BIOPRODUCTS FROM CANADA'S FORESTS

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New Partnerships in the Bioeconomy

by

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Preface

Highlights and Fast Facts

- This book presents an overview and a vision of bioproducts, specifically as they apply to the forestry sector.
- Bioproducts are commodities that are derived from biomass. Biomass is any type of microbial, plant or organic material (both new and waste) that is available on a renewable or recurring basis.
- Bioproducts include a broad range of commodities with applications to markets such as energy, transportation, chemicals, plastics, foods and food products, pharmaceuticals, nutraceuticals, and various other consumer goods.
- The bioproducts industry is a natural extension of the forestry, non-timber forest products, biotechnology, agricultural, marine, materials and manufacturing industries. Bioproducts from these sectors will form the new bioeconomy; a market of $100 billion[1].
- The bioeconomy has the potential to stimulate employment and generate wealth in rural and First Nation communities.
- Because the bioproduct industry generates commodities from renewable biomass and wastes instead of fossil fuels, it is often viewed as "green", with the potential of significantly reducing greenhouse gas emissions.
- More investment is needed by industry and governments to stimulate Canada's bioeconomy, to advance biomass as a sustainable alternative to petroleum resources, and to raise awareness of the potential economic, environmental and social benefits of bioproducts.

[1] Unless otherwise stated, all monetary values are reported in Canadian dollars.

In Canada the bioeconomy is expected to generate as much innovation and prosperity as the information technology and energy sectors combined. It will impact most of Canada's economic sectors: energy and transportation, food and agro-food, pharmaceuticals, nutraceuticals, forestry, materials and manufacturing, waste management and a large variety of consumer goods.

The bioeconomy holds promise to wean the Canadian economy from its dependence on fossil fuels as a primary source of energy, as well as platform chemicals in materials and manufacturing, while potentially helping meet Kyoto Protocol commitments on greenhouse gas (GHG) reductions. The bioeconomy also shows potential for reducing the environmental impact of economic activities by increasing the productive use of waste byproducts and developing goods that are biodegradable. Inroads in biotechnology, chemical engineering and an increase in consumer demand for "green" products are added incentives for the expansion of the bioproducts sector in Canada.

Canada is home to 7 percent of the Earth's landmass, 10 percent of its forests, large tracts of arable cropland (over 60 million hectares), 15 percent of the world's fresh water, and is bounded by the world's longest coastline. Coupled with a small population (0.5% of global), this gives Canada a unique resource advantage over most other nations in the world.

Canada's potential for producing biomass feedstocks for energy and other bioproducts is very large and mostly untapped. It is one of the few countries in the world that can rely on supplying a high portion of its own energy needs from biomass, currently meeting about 6 percent of its total needs from this source.

History shows clearly that the availability of cost-effective sources of energy is a critical determinant of economic growth. The world's current decreasing proven reserves and rising costs of non-renewable fossil fuels, along with the need to improve environmental performance, are a challenge for many sectors of the Canadian economy. Commercialization of new and more cost-effective technologies and products in our traditional resource sectors could diversify both markets and energy sources, while boosting rural economies, maintaining our existing industrial infrastructure and stimulating energy independence of northern communities.

In advancing the bioeconomy we are mindful not to create competition with other sectors of the economy. Forests are Canada's greatest source of renewable biomass, and as such are already a primary pillar of the economy, along with the agricultural and marine sectors. Most of the country's biomass production takes place in forests and supports the forest industry as Canada's most productive forests and ecosystems are dedicated to industrial forestry.

In practice, it would make no economic, social or political sense to compete with this industry in support of the bioeconomy. However, there is potentially an estimated 280 million tonnes of forest biomass available for production without interfering with current forestry operations (discussed in Chapter1). A *Primer on Bioproducts*, produced in 2004 by two Canadian Environmental Non-Governmental Organizations, Pollution Probe and the BIOCAP Canada Foundation, concludes that as much as 27 percent of Canada's fossil fuel use could now be supplied from currently underused residue biomass in Canada's forestry and farming operations (crop and animal remains, tree branches, mill waste), from marine residues and from municipal solid waste. A further 25 percent increase in today's tree and crop production could meet an additional 15 percent of the energy demand now being filled by fossil fuels.

Biomass alone isn't sufficient to meet all of Canada's energy needs. Moreover, ecological considerations may restrict biomass availability. Fortunately, its use is compatible with other renewable energy sources. Because it yields liquid fuels that can be stored inexpensively and chemicals that can be used to manufacture durable goods, biomass is highly complementary to hydro, wind and solar energy, which generates instant electrical energy but whose storage is costly.

As new techniques come into commercial application, the cellulose in forest biomass, a potentially much larger and environmentally sustainable resource than agricultural crops such as corn or grain, will become usable as a feedstock for the provision of ethanol and other industrial bioproducts.

In fact, Canada's biomass resources can potentially generate as much as $100 billion annually by providing the feedstock to produce energy, chemicals and materials, including hydrogen, ethanol, methane, pharmaceuticals, nutraceuticals, and bioplastics, as well as a large variety of biobased consumer goods.

In turn, this new industry has the potential, with participation from all stakeholders, to generate value-added opportunities and prosperity in rural and First Nation communities by drawing on their cultural traditions and creating employment in biomass-rich parts of the country. Governments, in turn, benefit through creation of fiscal revenues and reduced social problems associated with idle workforces. The private sector benefits through new business opportunities either to supplement current operations or as new stand-alone businesses.

A biobased economy can provide a solution to waste management. Energy in the form of carbon from wastes such as pulp residues, municipal carbonaceous material including waste wood and logging residues, can be harnessed to do work before they enter the carbon stream and add to GHG emissions. Furthermore, biomass can provide an alternative energy source for isolated communities that lack the infrastructure and access to fossil fuels, natural gas and electricity. While sensible on a community level, biomass can also provide increasingly important energy security at the national and regional levels.

The writing is on the wall. Car engines will be modified to reduce greenhouse gas and other emissions within the next ten to fifteen years. The large automakers are aggressively researching and developing technologies that will be both practical and inexpensive to replace the gasoline engine. Hydrogen fuel cells are perceived to be an ideal mechanism for energy storage, as its only combustion by-product is water. Currently, natural gas is the most economical source of hydrogen. Forest biomass, however, either as waste byproducts or dedicated biomass, may potentially become the primary source of hydrogen in the future. Indeed, there is evidence that a cord of wood can generate enough hydrogen to propel a hydrogen car for a year. In the more immediate future, there is a need to provide ethanol for blended gasoline, now mandated in several Canadian provinces.

Biomass has the potential to replace many valuable industrial chemicals currently made from non-renewable feedstocks. Platform chemicals are feedstock chemicals with a variety of different uses (see discussion in Chapter 3). Two platform chemicals becoming more important to society are Polylactic Acid (PLA) and Levulinic Acid (LA). Both can be produced from renewable resources like starch crops (corn, potatoes, rice) and cellulosic residues such as logging waste, agricultural waste, and solid municipal waste. This is sometimes referred to as "green chemistry". Both PLA and LA have a wide variety of uses, somewhere between 100-200 potential industrial applications. As a platform chemical, PLA alone currently has market potential in the magnitude of US $10 billion. These two platform bio-chemicals could significantly reduce greenhouse gas emissions, as well as the amount of waste sent to municipal landfills, while increasing profits for rural communities in terms of agriculture and forestry. What about genetically engineered plants that produce plastic monomers? These, too, will play a critical role in the bioeconomy.

Potential problems with accessibility of the resource, competition for woody residues of good quality such as sawdust and shavings by stable secondary industries and ecological questions of removing significant amounts of woody residues, and thereby nutrients, off site will compel innovative techniques to supply a steady feedstock of biomass. Agroforestry (Chapter 4) may well be the key solution for inevitable feedstock shortages. Advances in biotechnology in developing trees with desired traits and planting of marginal farmlands and associated carbon sink potential, ensure agroforestry as a critical provider of goods (both biomass and other bioproducts) of the bioeconomy.

Canada's diverse forest ecosystems have provided nutritious foods to the inhabitants of this land since time immemorial. Some of these foods have become major commodities today while others have largely been supplanted in the market by other crops. Forest foods contribute close to $1 billion in revenue to the Canadian economy (Chapter 5). This potentially lucrative and abundant forest-based food sector could become yet another sustainable source of bioproduct development, including community economic development opportunities, where forest inhabitants can benefit from enhanced access to and production of local forest foods.

Forest bioproducts can also develop in response to changing consumer attitudes and habits. World demand for functional foods and nutraceuticals is estimated at $56 billion and increasing rapidly. Canadian demand is estimated to be in the $1-2 billion range (Chapter 6). This demand is expected to increase with an ageing population that embraces the health benefits of natural products.

The demand for medicinal plants by the pharmaceutical industry is increasing significantly with an estimated 25 percent of prescription drugs in the *US* containing plant extracts or active principles prepared from forest plants. The worldwide industry and potential national and international markets for plant-derived drugs is already worth over US $40 billion (Chapter 7). Since many of our modern medicines have been derived from plants, and since so few plants have been fully investigated, it stands to reason that there are many more beneficial medicines yet to be discovered, with the potential to positively impact the future health of Canadians and the world population at large. Given mutually acceptable sharing of intellectual property, opportunities exist for collaboration with First Nation communities regarding traditional uses of medicinal plants as a means for aiding in the discovery of new forest plant-derived drugs.

More traditional bioproducts (interchangeably also called non-timber forest products, or NTFPs) include ornamental forest bioproducts such as Christmas trees, floral and greenery decorations, and arts and crafts. Although they do not contribute substantially to the gross domestic product, they have significant local impact. The current market for decorative and aesthetic products is roughly $175 million, Christmas trees and salal being the most important (Chapter 8).

Non-consumable values of the forest, generally included in discussions on non-timber values of the forest, such as nature viewing, hunting and fishing continue to be popular activities in Canada. While not tangible bioproducts per se, these activities and values must be considered when assessing the various demands on forested lands. Canadians spend upwards of $11 billion/year on nature-related activities, with the American visitors contributing another $700 million in revenues (Chapter 9). Wild fur trapping, although a shadow of the former industry that led to the exploration of Canada's lands, still contributes $23 million and the fur industry alone provides employment for 68, 000 Canadians.

If forested lands are to succeed as a major support of the bioeconomy, they must be protected from their greatest threats, forest pests. Public pressure is requiring the use of more biological pesticides, which are perceived as safer than the conventional chemical pesticides. Research, aided by the powerful tool of biotechnology, is aggressively targeting the development of biological pesticides, as well as the propagation of trees with selected traits for pest tolerance, increased yield, decreased lignin content, disease tolerance and cold- or drought-hardiness (Chapter 10).

Biotechnology is a critical component of the bioproducts sector and holds the key to enhancing the production of the biomass needed as feedstock for energy production, platform chemicals, and natural fibers. Environmental benefits of these biotechnology applications could include alleviating pressures on old-growth forests through enhanced establishment of agroforestry systems, a reduction in chemical pest-control through the use of target-specific biological pest control products, reduction in chemicals used in pulp and paper processing, and the conversion of formerly wasted residues to create useful products (Chapter 11).

The potential carbon sequestration value of Canadian forests is a popular and valuable short-term non-consumable "bioproduct" (Chapter 12). Forest carbon trading can be used to offset Canada's Kyoto target of reducing greenhouse gas emissions by 6% below 1990 levels and is among the least costly and most immediately available options for offsetting carbon emissions. The expertise certainly exists to manage such forest carbon projects, and emission credits can be generated at low cost which add value and diversify existing investments. Afforestation, reforestation and forest management activities, and the generation of forest carbon credits have the potential to underwrite some of the costs of shifting to more sustainable forest management practices. While government policies are under review, evidence indicates that forest companies, landowners and local governments are ready to begin this revolution. However, investors will, no doubt, continue to be wary of the risks created by complex measurement and verification activities associated with forest carbon management projects in Canada until they are adequately addressed.

Although the Canadian forest industry has a long history of innovation, other financial incentives for research and development will be needed to assist the industrial sector in the implementation of the bioproducts sector in forestry (Chapter 13). This will be critical for the development of technologies and processes that are sustainable from an economic, environmental and social perspective. Strategies must be devised to avoid competition for the resources traditionally used by the forest industry and thus there is a need to integrate the bioproducts sector into the current forestry and forest products sectors. Moreover, there will be a need to generate formal linkages between all sectors of the economy with vested interests in the future of the bioeconomy, to create the new partnerships required for success.

In this book, we paint our vision of the bioeconomy in broad strokes. Our vision entails a highly networked, responsible and competitive forest bioproducts sector in Canada. The book is not intended as a comprehensive treatise of each bioproduct and its market potential. Indeed, one of our most difficult tasks was to decide which topic to address and to what depth. Hence omissions were the result of practical considerations alone and do not reflect value judgment. Indeed, our primary goal was to share our vision so that others could become active members of the bioeconomy.

In practice, strategic directions, along with first order economic, social and environmental aspects of the bioproducts industry, will, in many cases, require additional in-depth analyses, business planning and demonstration research to validate many of our hypotheses and opinions. Advancing the bioeconomy conscientiously, however, will respond to Canadians' unwavering commitment to see sustainable economic growth that enhances traditional resource sectors and rural communities, diversifies energy sources and market opportunities, converts potentially polluting waste into useful products, and ultimately protects their own health, the health of their children, and the health of the environment.

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Chapter 1

FORESTS AS A SOURCE OF BIOPRODUCTS

Highlights and Fast Facts

- Canadian forests are a wealth of biodiversity. As many as 500 types of bioproducts derived from forest-based biomass (plants, microbes and animals) are commercially used in Canada today.
- A potential 280 million tonnes of forest-derived biomass are available for production and industrial use without interfering with current forestry operations.
- Biomass utilization is a profitable means to manage residues originating from logging, sawmill and pulp and paper operations.
- Available woody biomass can provide a feedstock to replace fossil fuels for production of various consumer and industrial bioproducts including biofuels, bioplastics, biochemicals and biopesticides.
- One tonne of wood waste biomass contains enough energy to power a car for over six months; via biomass-to-fuel conversion, it may be possible to build a "clean fuel" economy in Canada worth up to $104 billion.[1]
- To benefit from renewable and greenhouse gas-neutral bioenergy and bioproducts, government investment in research and development and the establishment of procurement strategies are needed to augment sustainable forest management practices.

[1] Unless otherwise stated, all monetary values are reported in Canadian dollars.

For over 150 years in Canada, forest resources have been inventoried as merchantable pulpwood and saw logs of commercially desirable tree species. The rest of the forest was perceived as playing a critical ecological role but was rarely the target of specific management. A successful twenty-first century bioproducts industry, however, requires innovative technologies and a new approach to the inventory and monitoring of Canada's forest resources, as well as creating new partnerships in the bioeconomy.

Forest bioproducts can be generated from any organic material found within forest ecosystems or associated forest industries. The capacity to capture value or manufacture new commodities is dependent on the degree of biodiversity present within forest ecosystems. Biomass can originate from timber productive forests, non-timber productive forests, unmanaged or managed stocks, logging wastes, mill wastes or agroforestry systems. The selection of a source of raw material for the bioproducts industry must be the result of careful analysis of a complex combination of economic, environmental, political and social factors. Profitability is a critical issue; however, ecological and social sustainability are equally important success criteria.

1. FOREST BIODIVERSITY AND BIOPRODUCTS

Forest species that were formally considered not to have commercial value include all microbial, animal or plant species that were not previously exploited by the forest industry. In the emerging bioeconomy, these same species can become a source of raw material for various types of industries, provide supplemental income or become part of major export enterprises. Until now, there has been little attempt at conducting an inventory of this resource, except perhaps for rare and endangered species or those of particular ecological interest, making the current task of evaluating their economic potential quite challenging.

Canadian forests, comprising 10 percent of global forest cover, offer a wealth of biodiversity. Approximately two-thirds of Canada's estimated 140,000 species of plants, animals and microorganisms live in the forest (Natural Resources Canada 2003). Of the species contained in the vast boreal forest, it is estimated that 95% are arthropods and microorganisms, and that 88% of taxa remain unclassified by taxonomists (Zasada et al. 1997). Their genetic diversity includes billions of genes that control basic metabolic functions and confer the ability of all living creatures in Canada's forests to adapt to changing environmental pressures.

All of Canada's forest species, and their inherent genetic diversity, may have commercial values; however, it is nearly impossible to ascribe a monetary value to any species without knowing its specific industrial or commercial application. Nevertheless, as many as 500 types of bioproducts

(Duchesne et al. 2000) derived from plants, microbes and animals are commercially used in Canada. Collectively, these species now contribute close to a billion dollars annually to the Canadian economy, but the potential for harvesting and value-added processing is much greater.

In practice, forest biomass and bioproducts are primarily derived from four main sources: wild stocks from timber productive forests, wild stocks from non-timber productive forests and lands, managed stocks from intensively managed forests, and domesticated stocks from agroforestry ecosystems.

1.1 Wild Stocks from Timber Productive Forests

Each species has its own set of ecological requirements and thus its abundance and distribution is based on its tolerance to, and/or preference of, environmental factors. It is difficult to make general statements about the distribution of individual species. In the case of commercially available wild mushrooms, for example, in the boreal forest of northwestern Ontario, the morels (*Morchella* spp.) is found only in one-year-old post-burn communities (Duchesne and Weber 1993), whereas chanterelle mushrooms (*Cantharellus* spp.) are found in mid-successional forest stands, and pine or matsutake mushrooms (*Tricholoma magnevelare*) are found uniquely in mature (60 year-old-plus) forest stands (A. Chapeskie, per. comm.).

Because bioproducts and timber can be harvested from the same lands, there is potential for conflict if two industries target species with different ecological tolerances. Some bioproducts can benefit from logging disturbance from the timber industry, as in the case of early successional species such as blueberries (*Vaccinium* spp.) in eastern Canada and salal (*Gaultheria shallon* Pursh) in western Canada. At the other end of the spectrum, some species of plants are unique to late successional forests and are sensitive to disturbance. For example, Pacific yew (*Taxus brevifolia*) supplies bark for the production of the cancer drug paclitaxel and occurs as an understorey plant in old-growth forests. As a species, Pacific yew is shade tolerant, slow growing and has a life span of 300 years typically occuring within the understorey of old growth stands of western red cedar (*Thuja plicata*), life span 1000+ years) and western hemlock (*Tsuga heterophylla*), life span 400years, US Department of Agriculture 1999). "Yew habitat is old growth forest. Remove that and yew species will decline" (Lizotte and Knapp 2003).

1.2 Wild Stocks from Non-timber Productive Forests and Lands

The density, abundance and types of bioproducts on non-timber productive lands are similar to those from timber productive forests, but their origin excludes the possibility of direct competition for resources with the timber industry. Non-timber productive forests are not suitable for timber harvesting for various ecological and practical reasons including growth rate, topography, species composition, legislation or land uses incompatible with timber management. As an example, transmission line corridors are a good source of raw materials and can meet the dual goal of controlling vegetation and increasing yields of other products from the land (Saari 1993). Bioproduct management on private land can provide income opportunities for landowners who are not willing or able to manage timber resources (Ihalainen et al. 2002).

1.3 Managed Stocks from Intensively Managed Forests

Intensive forest management offers a wealth of opportunities to augment the social and economic value of forests by increasing the number of commodities extracted. For example, there are many medicinal plants and berry-producing species (Mohammed 1999) that can be co-managed with timber values without conflict between the two industries.

Recently, le Ministère des Ressources naturelles du Québec took a landmark initiative by promoting the intensive management of blueberries along with timber values in alternating strips of land. Local blueberry harvesters who were faced with consumer demands that exceeded the supply prompted this initiative. It was demonstrated that timber outputs within suitable ecosystems were increased by intensively managing fiber (yields increased from 1.8 m^3/ha/yr to 4.7 m^3/ha/yr), which freed up roughly 60% of the land for the intensive production of blueberries (Ministère des Ressources Naturelles 2002). It is expected that by 2007, approximately 5,000 ha of forested land will be available for blueberry production in this combined arrangement (Natural Resources Canada 2003).

Figure 1-1 provides a model that illustrates the potential of bioproducts to enhance forest management productivity through their co-management with timber. According to this model, managing bioproducts in commercial forests can help offset the cost of early plantation silviculture and add to revenues by increasing the number of species harvested from a given parcel of land. This concept is highly pertinent to private lands where tenure is unquestionable. Depending on jurisdiction, this model will have varying applicability on public lands.

1.4 Domesticated Stocks from Agroforestry Ecosystems

Domestication involves actively manipulating the life cycle, growth and environmental factors of organisms, and is the basis of modern agriculture. In practice, there are many instances where the demand for forest-based bioproducts also dictates that they should be domesticated or managed intensively in agroforestry systems.

Cultivation of specialty bioproduct species in agroforestry settings is sometimes undertaken to eliminate the problems associated with finding scant resources from the wild (Ripa 1993), or for reducing pressure on wild stocks of threatened plant species. Such cultivation can help regulate the supply of raw material, a critical factor in all levels of the supply chain. Harvesters need to have access to dependable stocks in order to ensure a steady and predictable income. A secure supply of material is especially critical where large market values are involved, such as wild mushrooms or nutraceuticals, which include highly sought after plants such as ginseng (*Panax* spp.), licorice (*Ligusticum* spp.), cohosh (*Caulophyllum* spp.), ground hemlock (*Taxus canadensis*), ginger (*Asarum* spp.) and Pacific yew (*Taxus brevifolia*) (Wheeler and Hehnen 1993).

Meeting the special needs of consumers is a strong motivation to domesticate a particular type of bioproduct species. The Christmas tree market is one example where consumer demand for products of unique shape and quality cannot be supplied from wild stocks. Across Canada there are several initiatives to domesticate many native forest plants (Montgomery 2000). This concept is also appealing to the agriculture industry as it can offer novel, and often more lucrative, products.

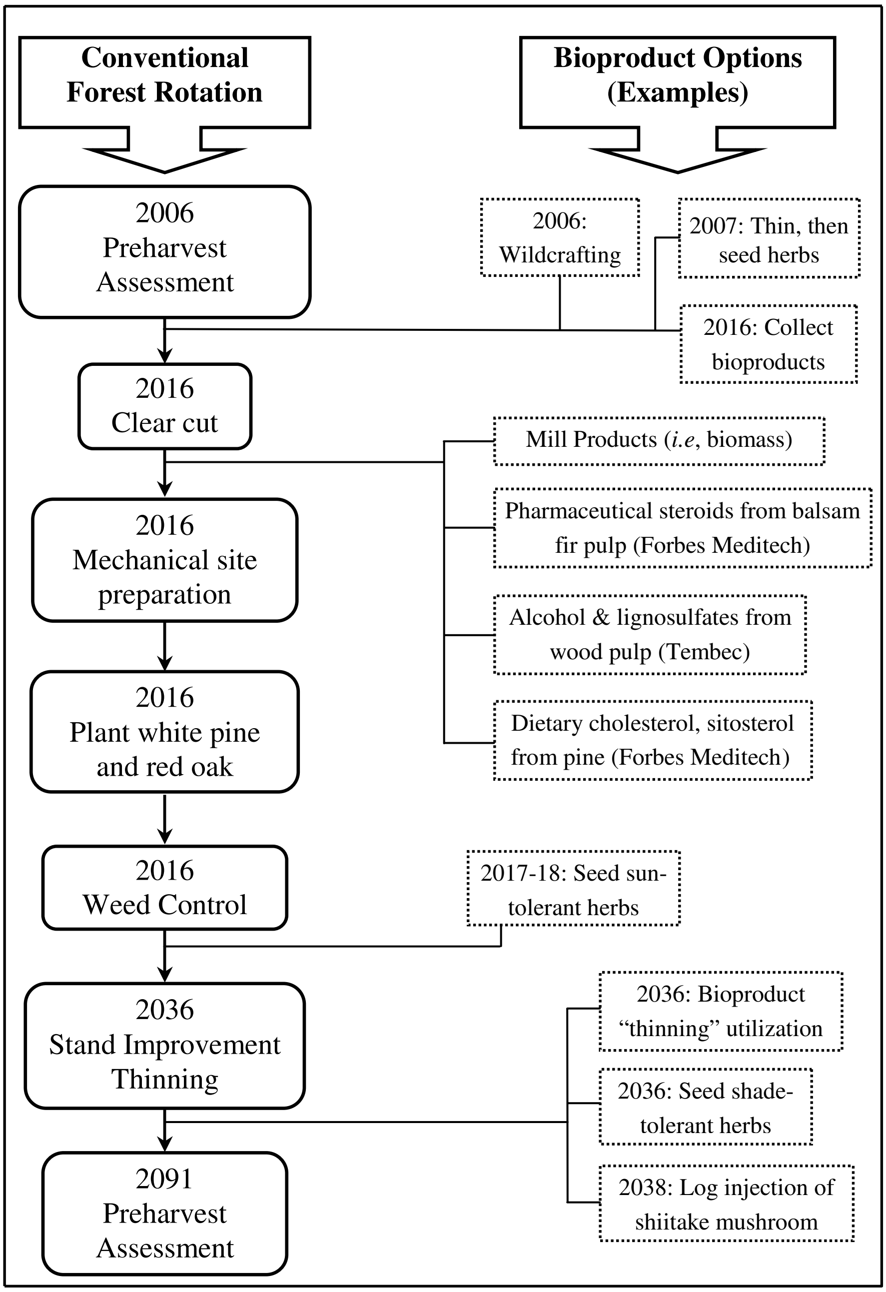

Figure 1-1. Managing Bioproducts in Commercial Forests.

2. BIOMASS ORIGINATING FROM CANADIAN FORESTS

By far the greatest annual growth of biomass in Canada occurs on forested lands which cover 41.8% (417.6 Mha) of the nation's total 998.5 Mha landmass (Natural Resources Canada 2003; Statistics Canada 2004). The sheer size of this resource provides Canada with a definite "green" advantage. Canada's timber productive forests produce roughly 360 Mm^3 of wood biomass annually, although productivity varies within and among ecozones (Lowe et al. 1996). This renewable source of virgin or residual feedstock is suitable for bioproduct and energy production, the major driver of a bio-based economy. Considering Canada's vast forest resources and the fact that only a small portion of these resources currently contribute to the bioproduct industry, the potential for new enterprise becomes evident.

Wood residues (underused or wasted biomass) are highly attractive from an industrial perspective because of their abundance and low cost. For some bioproducts, residue from harvesting, manufacturing and processing operations is the most efficient resource for commodity production. Not utilized, residue may be burned, left to decompose or landfilled. Given that each of these alternatives carries an environmental cost, conversion of residues into biofuels, or value-added bioproducts, can be an attractive alternative from many perspectives.

2.1 Estimating the Total Biomass Available from Canadian Forests

Table 1-1 summarizes the majority of biomass originating within Canadian forests and is the maximum annual harvest that would be available annually on a sustainable basis. In total, an estimated 278 million tonnes (Mt) of biomass could be made available for conversion to bioproducts. This is biomass originating from Canadian forests (including peat resources), and does not include biomass such as urban yard waste, municipal organic waste and virgin wood from non-timber productive forests.

Table 1-1. Annual Sustainable Canadian Forest Biomass. Economic Value in Canadian Currency and Ratios for Conversion of Biomass to Fuel[1].

Annual Potential Forest Biomass by Type		Commodity[6]							
		Methanol	Ethanol	Bio-oil	Hydrogen[7]	Levulinic Acid	Pellets-Briquettes	Wood Chips	Electricity
Woody Biomass from the Forest 81.50 Mt	B:C[2]	0.33	0.20	0.75	0.048	0.25	1.0	1.0	4.2
	TP[3]	26.90	16.30	61.12	3.912	20.38	81.50	81.50	342.30
	$[4]	30.68	18.59	15.71	12.47	30.30	25.06	9.78	20.54
Logging Residues 75.82 Mt	B:C	0.33	0.20	0.75	0.048	0.25	1.0	1.0	4.2
	TP	25.02	15.16	56.86	3.639	18.96	75.82	75.82	318.44
	$	28.54	17.30	14.62	11.60	28.19	23.32	9.10	19.11
Peat 70.00 Mt	B:C	0.33					1.0		3.5
	TP	23.10					70.00		175.00
	$	26.35					18.22		10.50
Short Rotation Plantations 21.91 Mt	B:C	0.33	0.20	0.75	0.048	0.25	1.0	1.0	4.2
	TP	7.23	4.38	16.43	1.052	5.48	21.91	21.91	195.30
	$	8.25	5.00	4.22	3.352	8.14	6.74	2.63	11.72
Sawmill Residues 19.93 Mt	B:C	0.33	0.20	0.75	0.048	0.25	1.0		4.2
	TP	6.58	3.99	14.95	0.957	4.98	19.93		84.00
	$	7.50	4.55	3.84	3.049	7.41	6.13		5.04
Municipal Waste Wood and Paper 8.04 Mt	B:C	0.33	0.20	0.75	0.048	0.25	1.0	1.0	4.2
	TP	2.65	1.61	6.03	0.386	2.01	3.138[5]	3.138[5]	33.75
	$	3.03	1.83	1.55	1.230	2.99	0.965	0.377	2.02
Paper Mill Sludge 1.55 Mt	B:C	0.33	0.20			0.25	1.0		1.04
	TP	0.52	0.31			0.388	1.550		1.61
	$	0.58	0.35			0.576	0.085		0.097
Commodity Price ($/t)		1140.7	1140.7	257.04	3187.5	1487.0	307.54[8]	120.06	60.00[9]
Total Production[3]		92.00	41.75	155.40	9.946	52.12	273.85	182.37	1150.4
Total Economic Value[4]		104.93	47.62	39.94	31.70	77.61	80.52	21.89	69.03

[1]Calculations for determining available biomass, commodity prices and conversion ratios are found in Appendix A.
[2]Biomass (B) to commodity (C) conversion ratio.
[3]Total production (TP) of commodities in millions of tonnes (Mt) or (mWh for electricity).
[4]Gross annual economic potential at competitive retail prices in billions of Cdn dollars. Some commodities are based on emerging technologies.
[5]The component of waste wood and paper that is wood is estimated to be 3.138 Mt.
[6]Some cellulosic conversion technologies are still being developed and are not yet cost competitive.
[7]Produced from the intermediate conversion of woody biomass to bio-oil.
[8]Peat priced at $260.30/t. Paper mill sludge priced at $55.05/t.
[9]Commodity price in mWh.

To understand the economic potential of the biomass quantified in Table 1-1, refer to Appendix A. This appendix provides the rationale and analysis for the calculations used to determine the biomass-to-commodity conversion ratios and the commodity price assumptions.

The need to define and prove sustainable productivity regarding organic matter or biomass removal from ecosystems is ongoing. Obvious declines in ecosystem productivity are rare and are usually attributed to poor soil management; however, uncertainty will continue to exist until sustainable productivity can be demonstrated conclusively (Powers 1999).

2.2 Forest Biomass as a Feedstock for Bioenergy Production

A potentially lucrative and environmentally benign venture involves the feasibility of using biomass as a renewable source of fuel. For example, one tonne of wood waste contains the equivalent of 18 GJ (Gigajoule 1×10^9 joules) of energy which is sufficient to operate a car for over six months (See Table 1-2).

Table 1-2. Examples of Energy Consumption (GJ) in Canadian Society[1].

Energy Consumption Mode (per year)	Energy Intensity (GJ)	% Change 1990 - 2002
Total Canadian Household Energy Use	1.4×10^9	8.6
One Individual Household - Total Energy Use	116.4	–10.6
- Space Heating	69.1	6.6
- Water Heating	25.2	12.1
- Appliances	15.1	2.5
- Refrigerator	3.1	–29.6
- Range	2.4	18.4
- Clothes Dryer	2.4	1.7
- Other[2]	5.6	51.4
- Lighting	5.1	15.7
- Space Cooling	1.8	165.0
Total Canadian Passenger Transportation Energy Use[3]	1.3×10^{15}	13.0
Passenger Transportation - One Small Car[4]	33.9	6.5
- One Large Car[4]	42.6	–12.0
- One Light Truck[4]	51.5	48.8

Note: 1 tonne of wood waste equals 18.0 GJ (Statistics Canada 2002).

[1]Adapted from: Natural Resources Canada 2004.

[2]"Other" includes televisions, video cassette recorders, DVD players, radios, computers, toasters, etc.

[3]Includes all forms of passenger transportation including motorcycles, school buses, urban transit, inter-city buses, air and rail.

[4]Average distance travelled per year in km: small car (16,846), large car (16,715), light truck (16,819).

The potential for bioenergy use is greatest in regions where wind, solar and hydrologic potential are low. In 1997, biomass provided approximately 5% of Canada's primary energy needs, most of which originated from the forest (Canadian Council of Forest Ministers 1997). The forest sector itself uses the largest share of the bioenergy and has increased its use by 51% from 1980 to 1997 (Canadian Council of Forest Ministers 2000), as demonstrated in Figure 1-2.

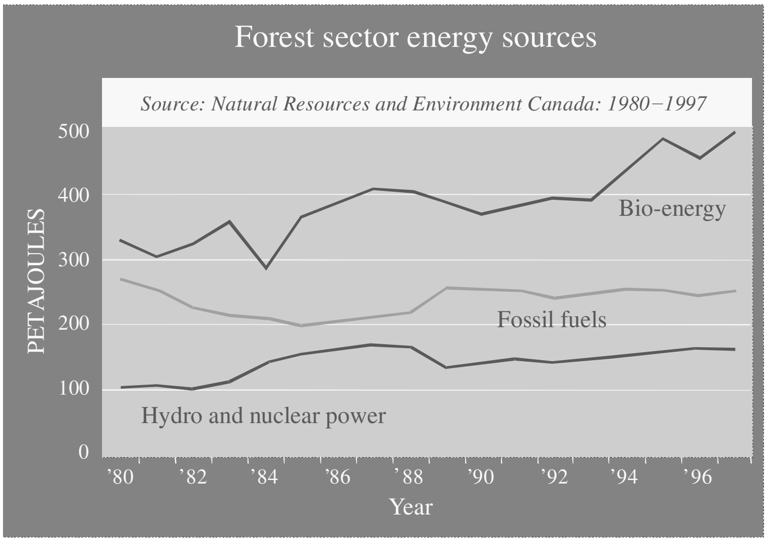

Figure 1-2. Forest Sector Energy Sources (Canadian Council of Forest Ministers 2000).

According to the Intergovernmental Panel on Climate Change (Canadian Council of Forest Ministers 2000), burning biofuels such as wood residues and pulping liquor does not result in net CO_2 emissions. Sustainable forest management includes the concept that biofuel CO_2 emissions are balanced by carbon removal, or sequestration, associated with forest growth.

From the 81.5Mt of woody forest biomass quantified in Table 1-1, it would be possible to generate 26.9 Mt or 34 billion litres of methanol fuel annually (Appendix A). This biofuel has the potential to supplement Canada's vehicle fuel consumption needs, considering that domestic sales in 2001 amounted to 38.7 billion L of motor gasoline and 22.6 billion L of diesel fuel oil (Statistics Canada 2002). This recognized biofuel market is estimated at $30.68 billion in methanol commodities (Table 1-1), not to mention jobs created laterally, environmental benefits, energy security and a decrease in health risks due to air pollution.

One of the challenges is that, compared to non-renewable fossil fuels such as oil and natural gas, wood and agricultural sources of biomass have a low energy density, leading to high transportation and handling costs. Woody material is more expensive to collect and transport than grains such as corn, barley and wheat. Woody biomass is also more costly to process due to an additional step required to breakdown cellulose into simple sugars that can be used as a food source by microorganisms for fermentation into ethanol. Once biomass is converted to fuel, however, it is easier to store and transport, and can be used for much more than just electricity generation, a limitation of solar and wind energy. As well, efforts to streamline handling and transportation of biomass resources could reduce costs and lead to an increase in the attractiveness of bioenergy use in the near future.

2.3 Composition of Woody Biomass

Woody, or ligno-cellulosic, biomass varies in composition depending on its origin, with higher lignin content in softwoods than hardwoods. Generally, this biomass is composed of 40% to 50% cellulose, 25% to 35% hemicellulose and 15% to 25% lignin (Wyman and Goodman 1993). Cellulose and hemicellulose are, respectively, six- and five-carbon chains that can be economically converted into reducible sugars and further converted into ethanol and other chemicals.

One of the current technological hurdles is the separation of lignin from cellulose and hemicellulose (Agriculture and Agri-Food Canada 2002). Lignin can be used as a high-energy combustible for boilers to power machinery or generate electricity, and also has potential as a feedstock for chemical synthesis of products, such as phenols, aromatics and olefins (Wyman and Goodman 1993).

2.4 Woody Biomass from the Forest

It is not reasonable to envision harvesting traditional timberlands to support the bioproduct industry, as it would have a two-fold negative economic impact. First, it would compete with traditional forestry employment, and second, the cost of the raw material would limit the economic feasibility of such operations. Alternatively, using non-merchantable wood from current forest operations offers a large quantity of biomass at a relatively low cost.

2.4.1 Estimating Woody Biomass Availability from the Forest

The Canadian forest inventory indicates that there are 418 million hectares (Mha) of forestland, of which 227 Mha are stocked timber productive forest with a species distribution of 62% softwood, 22% mixed wood and 16% hardwood (Lowe et al. 1996). The timber productive forests currently under management consist of 120 Mha; the remaining 107 Mha consists of trees that are young (46%), mature or over-mature (42%), of uneven age or unclassified (Lowe et al. 1996). Because the bioproducts industry does not discriminate against wood characteristics such as age, size, defects and species, timber productive forests can offer great opportunities for otherwise "non-economic" resources for the industry. Thus, it should be feasible to harvest the renewable timber from these lands, utilizing the entire 227 Mha.

The average growth for Canadian timber productive forests is 360 Mm^3/year (Lowe et al. 1996). In the 120 Mha that is currently suitable and available for wood production, the annual growth rate is calculated to be 197 Mm^3 (Lowe et al. 1996). Therefore, 163 Mm^3 of wood per year is available in addition to the present harvest. To calculate the existing biomass, the volume-to-biomass conversion ratio needs to be determined, thus allowing the conversion of 163 Mm^3 into dry tonnage. Penner et al. (1997) describe precise calculations for determining biomass from specific species, age groups, stands and regions, and account for variation in height and diameter at breast height (DBH). Extrapolating from Penner et al. (1997) by using the conversion rate of 0.5 t/m^3, which represents the dry weight of all softwood, hardwood and mixed-wood tree species, the 163 Mm^3 of available wood is equivalent to 81.5 Mt of biomass available annually on a sustainable basis for the bioproducts industry (Table 1-1). Biofuel derived from this biomass has the potential to contribute over $30 billion annually to the Canadian economy (Table 1-1), as well as provide many social and environmental benefits.

2.5 Biomass from Logging Residues

Logging residues resulting from timber harvest include leaves, branches, bark, damaged and decaying logs, and intact non-preferred trees species (*i.e.*, those not valued for their timber or pulp properties). This waste biomass is often piled for slash and burned or left to decay, causing emissions of greenhouse gases into the atmosphere.

In addition to bioproduct profitability, the removal of mechanical thinnings and slash that pose a forest fire threat could reduce the need for controlled burning, which can be dangerous and costly. Collecting, chipping and extracting is expensive, however, so to become a reality, this source of biomass will need to be subsidized by parties interested in fire prevention and integrated into current forestry practices.

2.5.1 Estimating Biomass from Logging Residues

Calculating logging residues is complex due to large variations in species composition, maturity, age and size within and among ecozones. To determine the biomass available from logging operations, it is necessary to estimate the total waste produced, which will also vary with silvicultural practices. For instance, trees cut for veneer and high quality lumber will yield higher amounts of waste biomass than those cut for pulp and particleboard manufacturers. It is also difficult to gauge residues generated from damaged and decaying roundwood or from "weed tree" species.

In 1999, forest harvesting took place over an area of 1,025,429 ha and the net merchantable volume of roundwood extracted was 193.9 Mm^3, composed of the following (Natural Resources Canada 2003a):

logs and bolts	161,859,000 m^3
pulpwood	25,980,000 m^3
fuelwood and firewood	2,902,000 m^3
other industrial roundwood	3,149,000 m^3

As demonstrated in the two methods of calculation shown below, it is estimated that for every cubic meter of roundwood harvested, approximately 0.782-0.855 m^3 are left behind as logging residues.

To calculate residues as a fraction of pulpwood, Penner et al. (1997) converted inventoried biomass data into corresponding biomass component estimates. Using this methodology, it was determined that 40-year-old black spruce (*Picea mariana*) in Newfoundland consisted of 14.4% bark, 25.2% branches and 38.6% foliage, including twigs. Thus, for every debarked tonne of black spruce harvested, roughly 0.782 t of waste biomass is generated. Using this fraction, a rough estimate of logging residues could be calculated as 78.2% of all merchantable roundwood produced, which equals 75.82 million dry tonnes (193.9 $Mm^3 \times 0.782 \times 0.5$ t/m^3).

A study on coarse woody debris (CWD) in northwestern Ontario demonstrated that approximately 112 m^3/ha of downed material could be collected from mixed-wood clear cuts (Pedlar et al. 2002). By comparing stock roundwood estimates of 131 m^3/ha in the productive forest (Lowe et al. 1996) to volume of CWD (112 m^3/ha), a ratio of 1:0.855 is achieved, suggesting that for every tonne of merchantable roundwood produced in Canada, there are 0.855 t of logging residues. Using this ratio, annual roundwood production would generate 82.89 M dry tonnes of logging residues (193.9 $Mm^3 \times 0.855 \times 0.5$ t/m^3).

Conservatively speaking, the 75.82 Mt of biomass residues generated by the logging industry has the potential, via biofuel conversion, to add $28.54 billion annually to the Canadian economy (Table 1-1).

2.5.2 Potential for Increased Biomass from Logging Residues

Interior cedar hemlock (*Tsuga* spp.) ecosystems in British Columbia have a higher incidence of on-site wastes than boreal and some temperate ecosystems due to the frequency of butt and pocket rot, and weak heartwood and sapwood that increase the possibility of breakage when trees are felled and skidded. The combined decay, waste and breakage estimates range between 55% to 68% for the harvesting of western red cedar (*Thuja plicata*) western hemlock (*Tsuga heterophylla*), hybrid white spruce (*Picea glauca x engelmannii*) and subalpine fir (*Abies lasiocarpa*), depending on the harvesting techniques (Renzie and Han 2002). In this logging operation, when roundwood wastes are added to slash (crown material and branches), the roundwood-to-residue ratio could be in the range of 1:2.5, suggesting that for every tonne of merchantable roundwood produced, roughly 2.5 t remain as logging residues. This is substantially higher than the figure used to quantify biomass Canada-wide.

Also of note, the estimated biomass does not include pre-commercial thinning, which is a major feedstock for biofuel production in countries such as Finland (Hakkila 2000).

2.5.3 Environmental Concerns

One concern with the extraction of logging residues is determining what percentage of logging residues can be removed before biological sustainability is compromised. Soil compaction and removal of organic material is often purported to have negative impacts on long-term productivity in forest ecosystems (Rob Flemming, Canadian Forest Service, Great Lakes Forestry Centre, per. comm.). Hyvonen et al. (2000) found that site-remaining logging residues, 16 years after clear-felling, increased the nitrogen levels by 30% in spruce (*Picea* spp.) sites and 70% to 80% in pine (*Pinus* spp.) sites. Nitrogen concentration and release is highest in needles and for this reason, logging residues are now left on site for the needles to fall off prior to chipping and bailing.

Logging residues can also be used for the application of a thin layer of CWD, which acts in a similar fashion to that of a mulch, providing enhanced retention of soil moisture by directly binding water and refracting solar radiation. As well, CWD stabilizes logging roads and skid trails, reducing