystem is the industry, the manufacturing facilities in the case of biomaterials. The initiation of the strong innovation ecosystem is the establishment of a few manufacturing facilities. Once the industry is rooted, the expansion of industry will follow if all components of the system work in synergy. Based on the assessment of this study, the promising agricultural biomaterial candidates for immediate commercial establishment in the province of Ontario are:

- Fibreboards and
- Non-structural biocomposites.

These biomaterials could be focused in the commercialization-dominated activities to develop the agricultural-based biomaterial industry in Ontario. The existing institutional and regulatory supports can be enhanced to promote the development of manufacturing facilities for fibreboards and non-structural biocomposites. The application of direct market pull measures could be effective policy instruments in creating markets for these biomaterials, especially in the construction/building sector. Other biomaterials and sectors should be assisted as R&D dominated activities, since they represent as future opportunities in Ontario with the growth of the industry cluster. The development of efficient feedstock supply chains requires both comprehensive field research and engagement with all stakeholders.

The strategic approach to accelerate the development of the agricultural biomaterial industry in Ontario is shown in Figure 5.2. The suggested actions are categorized as commercialization and R&D dominated activities.

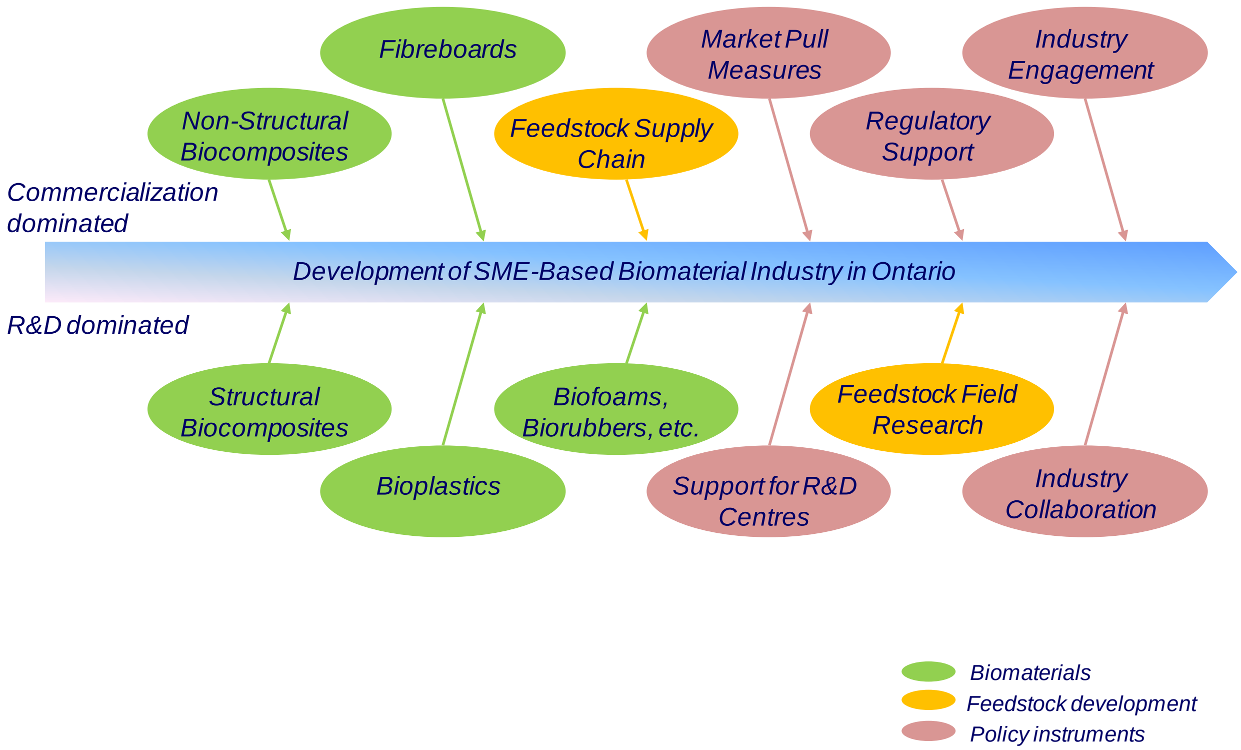

Figure 5.2 Strategic Approaches to Develop an Agricultural Biomaterial Industry in Ontario

The role of the government, as shown in Figure 5.2, is crucial in development of the SME-based biomaterial industry. The government's role extends from regulatory support to market-pull measures and enhancing industry engagement. The policy tools that the government can use to stimulate the biomaterial industry can be segregated by market-push and market-pull measures. The following section discusses these policy measures.

6. Policy Instruments

The government has different policy tools that can be used to address the demand and supply-side challenges confronted by the bioeconomy. The set of policy tools to be used by the government would depend on the availability of resources across the public agencies. The government can develop a policy framework comprising of market-push and market-pull strategies.

6.1 Market-Push Strategies

One of the policy tools in the form market-push strategies is **public funding** in the form of grants and loans/loan guarantees. Both these forms of funding are easy to administer and can be used to improve facilities along the supply chain (Conway and Duncan 2006; Sparling and Cheney 2012; Taylor et al 2005). Grants awarded for investments can range from research and development to construction of biorefineries (Conway and Duncan 2006). Grants have the advantage to incentivize firms as it provides direct support to ongoing activities, are relatively easy to administer and association of grants with labelling programs reduces the expenses associated with monitoring of environmentally beneficial bioproducts making it a feasible option for the bioeconomy (Taylor et al 2005). Grants can also aid in developing biorefinery facilities through partnership between stakeholders (public-private partnership) within the supply chain (Sparling and Cheney 2012). Among many, one of the grants operational in Ontario is Eastern Ontario Development Fund (EODF) which focuses on investing in clean technology businesses. Another fund focused on research and development is New Directions Research Program which provides grants for businesses to develop new and alternative products that diversifies uses of agricultural products. Details of these programs and other programs are discussed in Appendix B.

The other funding tool – loans – can facilitate investments by Canadian bioproduct firms. Existing loan programs make is easier to administer new loans, and the low costs and risk associated with loans for the government makes it a politically feasible policy tool (Taylor et al 2005). The government can further use these loan schemes to enhance skilled workforce by strengthening public and private skills development institutes/projects. Southern Ontario Fund for Investment in Innovation (SOFII) is one of the loan programs which provides loans to businesses for innovation that supports high-growth and innovate small and medium-sized enterprises (SMEs) in rural and urban communities across Southern Ontario (see Appendix B).

Tax credits, another policy instrument, on the other hand can enhance the producers' investment in the supply chain, especially for the first generation of the new production and marketing by decreasing the costs and risk associated in the manufacturing and commercializing new products (Goolsbee 1997; Hall and Jorgenson 1967; Hassett and Metcalf 1995; Conway and Duncan 2006). Ontario's Innovation Tax Credit is available to corporations performing scientific research and experimental development, while Ontario Tax Exemption for Commercialization (OTEC) program encourages commercialization of intellectual property in the area of bioeconomy and clean energy technologies (Appendix B).

6.1.1 Skilled Workforce

The government could also aid in the commercialization ability of biomaterials by enhancing the development of a skilled workforce for the industry. European Union, through Life Science, Marine and Agriculture University Forums, plans to develop bioeconomy curricula and subsidised vocational training schemes. Further, talented EU researchers will be trained to foster the development of bioeconomy, while public procurers will receive specific training on certification schemes and labels of bio-based products to facilitate public procurement (European Commission 2012). At the same time, the U.S. administration allocated Community College to Career Fund and launched Skills for America's Future Initiative in partnership with Aspen Institute to support the bioproduct firms in enhancing skills of workforce; to build link between community colleges and bioproduct firms to develop curricula and programs according to market needs; to develop entrepreneurial skills among students to promote enterprise development in the bioeconomy (The White House 2012).

Ontario has a huge skilled workforce in areas of bioeconomy with its huge network of 44 universities and colleges developing skilled workforce for the industry (NeoBio Consulting, 2004). However, there is a need for specific strategies similar to those of EU and US that is required to be taken by Canada and its provinces to develop the workforce of the bioeconomy. Based on the study by BioTalent Canada, the highest percentage of positions unfilled are in manufacturing, quality control/assurance, distribution and R&D, preclinical research, legal/intellectual property and business development. Overall, the skills shortages are mainly in commercialization and R&D with existing workers lacking industry knowledge. Most of these skills shortages are likely to be filled by individuals having university degree (BioTalent Canada 2009 & 2013). Thus, Canadian bioproduct industry and provinces recommends strategies similar to that EU and US which includes developing a workforce strategy by working with industry and academia to identify and develop the required critical skills of the workforce extending to broad areas of biological processes and environmental management, and developing curriculum specific to the industry skills; recommends recruiting professionals in positions of research, product development and managerial and acknowledges immigration as a priority tool for the bioeconomy (BioteCanada 2009; Yap 2011; Alberta Innovates Bio Solutions 2013; Manitoba Agriculture, Food and Rural Initiatives 2011). In addition to the existing recommendations, a comprehensive human capital strategy incorporating human capital formation, attraction and retention for Canadian bieoconomy is recommended. Public funding in the form of grants should be allocated to facilitate development of training institutes and industry-driven curricula which incorporates the value chain from feedstock production to sales of bioproducts. Grants should be further used to monitor and ensure an overall quality of life in the economic, social, political, health and working conditions of workers which will serve as advantages for attracting and retaining labour in Canada. An improved socio-political coordination between countries will ease the labour migration into Canada, reflecting the need for policy coordination between immigration and bioeconomy development (Chaykowski 2002).

6.1.2 Research and Development

In terms of technology/commercial push measures, biomaterial research centres and commercialization organizations are operating in Ontario. However, entrepreneurs in the Ontario agricultural sector need some assistance in technology acquisition and support through the research institutions such as NRC and BDDC to develop the Small and Medium Enterprises (SMEs) in the biomaterial industry. In terms of the development of biomaterials, which are labelled under research-dominated activities in Figure 5.2, there is a need for nurturing the R&D sector. *Horizon 2020* is the current financial instrument to finance EU's research and innovation in the bioeconomy. *Horizon 2020* is a seven year program from 2014 to 2020 with a total funding of Є80 billion from which Є4.7 billion has been allocated for "Food security, sustainable agriculture, marine and maritime research, and the bioeconomy". The aim of this initiative is to bridge the gap between the research and market as it will assist the enterprises to use the technological breakthroughs to viable commercial end-products. The research and innovation strategy will be the means for the EU to reduce the dependency on fossil resources and thus contribute to achieving its energy and climate change target of 2020 (European Commission, 2012). The U.S. government has taken several initiatives to boost the R&D for the bioeconomy as well. Starting from the Department of Agriculture, there are 13 Federal Departments and Agencies which are associated with R&D for the bioeconomy. In 2011, the U.S. Department of Agriculture (USDA) and Department of Energy's Biomass Program initiated a three to four years project of $30 million to support R&D in advanced biofuels, bioenergy and high-value biobased products. The Coordinated Agricultural Projects with a fund of $136 million was initiated by USDA to support the R&D in bioenergy system through partnership between academia, government and industry. All these initiatives aimed to develop a diverse group of sources for alternative renewable biofuels and biobased products. USA extended its R&D at improving the feedstock used in the bioufuel industry. In 2011, USDA-DOE Plant Feedstock Genomics for Bioenergy Program allocated $12.2 million to invest in research for improving special crops used in biofuel in order to increase the yield, quality and adaptability under extreme environments. The research focused on switchgrass, poplar trees, sorghum, miscanthus and energy cane which has the potential for growth on marginal lands which are not suited for food crops (The White House, 2012). All these research projects have been focused on improving the feedstock and commercialization of the biomaterials, which are necessary across Canada and Ontario.

6.1.3 Infrastructure Development

EU and USA promotes networks with required logistics for integrated and diversified biorefineries with supply chains of biomass and waste streams. These biorefineries will use renewable sources to produce a wide range of bio-based products, which will create new sources of income and jobs for the agriculture, forestry, fisheries and aquaculture sectors (European Commission 2012). U.S. has further allocated funding of around USD 786.5 million of USD 176.5 million for infrastructure support for commercial-scale biorefinery demonstration project of the bioeconomy. US federal government has implemented tax incentive policy to assist and incentivize industry to create and adopt technologies for bioproduct manufacturing. The aim of these projects is to enable private financing of commercial-scale replications (Duchesne and Wetzel 2003; OECD 2013).

Recommendations for Canadian bioeconomy can be drawn from Malaysia as it is becoming the bioeconomy hub of Asia Pacific, and established biofuel industry. Malaysia has developed dedicated bio-hub with supply routes for raw materials and compliance with waste regulations (O'Malley 2013); bioindustrial cluster with lower proximity of feedstock with facility to keep transportation cost low; facilities with central utilities and biomass collection center (Kasim 2013); and a bio-industrial park with centralized utility and shared laboratory spaces between industries (BiotechCorp 2012). The factors considered for developing infrastructure of biofuel industry has certain similarities, and further includes availability of farm storage operations and land for expansion (Stewart and Lambert 2011; Dooley 2008). It is recommended that these features be incorporated in developing an exclusive bioporduct park in Canada. The firms in the park will enjoy benefits in the form of efficient transaction of knowledge, sharing of technology, perceiving and implementing innovations more rapidly, and enhanced access to skilled employees and specialized infrastructure as a part of the cluster similar to Malaysia's BioNexus Partner Program (Porter 2007; BiotechCorp 2014). Networking support to link farm-based SMEs with research institutions, financiers, and potential markets should be introduced to foster the information infrastructure among the value chain actors.

Malaysia's government provides matching grants and soft loan schemes for biotechnology R&D and commercialization ventures, and at the same time attracts Foreign Direct Investments (Loh 2009; BiotechCorp 2012). All these financial instruments are viable options for financing the exclusive park, and can be further extended to public-private partnership venture or implementing investment tax credits. Financing supports in terms of leveraged funding, interest free loan and loan grantee could be of great assistance to the entrepreneurs of biomaterial SMEs in Ontario. Investment tax credit can be another mode of incentivizing producers to invest in the bioproduct industry. Tax credit programs have been successful implemented in Canadian Renewable Conservation Expenses program and thus it a politically feasible program for enhancing bioproduct industry (Taylor et al 2005).

Given that the cost of developing new infrastructure is an important challenge (Carleton Sustainable Energy Research Center 2013), the $135 million plant bio-based succinic acid plant – BioAmber plant in Sarnia, Ontario integrated with LANXESS and reduced capital costs between 25 and 50%. Additionally, industry experts and skilled labour forces of the petro-chemical cluster in Sarnia are invaluable assets to BioAmber in building and operating its plant. Thus, it is recommended that bioproduct facilities integrate with the existing industrial infrastructure, where applicable, to reduce costs.

6.2 Market-pull measures

Market pull measures are effective in developing markets. Government can introduce both indirect and direct market-pull measures within the bioeconomy. For indirect market pull measures, Ontario has recently introduced carbon cap and trade plan, and knowledge transfer programs exist across construction/building, automotive and household/consumer sectors. In addition to these measures, the knowledge transfer program already exists which will allow flow of effective information among the value chain actors in the industry. Since the construction/building sector is a potential sector for agricultural biomaterials, awarding greater LEED points for the use of agricultural biomaterials in the buildings can play important roles as indirect market pull measures.

At the consumer end of the supply chain, government can play a vital role in stimulating the emerging bioproduct market in Canada, especially in the early stages, by incorporating bioproducts in the federal and provincial public procurement process. It is an easy to administer tool but can become onerous due to lack of information (Uyarra and Flanagan 2009; Dalpe 1994; Taylor et al 2005).

Introducing eco-labels with specific standards will resolve the problem associated with lack of information and thus allow both public procurers and individual consumers to make an informed choice. The government can play the role in setting the standard and monitoring the implementation. Although eco-labels need to be verified for compliance with rigid ecological and performance criteria by independent registered bodies making it difficult to administer, positive experiences with existing programs, such as ECOLOGO, make it politically feasible for implementation for the Canadian bioeconomy. The labelling programs needs to be tied with government-led consumer awareness programs for increasing the credibility of both the product and its labels. Since new products are promoted in niche market, awareness programs become cheaper and less onerous (Taylor et al 2005).

6.2.1 Public Procurement

State procurement contracts were most effective in generating innovation than subsidies in R&D, inducing high standards, definition of clear sets of requirements to guide the innovation efforts and increasing competitiveness and cost-efficiency among the firms (Uyarra and Flanagan 2009). Thus, EU incorporated green procurement as a strategy by developing labels, an information list and training for the public procurers to promote the uptake of bioproducts, while encouraging public sector to purchase clean vehicles, including the ones using high biofuel blends (European Commission 2012; Dufey 2006). The US has implemented regulations where federal agencies are required to give preference to qualified bioproducts over traditional products for purchases over $10,000 per fiscal year. Further, the BioPreferred Program provides public purchasers information on 97 different categories of bioproducts representing 14,000 products certified by USDA and universal standard for assessing the biobased contents of the bioproducts (Handfield and Golden 2015; Golden et al 2015). As a result, different departments, like Navy, have replaced existing gasoline, diesel and jet fuels requirements with biofuels (The White House 2012).

Canada also encouraged both federal and provincial government to have procurement schemes for biofuels, which provided initial support for domestic producers in the industry (Laan et al 2009). Canada's existing procurement programs, such as Green Procurement Program, Procurement-Refuelling Stations, have encouraged provincial government to recommend procurement actions for bioproducts which includes i) initiating pilot projects within provincial government for specified bioproducts ii) developing process for comparing bioproducts with traditional counterparts iii) increasing the proportional purchase and use of bioproducts in operation of government departments and agencies iv) encouraging green procurement by the government among the grant recipients and external agencies funded by the government (Taylor et al 2005; Manitoba Agriculture, Food and Rural Initiatives 2011; Alberta Innovates Bio Solutions 2013). Environmental Commissioner of Ontario recommends the set-up of a central government greening office to produce legislations for green procurement, coordinate and implement those regulations at the ministry-level as well as the broader public sector which includes Ontario's municipalities, universities, colleges, school boards, hospitals and health centres. The greening office will also be identify and monitor the indicators for green procurement practices. This will then induce greater market-pull for green products and services (Environmental Commissioner of Ontario 2015). These recommendations provide a strong platform to initiate public procurement of bioproducts within Canada's bioeconomy.

6.2.2 Labelling and Consumer Awareness

Labelling is another market-pull strategy, if implemented, can increase consumer information and consumer confidence and allowing consumers to make informed choice. U.S Department of Agriculture's (USDA) BioPreferred Bioproduct Certification and Labelling Program by labelling 2,200 bioproducts till date is an outstanding example of labelling program in the bioeconomy. The label indicates the product's bio-based content and that its contents have been tested and certified by third-party. The differentiation of competitive products from the bioproducts incentivizes the firms to adopt such labelling programs. Although eco-labels need to be verified for compliance with rigid ecological and performance criteria by independent registered bodies making it difficult to administer, experiences with existing programs make it politically feasible for implementation for the Canadian bioeconomy. Although third-party verification increases costs, benefits realized in combination with public procurement and investment tax credits are greater for labelling. In order to strengthen the effect of labelling, there is need for consumers to be aware of the programs (Handfield and Golden 2015; Taylor et al 2005). The bioproduct industry can also apply Agriculture and Agri-Food Canada's recognized "Canada Brand" which is associated with safe and high-quality products after the bioproduct complies with the necessary parameters of the labelling (Agriculture and Agri-Food Canada 2015).

In the early stages, bioproduct firms target a niche market and creating awareness can then be of less onerous administrative work. Awareness programs combined with labelling programs can realize the environmental benefits of the bioeconomy. Given the fact that awareness programs are less expensive and are associated with low risk, it is politically feasible to introduce such programs (Handfield and Golden 2015; Taylor et al 2005).

6.3 Policy Implementation in Ontario Context

The application of policies for biomaterial firms remains same across the different sectors – construction/building, household/consumer and automotive sector. The government procurement program of biomaterials can play vital roles across all the sectors such as developing buildings (construction/building sector), purchase of office furniture (household/consumer sector) and green cars (automotive sector). However with recent major investments in the automotive sector in Mexico, it is unlikely that Ontario would create direct market pull measures for bio-based automotive parts. Such direct market pull measures could be considered as investment-unfriendly. However, for the construction/building sector, the direct market pull measures could be effectively designed to create agricultural biomaterial market for the sector. The measures can include greater LEED points for the use of agricultural biomaterials in the buildings, government procurement programs, and creation of building codes to promote the use of agricultural biomaterials.

There are some policy instruments/tools in place in Ontario to promote biomaterials. In terms of technology/commercial push measures, biomaterial research centres and commercialization organizations are operating in the province. The stronger commitments from governments would help accelerate the industry development. Direct market pull measures are more effective and can be applied to selected biomaterial market sectors.

Although fibreboards and non-structural biocomposites are identified as the promising biomaterials for immediate commercialization, the research and development efforts for commercializing other biomaterials should continue as seen in Figure 5.2. Although there are some elements of the feedstock supply chain that exist in the agricultural sector, but it needs to be developed further to serve the emerging biomaterial industry, including the best practices in storage and handling. The emergence of the agricultural biomaterial industry could be accelerated with the discussed policy instruments.

6.4 Horizontal Policy Approach

The conventional public administration emphasizes on creation of expertise within a series of departments or agencies facilitating vertical development of the management and accountability functions within each departments (Peach 2004). However, horizontal policy coordination is important as government requires harmonization between agencies and laws in relation to social, trade and financial issues, and cases where there are chances of overlap and duplication among the stakeholders (Task Force on Horizontal Issues 1996). A horizontal policy approach thus will provide the public managers with access to increased resources through combining the budgets, improve their understanding of the multi-dimensional nature of the social problems, and increase trust between agencies by identifying common interests (Peach 2004). Among the different frameworks used globally in horizontal policy making, the Canadian bioeconomy with multiple cross-cutting issues requires the framework which includes a vision, a set of strategic priorities, and guiding principles with an action plan for implementation through coordination of different government departments and is operated through a "single window" or a single funding agreement. This approach reduces the probability of duplication and addresses gaps across programs, and thus harmonizes the processes (Motsi 2004). The horizontal policy approach can be used to synchronize the efforts of policy makers and other stakeholders to connect research with the market of bioeconomy; to allocate funds for human resource development and develop immigration policies for attracting and retaining skilled workers; to prevent duplication of labelling, strengthen the cost-effectiveness of labelling through integration with other established eco-labelling programs and developing consumer awareness.

7. Summary, Conclusion and Recommendations

The development of the agricultural-based biomaterial industry in Ontario is investigated with an overarching goal of formulating strategies to accelerate the industry establishment. The specific characteristics of the agricultural sector and the availability of current and potential biomass feedstock are reviewed. The technology and market development status of selected biomaterials are analyzed, and promising biomaterials for immediate commercial establishment in Ontario are identified. The policy instruments to promote the biomaterial industry are examined and compared with those in other jurisdictions. The influential factors in commercializing biomaterials and barriers are also reviewed, and the evaluation matrix to screen the biomaterials/firms is developed. The strategic approach to accelerate the industry development is proposed with the prioritized market sectors and biomaterials.

7.1 Summary of Findings and Conclusion

Ontario's agricultural sector can readily meet the potential biomass demand of the emerging biomaterial industry. Miscanthus and switchgrass are proven purpose-grown biomass crops in Ontario at commercial scales, and they are potential feedstock for the emerging biomaterials industry. Approximately 3 million tonnes of purpose-grown biomass can be sustainably produced from 0.5 million acres, which is less than 6% of total cropland in Ontario, at current average yields. Additionally crop residues such as wheat straw and cornstalks could also be used as biomass feedstock, although the sustainable removal of crop residues requires further field research at present. A total of 6 million tonnes of biomass could be available annually in Ontario for the biomaterials industry. The price of biomass could range $ 60 – 150 per tonne, depending on crops/residues. Considering that the total biocomposites produced in Europe in 2012 were 352,000 tonne, it can be stated that Ontario has sufficient biomass supply for the emerging biomaterials industry.

The current technology and commercialization status of a number of biomaterials are reviewed. Bioplastics and biopolymers can be produced with fairly mature technologies. Although their market penetration is limited at present, the growth in market share is expected to be significant in coming decades. The major industry expansions of bioplastics and biopolymers are forecasted to be in Asia and South America where large markets exist and competitive sugar crops are available. The competitive edge of potential bioplastics and biopolymers in Ontario is likely not strong. The technology and market development of biofoams and biorubbers are similar to those of bioplastics and biopolymers. Structural biocomposites need further technology development, and the agricultural fibres used for the structural biocomposites are not grown as major crops in Ontario.

Non-structural biocomposites and fibreboards are promising candidates for commercial establishments in developing the agricultural-based biomaterial industry in Ontario. Technologies for producing non-structural biocomposites and fibreboards are well-developed, and potential markets, especially automotive and construction sectors, exist with greater biomass feedstock requirement. Due to the bulky nature of these biomaterials and associated logistic costs, the manufacturing plants sized for local demands could be competitive.

The influential factors in commercializing biomaterials are identified through industry analysis and consultation with industry experts. These factors are biomass feedstock, technology maturity, profitability, competition with substitutes and existing value chain/infrastructure. For instance, risks associated with feedstock depend on whether the crops is commercially grown and commoditized, and is a prominent factor in assessing the feasibility of the biomaterial. The major barriers to commercialization are lack of regulatory support, financial resources and an innovation ecosystem. The industry should be at the core of the innovation ecosystem to ensure the long-term prosperity of the sector. This central component, the industry, will provide information and tasks to its upstream and downstream components of the innovation ecosystem. The initial establishments of a few biomaterial firms, large or small, are essential to develop a functioning innovation ecosystem. The biomaterial industry will then likely expand with continued and sustained innovations.

Based on the influential factors in commercialization and barriers to the industry establishment discussed above, the evaluation matrix is developed to examine the potential of a biomaterial or firm in Ontario. The important parameters selected for the evaluation matrix are feedstock compatibility, technology maturity, profitability, economic development potential, competition with substitutes, regulatory and institutional support and existing value chain infrastructure. The weightings are assigned to the evaluation parameters. Although all evaluation parameters are important, feedstock compatibility, profitability and ability to compete with substitutes are considered as the most critical for financial feasibility. Many jurisdictions in North America are providing financial and other supports to potential bioproducts firms to attract the investment and create jobs. This evaluation matrix offers as a tool to screen the potential biomaterial firms in considering the level of governments' support.

The fundamental reason for regulatory support as a major barrier for commercialization of agricultural biomaterials industry is the lack of bioeconomy policies of federal government in Canada. But it is important to note that some provinces in Canada have developed policies to regulate their bioeconomy. The US, on the federal level, has the most developed bioproducts policies. However due to the wide scope of its definition, the bioproducts sector includes a strong focus on pharmaceutical and biofuels, leaving little focus on biomaterials made from agriculturally-sourced material. In the EU, however, there is a strong focus on linking agricultural-sector to bioproducts development. Both EU and US have most of their resources targeted toward funding research and development, with the US a little stronger on providing resources on fostering commercialization of the bioproducts. This report used policies of the bioeconomy from USA and EU to identify the policies available for the Canadian bioeconomy. The policies have been used to address the supply and demand-side challenges within the Canadian bioeconomy. Some of the policy measures for Ontario would include introducing investment tax credits, expenditure in developing skilled workforce, research and development, and infrastructure. The market-pull measures would include cap and trade plans, and public procurement.

Three target markets of biomaterials are analyzed from biomass demand. These markets are transportation/automotive sector, household/consumer sector and construction/building sector. The potential annual biomass demand in short to medium terms from the transportation/automotive and household/consumer sectors are 7,200 tonnes and 3,000 tonnes, respectively. Most policy instruments can be employed to promote the use of biomaterials in the transportation/automotive and household/consumer sectors. The construction/building sector is the promising agricultural biomaterial market with moderate biomass demand potential of 50,000 tonnes annually.

The strategic approach for immediate commercial establishments with subsequent creation of an innovation ecosystem should focus on priorities. This study suggests non-structural biocomposites and fibreboards as prioritized biomaterials with the construction/building sector as the prioritized market. With uncertainties in competing at export markets, the strategy could be sizing the biomaterial manufacturing facilities to meet the local markets as an initial development stage. This will allow the agricultural entrepreneurs to participate form the feedstock suppliers to value-adding levels in the biomaterial supply chain. Nott Farms (http://www.switchenergycorp.com/)and Gildale Farms (http://www.gildalefarms.ca/) are examples of the agricultural entrepreneurs in Ontario. The advantages of these agricultural entrepreneurs include lower overhead costs by integrating with their biomass production. This will likely allow them to compete with imported biomaterials.

7.2 General Recommendations

The emergence of the biomaterial industry in Ontario will require the concerted efforts by all stakeholders. The following general recommendations are suggested:

- The creation of clear directions, visions, policies and strong commitments from the governments are recommended. Better coordination among federal and provincial ministries/organizations is required to implement the commercialization programs effectively. The agricultural biomaterials face tough competition from its fossil-based alternatives. The regulatory and institutional supports are essential to initiate the industry establishment.

- Non-structural biocomposites and fibreboards targeting the construction/building sector should be considered as prioritized opportunities for immediate commercialization in Ontario.

- The entrepreneurs in Ontario's agricultural sector are potential manufacturers of biomaterials, and they should be provided with necessary assistances. With uncertainties in competing at export markets, the strategy could be sizing the biomaterial manufacturing facilities to meet the local markets as an initial development stage.

- Direct market pull measures should be explored to create markets for agricultural biomaterials. The construction/building offer considerable opportunities for those measures such as government procurement programs and incentives.

- The development of an innovation ecosystem for the biomaterial industry is recommended. The industry should be at the core of the innovation ecosystem to ensure the long term prosperity of the sector. The initial establishments of a few biomaterial firms, large or small, are crucial in developing a functioning innovation ecosystem. Once the industry is rooted, it will then likely expand if there is a healthy innovation ecosystem.

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Appendix A – List of Biomaterial Firms in Ontario

Name of Firm	Website/Contact
Advanced Micropolymers Inc	www.ampolymers.com
Advanced Polysaccharide Technologies Ltd.	apt-Canada@hotmail.com
Axcelon Biopolymers Corp	www.axcelonbp.com
AOC Resins	www.aoc-resins.com
Bi-Ax International Inc.	www.evlon.ca bharrow@biaxinc.com
Canadian General- Tower Limited	www.cgtower.com
Centre for Research and Innovation in the BioEconomy (CRIBE)	lorne.morrow@cribe.ca www.cribe.ca
Competitive Green technologies, Leamington	www.competitivegreentechnologies.com
Dixon Ticonderoga	www.dixonticonderoga.com
DuPont	www.dupont.com
Eco-synthetix	www.ecosynthetix.com
Flakeboard	www.flakeboard.com
Gallimore Healthcare Disposables	www.ghidisposables.com/index.html
GreenCore Composites	www.greencorenfc.com
Harco Plastics	www.harcoplastics.com
Interface Canada Inc.	www.interfaceflor.ca
Icynene Inc.	easterncdnsales@icynene.com
Lorama	www.lorama.com
Magno Decoma	www.magna.com
Naturpack	www.naturpack.ca
Norbord	www.norbord.com
Ontario Straw Bale Building Coalition	www.osbbc.ca
PolyOne	www.polyone.com/en-us/Pages/default.aspx
The Woodbridge Group	www.woodbridgegroup.com
Trivium Industries	www.triviumindustries.com
W. Ralston (Canada) Inc.	www.cttgroup.com
Wellington Polymer Tech. Inc	www.enviroshake.com
OMTEC Inc.	www.omtecinc.ca

Appendix B – List of Funding Programs Available in Ontario/Canada for Biomaterial Firms

Program Name	Description	Funding/ Incentives Details
The Jobs and Prosperity Fund https://www.ontario.ca/page/jobs-and-prosperity-fund	Four streams, companies are eligible to apply for: **New Economy stream**. helps private sector organizations: build innovation capacity, improve productivity, performance and competitiveness, expand export and trade opportunities, increase job creation capacity **Food and Beverage growth fund.** provides funding for food, beverage and bioproduct projects across the province with more than $5 million in eligible costs **The Strategic Partnership stream:** provides funding for industry partners that develop enabling technologies for Ontario's priority sectors. This stream is available for partnerships with at least $10 million in eligible costs. **Forestry Growth Fund**: fund is available to manufacturers and processors of wood and forest biomass across Ontario, including saw mills, pulp and paper mills, secondary wood manufacturing, and bio-economy projects with at least $5 million in eligible costs	Companies could receive a grant of up to 20%, a loan of up to 40%, or a combination of grants and loans up to 40% of eligible project costs.
Eastern Ontario Development Fund (EODF) Ontario Ministry of Economic Development, Employment and Infrastructure www.ontario.ca/easternfund	A grant program to help businesses create new jobs and invest in new technologies (e.g. clean technologies, life sciences), equipment or skills training for workers; that will attract or retain investment in Eastern Ontario. A company should employ at least 10 people (FTEs). Businesses that invest $500,000 or more in qualified projects that create at least 10 jobs over five years are eligible.	Individual businesses can receive up to fifteen per cent (15%) of total expenditures to a maximum grant of $1.5 million per approved project.
Market Readiness Program	The Market Readiness Program directly funds early-stage	OCE investment at the Customer

Ontario Centre for Excellence (OCE) www.oce-ontario.org/programs/commercialization-programs/market-readiness/how-it-works	commercialization by start-up companies. The ultimate goal of the program is to support the growth of start-ups into scalable businesses	Creation Stage can range between \$100,000 - \$125,000; at the Company Building Stage OCE can invest \$250,000 per application
New Directions Research Program Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) www.omafra.gov.on.ca/english/research/new_directions/index.html	The purpose of the New Directions Research Program is to stimulate the sustainable growth and competitiveness of Ontario's agri-food and agri-business sectors, and to strengthen rural communities. The development of new and alternative products provides potential to increase the diversification of agriculture. New knowledge and new technologies help Ontario's agri-food and agri-business sectors address challenges, expand market opportunities at home and abroad, and support thriving rural communities. It is a flexible program with limited funding amount. Therefore, only 2-3 research priority areas are selected for the annual call for proposal that may or may not include bioeconomy. The research fund is open to universities, research institutes, industry, governments, organizations or partnership networks.	Grant up to \$200,000 per project for the entire project duration.
Northern Ontario Heritage Fund Corporation (NOHFC) Ontario Ministry of Northern Development and Mines nohfc.ca/en/programs	The NOHFC offers five programs: the Strategic Economic Infrastructure Program the Northern Community Capacity Building Program the Northern Innovation Program the Northern Business Opportunity Program and the Northern Ontario Internship Program	NOHFC funding assistance and varies for different programs. Applications are accepted ongoing.

	NOHFC programs focus on the growth of the existing and emerging sectors, such as advanced manufacturing, agriculture, aquaculture and food processing, renewable energy and services, water technologies and services.	
Ontario Emerging Technologies Fund (OETF) Ontario Capital Growth Corporation (OCGC) www.ocgc.gov.on.ca/site/en/funds/ontario-emerging-technologies-fund/	The Ontario Emerging Technologies Fund is a $250 million direct investment fund that co-invests alongside Qualified Investors into innovative, high-growth, private, Ontario companies in three key sectors: Clean technologies Life sciences and Advanced health technologies The Fund is managed by the Ontario Capital Growth Corporation (OCGC), an agency of the Ontario Ministry of Research and Innovation	OCGC initial investment in an investment company is maximum $5 million and does not exceed $25 million in the life time of the investment.
Ontario Innovation Tax Credit Ontario Ministry of Finance www.fin.gov.on.ca/en/credit/oitc/index.html financecommunications.fin@ontario.ca	The Ontario Innovation Tax Credit (OITC) is a refundable tax credit. It is available to all corporations that perform scientific research and experimental development (SR&ED) in Ontario. The Canada Revenue Agency (CRA) administers the program on behalf of Ontario through the federal income tax system.	The OITC is calculated as 10% of qualifying SR&ED expenses. Qualifying expenses are: The maximum annual credit is $300,000.
Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and University of Guelph research agreement Ontario Ministry of Agriculture and Food and the Ministry of Rural Affairs (OMAFRA)	OMAFRA/University of Guelph partnership funds in seven research themes that include Bioeconomy-Industrial Uses, Environmental Sustainability, Production Systems, Agricultural Policy and Rural Development, Food for Health, Product Development and Enhancement through the Value Chain Collaborations and Emergency Management. Other universities, corporations, research institutes, all levels of governments, and rural organizations may	Grant may vary depending on the theme between $80,000 to $150,000 per project per year

	partner with the University of Guelph for this funding, but the principal researcher must be from the University of Guelph	
Ontario Network of Excellence (ONE) Ontario Ministry of Research and Innovation www.uoguelph.ca/research/omafra/	The Ontario Network of Excellence (ONE) is a collaborative network of organizations across Ontario, designed to connect innovators, technology-based businesses, entrepreneurs and researchers with services and programs to help then innovate and gain a competitive advantage.	Funding available under ONE research and commercialization programs varies.
Ontario Tax Exemption for Commercialization (OTEC) Ministry of Research and Innovation www.fin.gov.on.ca/en/credit/otec/	OTEC is aimed at supporting innovation in Ontario's economy by encouraging the commercialization of intellectual property developed by qualifying Canadian universities or colleges including in the area of bioeconomy and clean energy technologies.	Qualifying corporations can claim a refund for provincial income tax and corporate minimum tax paid for each of their first ten taxation years after incorporation.
The Ontario Research and Development Tax Credit (ORDTC) Ontario Ministry of Finance www.cra-arc.gc.ca/tx/bsnss/tpcs/crprtns/prv/on/rd-eng.html	The Ontario Innovation Tax Credit (OITC) is a refundable tax credit. It is available to all corporations that perform scientific research and experimental development (SR&ED) in Ontario. The Canada Revenue Agency (CRA) administers the program on behalf of Ontario through the federal income tax system.	The amount of the non-refundable credit is equal to 4.5% of eligible expenditures incurred by a corporation in a tax year. The credit may be applied to reduce Ontario corporate income tax that you would otherwise have to pay. An unused credit can be carried back 3 years and can be carried forward 20 years.
Ontario Venture Capital Fund (OVCF) Ontario Capital Growth Corporation (OCGC)	The $205 million Ontario Venture Capital Fund (OVCF) is a joint initiative between the Government of Ontario and leading institutional investors to invest primarily in Ontario-based and Ontario-focused venture capital and	OVCF is structured as a fund of funds with the primary objective of generating attractive returns for its investors.

www.ovcf.com	growth equity funds that support innovative, high growth companies. Ontario has committed $90 million to the fund, with the balance coming from partner institutions. The OVCF is managed by Northleaf Capital	
The Rural Economic Development (RED) Program Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) www.omafra.gov.on.ca/english/rural/red/	The Rural Economic Development Program provides funding for projects that help rural communities and regions build a foundation for economic growth and investment The RED Program has two project streams: Planning Stream: Implementation Stream Eligible applicants must be a legal entity and the applicants must: Demonstrate how the project will benefit rural Ontario Not have other provincial government funding for the project Provide financial funding to the project Have the experience and knowledge to complete the project	RED projects are cost-shared, with the provincial government investing up to 50 per cent of the project's eligible cost, or up to 90 per cent in limited circumstances.
Canadian Agricultural Adaptation Program (CAAP) Agricultural Adaptation Council (AAC)/ Agriculture and Agri-Food Canada (AAFC) www.agr.gc.ca/eng/?id=1396016168338	The Canadian Agricultural Adaptation Program (CAAP) is a five-year (2014-2019), $50.3 million program providing non-repayable contributions for industry-led projects that help the agriculture, agri-food, and agri-based products sector to adapt and remain competitive. The fund enhances the agri-food, and agri-based products sector's ability to seize opportunities, to respond to new and emerging issues, and to pathfind and pilot solutions to new and ongoing issues in order to help it adapt and remain competitive. Applicants must be Canadian legal entities; organizations	Funding for each project will generally not exceed $1 million and up to $4 million over 5 years.

	and associations, cooperatives, marketing boards, aboriginal groups, for-profit companies and individuals.	
Growing Forward 2 (GF2) ontario.ca/growingforward2	Growing Forward 2 (GF2) is a comprehensive federal-provincial-territorial initiative aimed at encouraging innovation, competitiveness and market development in Canada's agri-food and agri-products sector. In Ontario, the federal and provincial governments are investing $417 million over five years (2013-2018) to help agri-food and bio-product processors, organizations and collaborations grow their profits, expand markets and manage risks.	Businesses can apply for cost-share funding for skills development, training, assessments and implementation that align with six areas of focus. Innovation is a key component present throughout all areas of focus. Individual businesses are eligible to receive a cumulative total of $350,000, and organizations and collaborations are eligible to receive up to $3 million over the life of GF2.
AgriInnovation Program Agriculture and Agri-Food Canada www.agr.gc.ca/eng/?id=135430 1302625	The AgriInnovation Program supports funding under two streams. Industry-Led Research and Development-supports pre-commercialization research, development and knowledge transfer leading to innovative agriculture, agri-food and agri-based practices, processes and products. Enabling Commercialization and Adoption- support for pre-commercial to fully commercial products and services.	The total maximum contribution to an applicant from all streams under the AgriInnovation Program cannot exceed $10 million per year.
The Industrial Biomaterials Program National Research Council Canada www.nrc-cnrc.gc.ca/eng/news/releases/2	The Industrial Biomaterials program is a $55-million initiative over five years from 2013, for Canadian firms transform agricultural and forestry by-products to create new industrial materials	NRC scientists works with key collaborators from across the biomaterials supply chain to develop high quality, sustainable and cost-effective non-food biomass-based materials

013/industrialbiomaterials_nr.html?wt.mc_id=fn_releases		
Industrial Research Assistance Program (IRAP) National Research Council (NRC) www.nrc-cnrc.gc.ca/irap-pari	The Industrial Research Assistance Program (IRAP) helps Canadian small and medium-sized enterprises (SMEs) develop innovative technologies and successfully commercialize them in a global marketplace by providing technical and business advisory services and financial assistance. Canadian small or medium-sized incorporated business (500 employees or less) are eligible for support	IRAP provides financial support for research and development activities on cost-shared basis to qualified small and medium-sized enterprises in Canada to help them develop technologies for competitive advantage
Investing in Business Innovation FedDev Ontario www.feddevontario.gc.ca/eic/site/723.nsf/eng/h_00324.html	Investing in Business Innovation provides funding to boost private sector investment in start-up businesses to accelerate the development of new products, processes and practices and bring them to market faster to further develop southern Ontario's economy. Start-up businesses, having 50 employees or less, located in southern Ontario that are planning to undertake commercialization activities and have a signed draft term sheet from a recognized angel or venture capital investor can apply. Incorporated not-for-profit angel investor networks located or representing angel investors in southern Ontario.	Start-up businesses will be eligible for repayable contributions up to $1 million (33⅓ percent) of total eligible and supported project costs. Angel investor network applicants (not-for-profit) may request one-time non-repayable funding of up to $50,000 to help them attract new investors. Organizations representing so angel networks may request non-repayable funding of up to $2 million to support investment attraction.
Scientific Research Experimental Development Tax Incentive Program (SR&ED) Canada Revenue Agency (CRA) www.cra-arc.gc.ca/txcrdt/sred-rsde/bts-eng.html	The Scientific Research and Experimental Development (SR&ED) program is a federal tax incentive program to encourage Canadian businesses of all sizes and in all sectors to conduct research and development (R & D) in Canada that will lead to new, improved, or technologically advanced products or processes. In general, work that qualifies for SR&ED includes,	Canadian controlled private corporations (CCPC) can earn an investment tax credit (ITC) of 35% up to the first $3 million of qualified expenditures for SR&ED carried out in Canada, and 20% on any excess amount.

	experimental development, basic research, applied research, and support work.	A CCPC can also earn a 15% non-refundable ITC on any amount over that threshold.
Southern Ontario Fund for Investment in Innovation (SOFII) FedDev Ontario www.sofii.ca	The Southern Ontario Fund for Investment in Innovation (SOFII)) supports high-growth, innovative small and medium-sized enterprises (SMEs) (SMEs) in rural and urban communities across Southern Ontario.	Repayable loans of $150,000 to $500,000 are available, on a matching basis.

Useful links for Government funding/grants/loans/incentives.

1. AgPal Program and Service Finder http://www.agpal.ca/#QHIxMEBhMjJ8YTIzfGEyNHxhMjFcXA
2. Ontario Government: Select government programs for businesses http://www.investinontario.com/incentive-programs-and-services
3. Ontario Ministry of Agriculture, Food, and Rural Affairs www.omafra.gov.on.ca/english/research/programfundingindex.htm
4. Ontario Ministry of Finance Revenue – Credits, Benefits and Incentives; www.rev.gov.on.ca/en/credit/index.html
5. Agriculture and Agi-Food Canada- Programs and Services; http://www.agr.gc.ca/eng/programs-and-services/list-of-programs-and-services/?id=1362151577626
6. Canada Business – Government grants, loans and financing www.canadabusiness.ca/eng/82/149/