A Canadian Biomass Inventory: *Feedstocks for a Bio-based Economy*

Final Report

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Executive Summary

A detailed analysis was carried out to assess the capacity of Canada's biological resources – in particular, agriculture and forestry - to support a bio-based economy. In a bio-based economy, the agriculture and forestry sectors are involved in the large-scale production of bio-based energy (e.g. fuels), industrial chemicals and feed-stocks, in addition to the production of food, feed and fibre.

The analysis explored Forest Production, Agricultural Production and Municipal Waste streams. Key findings of the analysis include:

- **Land Area:** Of the 998 M ha of land in Canada, about 42% is forested, and about 25% (245 M ha) is considered Timber Productive Forest. A further 6.8% (67.5 M ha) of Canada is agricultural land, of which 36.4 M ha (3.6%) is cropland.
- **Standing Biomass / Bio-energy stock:** The 245 M ha of Timber Productive Forest in Canada has a biomass carbon stock of about 15,835 Mt C. This resource has an energy content (566 EJ) that is equal to 69 years of Canada's current energy demand that is met by fossil fuels (8.24 EJ/yr).
- **Annual Harvest:** Each year, the biomass harvest from Canada's forestry and agricultural sectors is about 143 Mt C, an amount of carbon that is similar to the atmospheric emissions of carbon from fossil fuel use in Canada (about 150 Mt C/yr in 1998):
  - The energy content of the annual biomass harvest in Canada (5.1 EJ/yr) is equal to 62% of the energy derived from fossil fuel combustion;
  - A 25% increase in forestry and agricultural production in Canada could provide about 1.25 EJ/yr in biomass energy, an amount equivalent to about 15% of the energy that Canada now gets from fossil fuels.
- **Residual or Waste Biomass:** There are large residual or waste biomass carbon streams associated with the existing agriculture and forestry, and coming from municipalities:
  - Of the >66 Mt C/yr in the residual or waste biomass carbon stream, about 60 Mt C/yr may be considered an 'available' feedstock for a bio-based economy. This represents about 42% of the entire forestry and agricultural harvest;
  - The energy content of this biomass resource, conservatively calculated to range from 1.5 EJ/yr to 2.2 EJ/yr, is equivalent to between 18% and 27% of Canada's current energy demand that is met by fossil fuels (8.24 EJ/yr).

This study illustrates the major potential that Canada has to utilize its vast forestry and agricultural resources to provide a renewable and sustainable supply of bio-based energy, chemicals an materials to help meet the needs of society.

Such a bio-based economy would help the nation meet its international climate change commitments while stimulating the rural economy and encouraging innovation and economic growth. Certainly, when it comes to a bio-based economy, Canada has a 'Green Advantage' relative to other developed countries of the world.

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1. General Introduction

1.1. Why a Biomass Inventory?

Countries around the world are reconsidering biomass as a potential source of renewable and sustainable energy, chemicals and materials; in essence, biomass will provide the feedstocks for a bio-based economy.

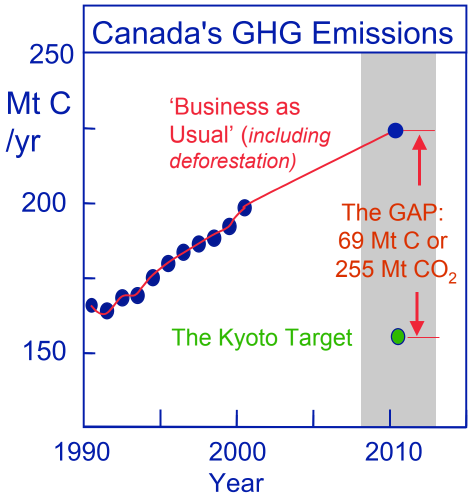


Fig. 1. Canada's greenhouse gas emissions from 1990-2000 (blue circles), and the Kyoto target (green circle) for the 2008-12 commitment period. The 'business-as-usual' projection (upper blue circle) shows a 'gap' of about 69 Mt C/year (=255 MT CO$_2$equivalents/yr). Values from Canadian GHG Inventory for 1990-2000 (Env. Canada, July 2002) and The Climate Change Plan for Canada (Env. Canada, Nov. 2002).

There are many 'drivers' that have come together to focus attention on biomass and a bio-economy, including:

- **Climate change and the mitigation of greenhouse gas emissions.** Biomass is a renewable resource that can be produced with little or no greenhouse gas emissions, especially when compared to the use of fossil fuel feedstocks. Therefore, new industrial uses for biomass may help many countries, including Canada, meet their international commitments associated with ratification of the Kyoto Protocol in Dec 2002 (Fig. 1).
- **Energy supply and security.** The political unrest in the Middle East and the ever-increasing global demand for fossil fuels from this region (>80% of the world's energy supply) raise concerns about the supply of both oil and natural gas at the global level. Shortages will result in price instabilities that will have an adverse effect on economies with large import requirements.
- **Innovation.** The new bio-based economy will rely on very different technologies than the wood burning and simple biomass processing technologies that provided human civilization with energy, chemical and material needs prior to the 20th century. New developments in chemistry, chemical engineering and biotechnology allow agriculture and forestry to provide not only enhanced food, feed and fibre, but also fuels, industrial feedstocks and environmental services.
- **Rural Development.** Due to agricultural subsidies and trade barriers in a number of developed countries, Canadian agricultural and forest products have been undervalued in the export market in recent decades. A bio-economy will provide new markets for agricultural and forest products in addition to new jobs for processing these products.
- **Air Quality.** Air quality concerns in cities caused by smog, nitrogen oxides and air-borne particulates have been attributed to the use of fossil fuels. In particular, gasoline and diesel used as transportation fuels contribute to air quality decline. Cleaner burning fuel alternatives are in demand, and bio-fuels provide one alternative.

Canada has a large, vegetated land mass and well-developed forest and agricultural industries. Consequently, this nation is likely to have a 'green advantage' for the use of biomass as a source of renewable energy, chemicals and materials.

Canada's Green Advantage

- 0.5% of world population
- 7% of global land area
- 10% of world forest

The purpose of this study was to explore the magnitude of Canada's biomass resource by:

(a) Quantifying Canada's forestry and agriculture production in units of carbon harvested per year and the energy content of that harvest. Comparing the amount of biomass carbon harvested to Canada's current fossil fuel and energy usage should allow an assessment of the extent of increase in agricultural or forest production that would be required to make a significant contribution to Canada's energy needs;

(b) Estimating the extent of waste biomass carbon streams produced by Canada's forestry, agricultural and municipal sectors and the contribution these could make to the energy needs of Canada.

This study was not intended to offer an economic assessment of the potential of biomass from any specific sector, or to identify regions with strong potential for future development. Neither was it designed to identify all hurdles associated with the production, processing or marketing of biomass to support a bio-based economy. The study does not offer a full assessment of the potential from marine biomass. Although marine-source biomass has some potential for the future, an infrastructure for the production and harvest of algal and marine invertebrate and vertebrate life does not currently exist; some marine source waste from fish processing plants is included in the municipal waste stream of this study.

This assessment is an extension of an earlier, less detailed study (Layzell, 2001) , and provides an accurate assessment of carbon and energy stocks upon which policy decisions may be confidently based.

1.2. The Approach Used

This inventory was undertaken to evaluate the current status of biomass production and availability from three sectors: forestry, agriculture and municipal waste.

The magnitude of the agricultural and forest harvest was obtained from a wide range of sources including Statistics Canada, Natural Resources Canada and Agriculture and Agri-food Canada. Allowances were then made for other biomass harvested but not included in the official numbers, and then these values were converted into units of mega- tonnes (Mt) of elemental carbon (C) harvested per year. Eventually, summary values were converted into energy content in units of Exajoules (10^{18} joules) per year.

The energy potential of the biomass carbon streams were compared with the non-biomass energy use in Canada (Table 1.1). Biomass energy has been estimated as providing about 4.1% of Canada's energy supply in the mid 1990's (Klass, 1998).

Table 1.1. Canada's non-biomass energy use; year 2000 estimate

Source	EJ/yr
Coal	1.40
Oil	2.92
Natural Gas	3.91
Total FF	8.24
Net Nuclear	1.05
Net Hydro	3.30
Total	12.60

from Canada's Energy Outlook, 1996-2000

The calculation of the waste C streams was more complex and involved identifying the sources and quantities of biomass carbon that are not currently being used as a primary product, nor in the production of energy or bioproducts. All conversion factors were assessed for validity and compared to the best-known standards and the most recent scientific literature.

Where biomass residues had a measurable diversion for traditional uses or where known hurdles in harvesting or post-harvest processing exist, reduction factors were introduced. A final figure of biomass available from each sector is provided.

1.3. Acknowledgements

Numerous contributors offered information and statistics for this report, as well as helpful discussions. Their assistance was invaluable and greatly appreciated, but the authors accept all responsibility for the calculations and interpretations provided in this report.

2. Biomass from Forest Resources

2.1. Introduction

Forested lands constitute Canada's greatest biomass reserve, and provide resources for the $74B/yr forest industry. As well as providing wood and specialized forest products, the forest industry generates biomass residues suitable for bio-product and energy production.

In Section 2.2, the extent and distribution of forested land is described, with special emphasis on that portion classified as 'timber-productive forest' (TPF). Total biomass and carbon stocks, derived using different model systems, are assessed for the TPF regions (Section 2.3) and then information on how these models contribute to the determination of the annual allowable harvest, along with actual harvest data for each region is provided (Section 2.4).

The processes of harvest and preliminary handling eliminate non-merchantable fractions of the total harvest, thereby creating wood residues. Wood residues are of particular interest because they represent a biomass resource available in every region. Some wood residues are used for co-generation or secondary manufacturing; however, unused wood residues from the harvest site and mill may be combined to provide an estimate of biomass currently available for bio-products and energy (Section 2.5).

The forest industry uses both volume and mass units. In this chapter, measurements are converted to units of carbon for easy comparison, and energy values (EJ) are provided for wood residues.

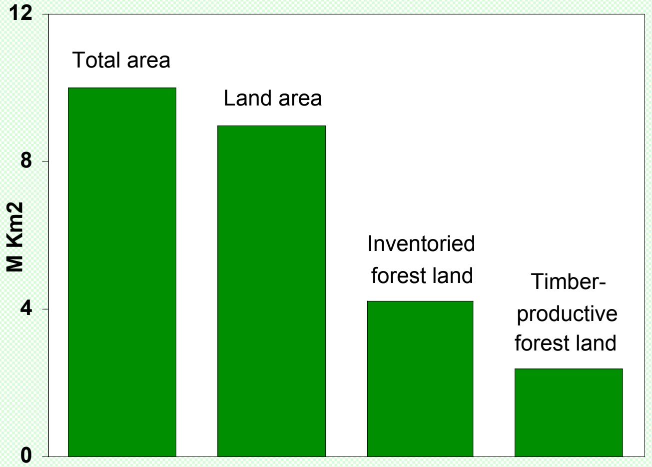
2.2. Land Area of the Timber Productive Forest

By far the greatest proportion of annual biomass accumulation occurs on forested lands, which cover 4.17 M km^2 (41.8%) of Canada's total 9.98 M km^2 landmass (Statistics Canada, 2001 report of data collected by NRCan, GeoAccess Division).

Canada's forests account for 10% of the world's forest resources (Penner *et al.,* 1997) and they have a high rate of public ownership, with 71% provincially owned, and 22% federally owned (including territorial forests). Only 7% of forested land is privately held.

Of inventoried forest land, about 58% is considered to be "productive" (i.e. that available for growing and harvesting trees). The remaining 42% is reserved forest land and therefore not available for

Figure 2.1 Distribution of Forested Lands in Canada, 1991



production and protected from harvest by law (Statistics Canada, CANSIM Matrix 6076, 1991). Timber productive forests account for 25% of Canada's total land area (Lowe *et al.,* 1996), and these have been evaluated for density (stocking) and productivity.

The proportions of inventoried and timber-productive forest lands of the total landmass of Canada are presented in Figure 2.1, and the regional distribution of forested area is provided in Table 2.1.

Table 2.1 Regional Distribution of Forests[1]
(TPF = Timber Productive Forest)

	Area (Mha)					ha/yr
Region	**Total**	**Fresh Water**	**Land**	**Forests**	**TPF**	**Annual Harvest[3]**
NL	41	3.1	37.4	22.5	11.27	17,415
PE	1	0	0.6	0.3	0.28	5,780
NS	6	0.2	5.3	3.9	3.77	49,680
NB	7	0.1	7.1	6.1	5.95	111,077
QC	154	17.7	136.5	83.9	53.99	384,208
ON	108	15.9	91.8	58	42.2	201,522
MB	65	9.4	55.4	26.3	15.24	15,509
SK	65	5.9	59.2	28.8	12.63	21,169
AB	66	2	64.2	38.2	25.71	42,210
BC	94	2	92.5	60.6	51.74	176,312
YT	48	0.8	47.4	27.6	7.47	x
NT	135	16.3	118.3	61.4	14.32	547
NU[2]	209	15.7	193.6	54.5	x	x
Canada	**998**	**89.1**	**909**	**417.6**	**244.6**	**1,025,429**

Totals may not add up due to rounding.
[1] Data source, Lowe *et al.,* 1996.
[2] Data source, NRCan, GeoAccess Division
[3] Data from NRCan 1999, Compendium of Forest Statistics

2.3. Biomass and Carbon Stocks in the Timber Productive Forest

In this section, biomass and carbon stocks that are available within the timber productive forest are estimated. These stocks include the bole of the trees that provide the merchantable product (Section 2.3.1) and the non-stem biomass (Section 2.3.2) that includes the bark, branches and leaves of all tree species within the forest.

2.3.1. Merchantable biomass and carbon stocks

Merchantable trees are the targeted biomass for harvest by the forest industry. A traditional tool of forest management, known as a "forest inventory", is used to determine the appropriate volume of trees for harvest, or "annual allowable cut" (AAC), for any given region. Over time, models to determine the volume of merchantable tree stems (Bonner, 1982) have become more refined and have taken into consideration many factors affecting the growth of forest species in order to improve sustainability of AAC rates.

The merchantable volume reports only the wood portion of a stem suitable for harvest from stump to top in cubic meters (m^3). Site-specific factors such as the overall productivity of the land (Class I or Class II), the tree density or "stocking" factor, and local merchantability limits (the minimum size of tree cut for sale, for example) are also considered. A detailed "forest inventory", called the "Canadian Forest Inventory" (CANFI), was produced for the year 1991, with an update in 1994 (Lowe *et al.,* 1996). A summary of timber productive forest volume, by region and composition is provided in Table 2.2.

The assessment of forest volume is used to establish the annual allowable cut (AAC). It is unusual for the entire quota to be filled in any given year because of technological challenges associated with harvest, and fluctuations in the marketplace. Although the AAC has hovered around the 230 M m^3 mark for all of Canada, in the period from 1970 to 1999, actual harvest has been somewhat lower. The proportion of the AAC allocated by region is illustrated in Figure 2.2, and is proportional to the timber productive forest volume shown in Table 2.2.

Figure 2.2. Allowable Annual Cut, by Region, 1999

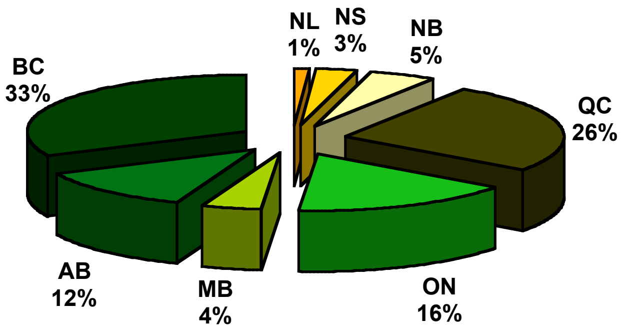


Table 2.2 Timber-Productive Forest Volume and C Stocks of Merchantable Trees, 1996[1]

	Coniferous	Broadleaved	Total Volume	Total Carbon
Region	Volume M m^3			Mt C^3
NL	492	40	532	127
PE	16	10	26	6
NS	156	106	263	63
NB	434	212	646	154
QC	2,938	1,320	4,258	1014
ON	2,399	1,384	3,783	901
MB	612	326	938	223
SK	461	435	896	213
AB	1,922	1,198	3,120	743
BC	9,884	711	10,595	2523
YT	572	66	638	152
NT	333	133	466	111
NU[2]	x	x	x	x
Canada	**20,218**	**5,941**	**26,159**	**6,229**

Totals may not add up due to rounding.
[1] Data source, Lowe *et al.,* 1996.
[2] Data not available.
[3] Assumes 4.2 m^3 per t C in biomass

2.3.2. Non-Stem Biomass and Carbon Stocks

Biomass and Carbon Density The forest industry's "biomass inventory" assesses **all non-stemwood,** above-ground tissues including the bark, branches and leaves of all tree species within a given stocked timber-productive forest, regardless of the size of the individual trees, or their suitability for commercial harvest. This assessment gives the best estimate of all materials with potential as a feedstock for bio-based energy, chemicals and materials.

Table 2.3 Average Non-stem Biomass Density by Province, 1997[1]

	Species				**Weighted Average[2]**	**Carbon[3] Density**
	Coniferous	**Mixed**	**Broadleaved**	**UC**		
Region	**ODT/ha**					t C/ha
NL	52	76	84	80	54	23.8
PE	73	83	99	x	84	37.0
NS	71	70	83	x	75	33.0
NB	87	87	90	16	81	35.6
QC	59	89	105	43	70	30.8
ON	83	85	101	84	87	38.3
MB	46	74	72	x	55	24.2
SK	35	67	89	x	54	23.8
AB	82	92	68	x	78	34.3
BC	169	111	80	55	158	69.5
YT	x	x	x	x	72	31.7
NT	x	x	x	x	52	22.9
NU[2]	x	x	x	x	x	x
Canada	**101**	**81**	**88**	**28**	**89**	**41.4**

x - data not available; UC – unclassified

[1] Data source Penner *et al.,* 1997

[2] Weighted for the hectares of each species in each region

[3] Assumes 12% water in oven dried biomass, and 50%C in dry weight, therefore 0.44 t C/ODT

The earliest methods of estimating total biomass used extrapolation of harvest data, but included inherent errors because critical factors such as land productivity, or the nature of tree and understory species were not considered. More recent models for estimating total biomass have been refined to accommodate more variables (Bonner, 1985). The best, currently available biomass model permits estimation of biomass on both high productivity (Class II) and lower productivity (Class I) lands as defined by provincial standards (Penner *et al.,* 1997).

The model of Penner *et al.* (1997) used a series of equations to convert merchantable stem wood volumes (m^3) from the forest inventory, to biomass estimates in oven-dried tonnes per hectare (ODT/ha). Conversion factors to account for all aboveground biomass of merchantable, as well as intact sub-merchantable trees are included, so that the estimate accounts for all aboveground but non-stem wood, biological tissues attributable to trees and tall shrubs within a given stand. Biomass of small shrubs and herbaceous foliage is not included in the biomass inventory.

Site-specific factors affecting growth rate and stand density, regional and species merchantability limits, typical stump height and regional yield tables were included in the model, so that the degree of accuracy, as confirmed by actual field measurements was high (Penner *et* *al.,* 1997). The average non-stem biomass, as determined using this model, is shown in Table 2.3 for various regions and forest types.

All biomass measurements were presented as "oven-dried tonnes" (ODT); biomass that has been oven-dried for analysis retains 12% moisture on average. These values were converted to t C/ha.

Total Biomass and Carbon. When the average values for non-stem biomass density were applied to the land areas for each region, values for total non-stem biomass were derived as shown in Table 2.4. As expected, total biomass was greater in more heavily forested regions.

Table 2.4 Total Non-stem Biomass and Proportion of Total Biomass that is Merchantable, by Region, 1997

		Non-Stem Biomass			Merchantable	
	TPF[1]	Average[2]	Total	Carbon[3]	Carbon[4]	
Region	M ha	ODT/ha	M ODT	Mt C	Mt C	% of Total
NL	11	54	610	268	127	32.1%
PE	0	84	25	11	6	36.0%
NS	4	75	285	125	63	33.3%
NB	6	81	486	214	154	41.8%
QC	54	70	3,780	1663	1014	37.9%
ON	42	87	3,671	1615	901	35.8%
MB	15	55	836	368	223	37.8%
SK	13	54	680	299	213	41.6%
AB	26	78	2,005	882	743	45.7%
BC	52	158	8,169	3594	2523	41.2%
YT	8	72	540	238	152	39.0%
NT	14	52	744	327	111	25.3%
NU[2]	x	x	x	x	x	x
Canada	**245**	**-**	**21,831**	**9,606**	**6,229**	**39.3%**

[1] From Table 2.1

[2] From Table 2.2

[3] Assumes 12% water in oven dried biomass, and 50%C in dry weight, therefore 0.44 tC/ODT

[4] From Table 2.2

Across Canada, total estimated biomass on TPF land was estimated at 21,831 OD Mt, or 9,606 Mt of carbon, assuming that oven dried biomass was 44% carbon.

Figure 2.3 illustrates the distribution of non-stem biomass across Canada (calculated by the method of Penner *et al.,* 1997). Other national biomass inventories, such as the Alexeyev *et al.,* 1995 study of Russia and the Birdsey (1992) study of the United States, have used similar study techniques to generate reasonable national estimates. All studies that are based on the approach of estimating total biomass from stemwood volume are admittedly prone to error where local variability in soil type and moisture accessibility is high, however, the calculations presented in Table 2.4 are reasonably aligned with those of Russia and the United States.

Comparing Merchantable and Non-Stem Biomass and C Stocks The data from Tables 2.2 and 2.4 were combined to calculate the proportion of total forest biomass that is merchantable. The results for the major regions of Canada are provided in Table 2.4. Note that values ranged from a 25% to 46%. The national average shows that about 39% of the total biomass in the timber productive forest is merchantable.

Figure 2.3 Distribution of Non-Stem Forest Biomass by Region.

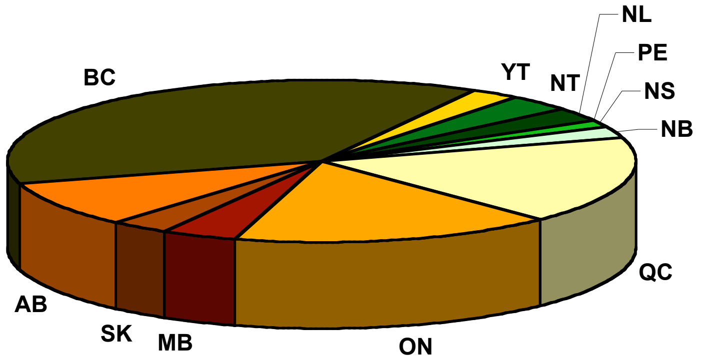
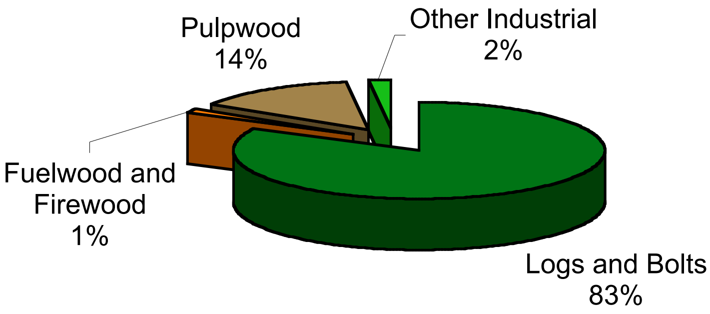


Figure 2.4. The Proportion of Forest C Stocks that are Merchantable



2.4. The Annual Biomass and Carbon Harvest

2.4.1. *Merchantable Harvest of Roundwood*

Recording the volume of merchantable tree stems (roundwood) harvested and sold from each region has formed the basis of traditional forest resource assessment and management. Roundwood is categorized by anticipated or dedicated use, and sold as “logs and bolts” for lumber, “fuelwood and firewood” for energy, “pulpwood” for pulp, fibre, chip or chemical feedstocks and “other industrial” roundwood for a variety of purposes, such as utility poles and pilings.

These statistics provide a measure of the volume of timber harvested by region and updates are appended to the National Forestry Database on an annual basis (National Forestry Database, 1991).

A summary of roundwood harvested by category and region is presented in Table 2.5. When the area of harvested roundwood data is compared to the inventoried land total, less than half of 1% of timber-productive land (about 1 M ha, Table 2.1) is harvested in any year. BC produces the highest volume of total harvested forest products, with 78 M cubic meters harvested annually; QC is a distant second at 43 M m^3. The Canadian forest industry harvests over 200 M m^3 of roundwood every year, with a carbon equivalent of about 47 Mt C/yr.

Table 2.5 Merchantable Volume of Roundwood Harvested, 2000[1]

	Roundwood Harvested							**Non-Stemwood Total**
	Logs & bolts[2]	**Fuelwood & firewood[3]**	**Pulpwood[4]**	**Other industrial[5]**	**Total**			
Region	**000 m^3/yr**				**M m^3/yr**	**M ODT/yr[6]**	**Mt C/yr[7]**	**Mt C/yr[8]**
NL	602	429	1,837	x	2.87	1.55	0.68	1.45
PE	345	188	133	5	0.67	0.36	0.16	0.28
NS	3,898	68	2,168	29	6.16	3.33	1.47	2.94
NB	8,231	33	3,573	x	11.84	6.39	2.82	3.92
QC	37,462	2,000	3,905	117	43.48	23.48	10.35	16.99
ON	16,878	124	7,989	3,127	28.12	15.18	6.69	12.01
MB	594	53	1,526	15	2.19	1.18	0.52	0.86
SK	2,113	3	2,157	272	4.55	2.45	1.08	1.52
AB	16,752	5	4,813	357	21.93	11.84	5.22	6.20
BC	78,422	x	x	x	78.42	42.35	18.67	26.60
YT	1	30	x	x	0.03	0.02	0.01	0.01
NT	3	19	x	x	0.02	0.01	0.01	0.02
NU	x	x	x	x	x	x	x	x
Canada	**165,301**	**2952**	**28,101**	**3922**	**200.3**	**108.2**	**47.7**	**72.79**

[1] Data source, National Forestry Database Program, 2000.

[2] Logs and bolts refers to stemwood sold for sawmill lumber and veneer wood.

[3] Fuelwood is used for industrial and institutional energy production; firewood is used for residential and household energy production: both terms refer to commercial stemwood sold for fuel.

[4] Pulpwood refers to stemwood sold for pulping, chipping, fibre and paper manufacture.

[5] Other industrial stemwood is sold for the manufacture of poles, pilings and composite board.

[6] Assumes 0.54ODT per m3

[7] Assumes 1tC occupies approximately 4.2m^3

[8] Calculated from the Mt C/yr roundwood harvest assuming the proportion of total biomass that is merchantable as per Fig. 2.4

The distribution of harvest volume by usage category is illustrated in Figure 2.5. Note that about 22% of the sawlog is waste (bark, sawdust, etc).

2.4.2. Harvest of Non-Stem Biomass

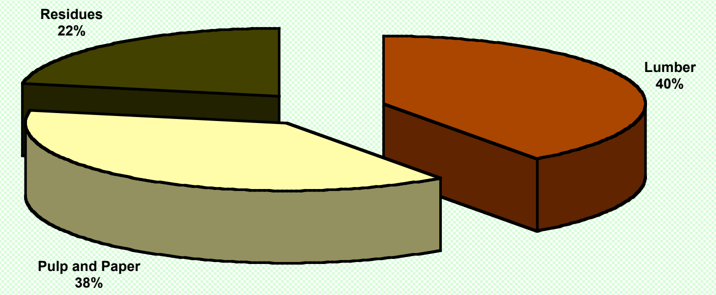
Roundwood harvested for logs and bolts leaves behind residual biomass in the form of tree tops and branches. In Tables 2.2 and 2.4 of this document, estimates were provided for the stocks of merchantable trees (i.e. potential roundwood stock) and the non-stem biomass, respectively, the latter of which is typically left at the harvest site. Fig. 2.4 shows that only about 39% of the total biomass in the timber productive forest is merchantable.

Assuming that the proportion is similar in the forest that is harvested each year, then an estimate can be made of the harvest of non-stem biomass using the roundwood harvest data. This calculation is shown in Table 2.5 and predicts that a 47.7 MtC/yr roundwood harvest would leave an additional 72.8 Mt C/yr at the harvest site for a total biomass harvest of about 120 MtC/yr.

However, the proportion of the timber productive forest that is actually harvested each year varies widely (by 10 fold) among provinces. Therefore, very different numbers are obtained for all of Canada when the values of Penner (1997) were applied to the actual annual harvest area for each province and then summed for a national total (Table 2.6). In this case, the non-stem biomass was estimated to contain about 40.4 Mt C/yr rather than 72.8 MT C/yr, and given a roundwood harvest of 47.6 MtC/yr, it was estimated to account for 54% of the total above ground woody biomass, not 39% as predicted in Table 2.4.

The more conservative values outlined in Table 2.6 were the one that have been used in the subsequent calculations carried out in this paper.

Figure 2.5 Typical Sawlog Usage



2.4.3 Non-stem Biomass for Ecological Service

Leaving some biomass at the harvest site offers a variety of benefits and promotes sustainability. Tree branches and tops provide cover for wildlife, prevent erosion, help to maintain soil carbon stocks, protect emerging tree seedlings and minimize moisture loss from the forest floor. The amount of biomass that should be left is site specific, and depends upon the nature of the harvest operation (clearcut vs. select cut), geophysical characteristics (slope, soil type and depth), local climatic considerations and predominant harvest species, as well as many other factors. Furthermore, considerable debate amongst scientists and foresters exists in regards to the amount of biomass required for site regeneration and sustainability; the percentage of required biomass is proposed to range from 0 to 100% and it is clear that no figure will adequately account for the needs of every harvest site. Thus, it is proposed that the non-stem biomass carbon and energy, presented as 40.37 M t C/yr and 1.44 EJ/yr in Table 2.6 be considered the upper limit of biomass removal. Furthermore a lower range (20.18 M t C/yr and 0.72 EJ/yr), representing a 50% reduction in biomass removal, is also proposed to ensure sustainability and to account for the specific requirements of individual sites.

Table 2.6. Summary of Harvest Site Biomass

		Non-Stem Biomass				Merchantable Roundwood			Total	
	Harvest Area[1]	Average [2]	Total	Carbon[4]	Energy[5]	Volume[6]	Carbon[7]	Energy[5]	Carbon [4]	Energy[7]
Region	ha	ODT/ha	M ODT/yr	M t C/yr	EJ/yr	M m3/ yr	M t C/yr	EJ/yr	Mt C/yr	EJ/yr
NL	17,415	54	0.94	0.41	0.01	2.87	0.68	0.02	1.10	0.04
PE	5,780	84	0.49	0.21	0.01	0.67	0.16	0.01	0.37	0.01
NS	49,680	75	3.73	1.64	0.06	6.16	1.47	0.05	3.11	0.11
NB	111,077	81	9.00	3.96	0.14	11.64	2.77	0.10	6.73	0.24
QC	384,208	70	26.89	11.83	0.42	43.48	10.35	0.37	22.19	0.79
ON	201,522	87	17.53	7.71	0.28	28.12	6.69	0.24	14.41	0.52
MB	15,509	55	0.85	0.38	0.01	2.19	0.52	0.02	0.90	0.03
SK	21,169	54	1.14	0.50	0.02	4.55	1.08	0.04	1.59	0.06
AB	42,210	78	3.29	1.45	0.05	21.93	5.22	0.19	6.67	0.24
BC	176,312	158	27.86	12.26	0.44	78.42	18.67	0.67	30.93	1.11
YT	x	72	x	x	x	0.03	0.01	0.00	0.01	0.00
NT	547	52	0.03	0.01	0.00	0.02	0.01	0.00	0.02	0.00
NU[3]	x	x	x	x	x	x	x	x	x	x
Canada	**1,025,429**	**77**	**91.75**	**40.37 (20.18)[8]**	**1.44 (0.72)[8]**	**200.1**	**47.64**	**1.70**	**88.01 (67.82)[8]**	**3.15 (2.42)[8]**

[1] Data from NRCan 1999, Compendium of Forest Statistics

[2] Data source, Penner *et al.,*1997

[3] Data unavailable.

[4] Assumes 12% water in oven dried biomass, and 50%C in dry weight, therefore 0.44 tC/ODT

[5] Calculated as 35.76 GJ/tonne C

[6] Data source, National Forestry Database Program, 2000

[7] Assumes 4.2 m3 per tC

[8] Reduced figures represent a 50% reduction in biomass removal from the harvest site to promote sustainability.

2.5. Mill Residues

Wood residues, currently available as a product of mill processing, offer a second source of waste biomass from forestry. One factor, which should not be underestimated in any analysis of mill waste use, is the fluctuating nature of the market place and the potential impact of soft wood lumber trade issues on the sustainability of spin-off industries.

Interest in extracting value from harvest residues prompted the development of a Canadian wood residue database in the early 1990s (National Wood Residue Database, Kennedy Technology Development Ltd., 1992) and the residue inventory has been maintained periodically, by a number of governmental and forest industry associations. Ongoing tracking of residue resources does not currently occur in all regions of the country.

As shown in Fig. 2.7, approximately 78% of a typical sawlog from a roundwood harvest site is useable: 40% is harvested for lumber and 38% is chipped for pulp and paper production. The remaining 22% is the residue fraction and consists of sawdust, bark and shavings. Measurements of residue production (Table 2.7), varied greatly by province but averaged about 19% nationally (equivalent to about 18 Mt Bone Dry Tonnes of biomass per year).

The residue portion may be used for a wide variety of purposes including value-added forest products and energy production, although economic considerations have meant that this fraction has been historically under-utilized.

The most recent data, compiled in 1999, shows a trend towards better utilization of forest residues (Hatton, 1999). Best estimates suggest that residue use averages 70% across the country; this fraction currently contributes to both value-added forest product manufacture, and to the production of energy through co-generation (Table 2.6).

The remaining 30% of residues (equivalent to about 2.7 MT C/yr, Table 2.6) are left along the side of logging roads if delimbing occurs in a centralized areanear the harvest site, landfilled, or incinerated without energy recovery. Incineration has been the focus of considerable debate, as the burning of mill residues, also commonly called “hog fuel” can result in the emission of particulates; both hog-fuel burners and particulate emissions are regulated by permit. Legislation to completely eliminate beehive burners, has been unsuccessful in fully addressing the problem, but an economically viable alternative could reduce the problem of particulate emission and improve efficiency of energy recovery.

Similarly, abandoning non-merchantable biomass at the harvest site, or land-filling wood residues overlooks the opportunity to harvest both bio-products and energy from this potential resource; even harvesting biogas from the landfill site would improve efficiency.

As the utilization rate of residues has increased, the availability of the surplus has fallen, and it is expected that this trend will continue. Both residue production and surplus availability are greatest in BC, AB, ON and QC, which together account for 94% of current surpluses (Hatton, 1999). AB has addressed this gap with the installation of cogeneration facilities, with more planned pending funding support.

2.6. Energy from Forest Biomass

The previous sections have examined Canada’s forest resources and reported values in Mt C stocks or Mt C harvested per year. This biomass contains a considerable amount of energy, estimated at 35.76 GJ / t C (Layzell, 2001).

For example, the 245 M Ha of the timber productive forest of Canada contains about 15,800 Mt C (Tables 2.2 and 2.4) which converts to about 566 EJ of energy. The annual energy use in Canada is about 12.6 EJ/yr, of which 8.24 EJ/yr is fossil fuel derived (Table 1.1). At any point in time, the standing biomass in the Canadian forest contains sufficient energy to provide about 45 years of Canada’s current total non-biomass energy needs, and about 69 years of Canada’s fossil fuel derived energy demand.

Each year, Canada’s forestry sector harvests about 47.7 Mt C/yr as roundwood, and about 40.4 Mt C/yr of non-stem biomass for a total harvest of 88 Mt C/yr (Table 2.6). This harvest alone has an energy content of about 3.1 EJ/yr, or approximately 36% of the current national energy that is provided from fossil fuels. When biomass removal from the site is reduced by 50% to promote sustainability and protect ecosystem balance, a total harvest of 67.82 Mt C/yr, with energy content of 2.42 EJ/yr, or approximately 29% of current national energy from fossil fuels is proposed.

Of course the majority of the roundwood harvest is used for forest products, but a significant portion of the non-stem biomass (20.2 - 40.4 Mt C/yr) should be available and has an energy content of 0.72 - 1.44 EJ/yr or as much as 17% of Canada's current fossil fuel energy use.

Table 2.7 Wood Residue Production, Use and Surplus 1998[1]

	Residue Production		Residue Utilization		Residue Surplus			
Region	**M BDT/yr[2]**	**% Harvest[3]**	**M BDT/yr[2]**	**% Used**	**M BDT/yr**	**M t C/yr[4]**	**% harvest**	**EJ/yr[5]**
NL	0.07	5.1%	0.05	71	0.02	0.01	1.46%	0.000
PE	x	x	x	x	x	x	x	x
NS	0.2	6.8%	0.14	70	0.06	0.03	2.04%	0.001
NB	0.61	10.8%	0.43	70	0.18	0.09	3.19%	0.003
QC	5.73	27.7%	4.09	71	1.64	0.82	7.92%	0.029
ON	1.53	11.5%	1.08	70	0.45	0.225	3.36%	0.008
MB	0.08	7.7%	0.06	75	0.02	0.01	1.92%	0.000
SK	0.16	7.4%	0.11	68	0.05	0.025	2.31%	0.001
AB	1.57	15.1%	0.67	42	0.9	0.45	8.62%	0.016
BC	7.75	20.8%	5.69	73	2.06	1.03	5.52%	0.037
Canada	**17.7**	**18.6%**	**12.32**	**70%**	**5.38**	**2.69**	**5.64%**	**0.096**

[1] Data source, Hatton, 1999

[2] BDT - bone dry tonnes; all water extracted from sample

[3] Calculated residue production divided by the roundwood harvest (ODT/yr, Table 2.5) corrected for the 12% water content

[4] Assumes 0.5tC/BDT biomass

[5] Assumes 35.76 GJ / tonne C

In addition, processing the roundwood yields a biomass residue that is surplus to current use in the amount of 2.7 MT C/yr and with an energy content of about 0.1 EJ/yr (Table 2.7). Therefore, without additional forest harvest, Canada has an untapped forest biomass resource of about 43.1 Mt C/yr, equivalent to 1.54 EJ/yr, an energy value of about 19% of the national fossil fuel use.

3. Biomass from Agricultural Sources

3.1. Introduction

Agricultural activity in Canada produces millions of tons of biomass each year and has the potential to offer feedstocks for bioenergy and specific bioproducts while improving the rural economy.

Biomass may be classified into two general categories: virgin biomass, which is the primary outcome of intentional biomass cultivation; and waste biomass, which comprises the residual fraction from primary harvest, as well as livestock wastes.

3.2. Agricultural Land Use

Farmland occupies about 67.5 M Ha of Canada's land area, or 6.7% of the total. Crops are grown on 36.4 Mha (3.6% of the total landmass, or 53.9% of farmland). Agricultural land use is detailed in Table 3.1.

In general, agricultural production occurs on Class 1 and 2 lands, which offer superior soils and geophysical characteristics, as well as appropriate growing seasons. These lands are concentrated in the southernmost regions of the country, and must compete with urban development. Class 3 lands may be improved and brought into cultivation, but the proportion of land used for agricultural production has increased very little over the last 25 years (Agriculture Canada, 1985; Statistics Canada, 2002).

Of the lands used for agricultural production, about 54% are used for crop production, 7% are summer-fallowed, a further 7% is used for the production of tame hay, while 23% is considered "natural pasture". Other lands are occupied by rural buildings, wetlands and bush-lots and occupy about 9% of total agricultural lands (Table 3.1).

Table 3.1 Farm Land Area, Canada, 2001

	Area (Mha)						
Region	Total Land	FarmLand[2]	Crop Land[3]	Summerfallow	Tame Pasture[4]	Natural Pasture	All Other[5]
NL	41	0.04	0.01	0.001	0.003	0.007	0.02
PE	1	0.3	0.2	0.001	0.01	0.001	0.06
NS	6	0.4	0.1	0.001	0.02	0.03	0.2
NB	7	0.4	0.1	0.001	0.02	0.03	0.2
QC	154	3.4	1.8	0.01	0.2	0.2	1.2
ON	108	5.5	3.7	0.01	0.3	0.5	1.0
MB	65	7.6	4.7	0.3	0.4	1.6	0.7
SK	65	26.2	15.4	3.1	1.4	5.1	1.2
AB	66	21.1	9.7	1.2	2.2	6.7	1.2
BC	94	2.6	0.6	0.04	0.2	1.2	0.5
YT	48						
NT	135						
NU	209						
Canada	**998**	**67.5**	**36.4**	**4.7**	**4.8**	**15.4**	**6.2**

[1] Data source, Statistics Canada, Census of Agriculture, 2001

[2] Includes all farms reporting income from agricultural production.

[3] Includes all crops except Christmas tree production.

[4] Includes all tame and seeded pasture lands.

[5] Includes Christmas tree production.

3.3. Crop production

3.3.1. Crop Types and Production Rates

Many of the agricultural crop species grown in Canada store carbon in the form of starch. This group includes the cereal grains (wheat, barley, oats, rye), and grain corn. Together, starch-producing crops occupy 59% of the land area devoted to the production of the **ten major crop species**, and account for 54% of the dry tonnage produced (Table 3.2).

Other crops, such as canola, soybeans and flaxseed are grown for their carbon dense seed oils (lipids). Seed oil crops occupy approximately 17% of the land area devoted to major crops, and produce about 9% of the total crop tonnage.

The remaining portion of land devoted to the ten major crops (23%) is used to produce forage crops such as tame hay, and fodder corn. Forage crops, which contain lignocellulosic carbon, are essential livestock feeds and represent 36% of major crop production.

The major crops listed in Table 3.2 each occupy a significant land area and have dedicated market commitments. Nevertheless, the total area occupied by these crops (31.8 M ha) represented only 47% of all agricultural lands (67.5 M ha) in 2001 (Statistics Canada, 2001

Table 3.2 Agricultural Crop Production, Canada[1]

	Production					
Crop	**Area M ha**	**Yield ODT/ha**	**Total M ODT**	**C in Yield Mt C/yr**	**C in plant[3] Mt C/yr**	**Energy EJ/yr**
Wheat	10.95	1.88	20.57	8.64	17.28	0.62
Barley	4.70	2.31	10.85	4.56	9.11	0.33
Oats	1.91	1.41	2.69	1.13	2.26	0.08
Grain corn	1.29	6.42	8.31	3.49	6.98	0.25
Sum of starch crops	**18.85**		**42.42**	**17.81**	**35.63**	**1.27**
Canola	3.83	1.29	4.93	2.46	4.93	0.18
Soybeans	1.08	1.51	1.63	0.82	1.63	0.06
Flaxseed	0.67	1.06	0.72	0.36	0.72	0.03
Sum of oil crops	**5.58**		**7.27**	**3.64**	**7.27**	**0.26**
Rye	0.18	1.26	0.23	0.10	0.10	0.00
Fodder corn	0.18		5.21	2.19	2.19	0.08
Tame hay	7.07	3.27	23.15	9.72	9.72	0.35
Sum of forage crops	**7.44**		**28.59**	**12.01**	**12.01**	**0.43**
Totals	**31.87**	**av. 2.27**	**78.27**	**33.46**	**54.91**	**1.96**

[1] Crop production and area statistics from Statistics Canada, Census of Agriculture 2001, with the exception of "fodder corn", which is derived from provincial statistics for 2001. Area devoted to fodder corn production is underestimated because of non-reporting by the Province of Alberta, which reveals production tonnage, but not production area; thus, yield has not been calculated for this parameter.

[2] Carbon content is assumed to be 50% of oil seed crops and 42% of starch seed crops and forages.

[3] Assumes a harvest index of 50% for seed crops and 100% for forage crops.

Census of Agriculture).

The remaining land base includes arable land that is more fluid in seasonal usage and encompasses the demands of livestock rearing, specialty crop production, fruit and vegetable production, ornamental and landscape species cultivation and numerous minor enterprises. As well, some land is occupied by farm buildings, roads, wetlands and bush and is not considered readily available for crop production.

Cultivation of biomass for bioenergy or for targeted bioproducts seems likely to initially occur on less dedicated agricultural lands, where localized response to regional needs may be more quickly addressed, and where a strong interest in non-food uses of agricultural crops has already been identified (Jannasch *et al.*, 2001).

3.3.2. Annual Carbon Production

Since oil is more highly reduced than starch, oil seeds (e.g. canola, soyeans) have a higher C content (about 50% of dry weight) than that of starch containing seeds such as wheat or corn (about 42% of dry weight). Similarly, lignocellulosic plant material has a C content of about 42% of dry weight (Klass, 1998).

Assuming these values, the carbon content of the agricultural harvest in Canada is about 33 Mt C / yr, 53% of which is associated with the starch producing crops.

However, an accurate assessment of the carbon content related to yield must also account for the portion of the plant that is harvested. Forage crops are harvested nearly intact, and hence are considered to have a harvest index of 100%; in contrast, the reported harvested portion of cereal grains and seed crops represents only about 50% of the total plant mass and consequently, only 50% of the total carbon. From the ten major agricultural crops listed in Table 3.1, carbon content of the entire crop has been estimated at 55 Mt C/yr (Table 3.2).

The difference between the whole plant C yield and the crop yield is about 21.4 Mt C/yr and is considered to be crop residue, consisting of straw and chaff of cereal crops, stover of corn and unused fodder crops.

3.4. Crop residues

3.4.1. Factors Affecting Residue Production

The maximum C potential of crop residues overestimates true availability because some residues must remain in the field to ensure soil fertility, and other portions are lost during collection. As well, residues perform traditional roles, serving as animal bedding and agricultural mulches.

Straw to grain ratios vary with individual crop species, and the extent of drought stress experienced by the crop in an individual year. When the soil type and soil moisture deficit (SMD) data is known for an individual region, the straw to grain ratio may be predicted with a high degree of accuracy (see “Agricultural Fibre in Manitoba”, 2000). Under average weather conditions, the straw to grain ratio for wheat is conservatively estimated to be 1.3:1 (Klass, 1998; Levelton, 2000); all other seed crops are assumed to average a 1:1 ratio of harvested to residue fractions.

Both of these ratios reflect the lower limit of actual production, which may be as high as 1.7:1 for wheat (Levelton, 2000) and 1.4:1 for other crops (Helwig *et al.,* 2002). It is important to note that the amount of straw produced can be altered simply by cultivar selection and that this particular characteristic is one amenable to adjustment both by traditional breeding methods and by genetic alteration, thus offering growers the potential for economic reward when residues are in demand.

The development of new semi-dwarf varieties of wheat with improved wind tolerance and lower lodging rates, in contrast, produced similar amounts of crop residue, but a larger proportion of chaff to harvestable straw (Bulman *et al.,* 1995). While semi-dwarf varieties are not yet widely grown, improving collection technology to capture more chaff would allow producers to reap the benefits of better field characteristics, while retaining optimal residue biomass (Prairie Agricultural Machinery Institute (PAMI, 2003).

3.4.2. Use of residues to maintain soil health

In all crop systems, a portion of the crop residue must be returned to the soil to ensure the maintenance of soil tilth, humic content and fertility. The requirements of individual soils depend on a number of factors, which include but are not limited to, soil type and pH, soil fertility and method of fertility enhancement, susceptibility to wind or water erosion, the nature of crop rotation patterns and the depth of tillage.

For cereal crops, residues may be removed when yield exceeds 4.0 t/ha (Kerstetter and Lyons, 2001; assumes 2.4711 acres/ha, 2204 lbs/t, 36.7 bushels of wheat/t). On prairie soils, between 750 and 1500 kg/ha of crop residue is essential to prevent wind erosion (Bulman *et al.,* 1995), with conservation tillage reducing the requirements to the very lowest end of this scale (Larson, 1979).

Minimal residue requirements for cereal croplands are estimated to be 20% of total crop residues (Stumborg *et al.,* 1996). At the present time, grain corn, canola and soybean stovers are often not removed from the field, primarily because there is no infrastructure for their subsequent use. Under conservation tillage systems in Ontario and Quebec, the advantages of improved soil warming in the spring and facilitation of seedling emergence are believed to justify the cost of grain corn stover removal (Helwig *et al.,* 2002); this stover is usually composted or burned without energy capture.

3.4.3. Recovery of stover residues

Biomass of soybean and canola stover are estimated to be equal the harvested crop, but may be difficult to recover as natural degradation processes cause leaf drop by the time seed pods are sufficiently dry for harvest. Similarly, wet fall conditions frequently delay the harvest of grain corn until after the soil has frozen and considerable biomass losses have occurred.

The relationship between mass of stem and leaf tissue at the time of harvest is not known, so the recovery rate of stover has been reduced to 50% to account for anticipated losses during harvest. Similarly, other crops have been assumed to have lower than ideal recovery rates to account for the vagaries of harvest season weather, and consequent losses due to excessive moisture or mud.

Improvements in the recovery of residues offer the potential to increase biomass availability by 30 – 40 percent (PAMI, 2003). This single factor could mean an increase in carbon harvest from 14.6 Mt C/yr to 20.4 Mt C/yr.

3.4.4. Market diversions of agricultural residues

Historically, agricultural residues have been used for livestock bedding, insulation and mulching. More recently, interests in using straw for ethanol production (Iogen Corp., Ottawa, ON) or the manufacture of composite board (“Wood Stalk ”, Dow-Bioproducts, Elie, MB) have created local demand for cereal grain straw and prompted interest in improving efficiency of harvest and transportation infrastructure (PAMI, 2003).

In Eastern Canada, approximately 65% of straw residues supply existing markets (Helwig *et al.,* 2002), but the distribution of usage is very different in the Western provinces. In Manitoba for example, 93.5% of barley straw is committed to livestock bedding but only 6.7% of wheat straw is used for livestock bedding with a further 6% used for the production of strawboard in the Elie plant just west of Winnipeg; by comparison, there is virtually no demand for the

600,000 tonnes of oat straw produced per year (see, “Agricultural Fibre in Manitoba”, 2000). Only 25.8% of the total 4.7 M tonnes of straw available in Manitoba supplies dedicated usage, and burning in the field eliminates a considerable fraction

In the calculations presented here, 50% of cereal grain straw is considered to be available although this number seems very low given the apparent potential outlined by the Manitoba statistics, which suggest that over 70% of straw may be available. Actual harvest data however, show extreme variability in the production of straw residues over the six-year period from 1992-1998 (see, “Agricultural Fibre in Manitoba”, 2000) as a result of poor weather conditions. Over the longer term, 50% availability provides a more realistic framework for biomass planning in the west and more accurately matches harvest data for Eastern Canada, where weather patterns were less severe over the same survey period and harvests more stable.

For crops such as grain corn, where stover has not traditionally been harvested, 100% of recoverable residues are considered available for biofuel or bioproducts manufacture or for use as an energy source.

Agricultural residues that are recoverable from the field, while preserving soil integrity and accounting for losses during the harvest process, provide 14.6 Mt C/yr with an energy value of 0.5 EJ. Traditional uses reduce current availability to 8.6 Mt C/yr, with energy potential of 0.3 EJ, but emerging markets have already shown that residue diversion can occur quickly with economic motivation.

Table 3.3 Biomass from Agricultural Crop Residues in Canada, 2001

	Yield of Crops and Crop Residues						Currently Available Residues		
Crop	Total Production	Straw/ Stover	Sustainably Removable Residues (SRR)[1,2,3,4]	Recoverable SRR[5]		Energy Potential of SRR[8]	Amount Available[6]	C Content[7]	Energy Potential[8]
	M ODT/yr	**M ODT/yr**	**M ODT/yr**	**M ODT/yr**	**M tC/yr**	**EJ/yr**	**M ODT/yr**	**Mt C/yr**	**EJ/yr**
Wheat	20.6	26.7	21.4	14.97	6.74	0.241	7.49	3.37	0.120
Barley	10.8	10.8	8.68	6.07	2.73	0.098	3.04	1.37	0.049
Oats	2.7	2.7	2.15	1.51	0.68	0.024	0.75	0.34	0.012
Grain corn	8.3	8.3	6.65	3.33	1.50	0.054	3.33	1.50	0.054
Canola	4.9	4.9	3.94	2.76	1.24	0.044	2.76	1,24	0.044
Soybeans	1.6	1.6	0.33	0.16	0.07	0.003	0.16	0.7	0.003
Flaxseed	0.72	0.72	0.57	0.40	0.180	0.006	0.20	0.9	0.003
Rye	0.23	0.23	0.18	0.13	0.57	0.002	0.06	0.29	0.001
Fodder corn	5.2	0	0	0	0.26	0.009	0.26	0.12	0.004
Tame hay	23.1	0	0	0	1.157	0.041	1.16	0.52	0.019
Totals	**78.27**	**56.09**	**43.89**	**29.33**	**14.62**	**0.523**	**17.79**	**8.64**	**0.309**

[1] Assumes that straw to grain ratio for wheat is 1.3:1 (Levelton, 2000 Assessment of net emissions of GHG from EtOH-blended gasolines in Canada; lignocellulosic feedstocks, R-2000-2 AAFC). This ratio represents the lower end of Levelton's proposed range of 1.3 - 1.7:1.

[2] Assumes a straw to grain ratio of 1:1 for all other cereal grains (Helwig *et al.*,2002).

[3] Stover from grain corn production in Eastern Canada averages 2.5 ODT/ha and equals the quantity of corn grain harvested in OTDs (Helwig *et al., 2002).* Statistics Canada, however, shows that harvested yield averages just over 6 ODT/ha which is substantially different... it is unclear whether the Stats can figure includes fodder and grain corn, or grain corn alone. A 1:1 ratio of harvested crop to stover is assumed.

[4] Assumes an average sustainable removal rate of 80% (Klass, 1998; Helwig *et al.,* 2002) for all crops except soybean. Soybean stover is not generally considered harvestable except on conservation tillage soil, which constitutes approximately 20% of soybean land, where they may be completely removed. Hence, yield of sustainably removable soybean residues is assumed to be 20% of stover.

[5] Assumes that not all sustainably removable residues may be retrieved, and reduces these by 30% to account for difficulties during recovery, except for grain corn and soybeans, which are reduced by 50% to account for late harvest.

[6] Assumes that biomass will continue to be diverted to traditional uses, leaving available: 50% of cereal straws; 100% of recoverable grain corn stover, canola, and soybean stover; 5% of fodder corn, and tame hay which is unused in an average year (Helwig *et al.,* 2002). This assumption overestimates availability of straw in NB and PEI, where production is quite low, and underestimates availability in MB and SK where production is higher on average.

[7] Carbon content is based on an average yield for agricultural residues of 45% C in OD biomass (Bioenergy Conversion Factors_ .

[8] Assumes that 35.76 GJ of energy may be derived from each tonne of carbon from dried biomass. This conversion factor has been tested against upper and lower heating values, both theoretical and measured, for a variety of biological feedstocks and is accurate to 5% in every case. Comparative figures from Klass, 1998, were used to derive this conversion factor.

3.5. Biomass from livestock waste

Livestock manure is a readily available source of waste biomass in Canada. In general, manures are used directly as soil amendments, and the opportunities for deriving energy is overlooked.

However, there are problems associated with direct application of manure to soils including bacterial contamination of surface and groundwater supplies, over-enrichment of soils with nitrogen or phosphorus and nuisance odours. In addition, manure produces methane gas and nitrous oxide, two potent greenhouse gases.

Treatment of manure by aerobic or anaerobic digestion systems, with concomitant harvest of biogas, could mitigate these problems, while producing a nutrient-rich fertilizer and providing a renewable energy resource.

3.5.1. Livestock Waste Production

Table 3.4 shows livestock waste production by four major industries: dairy, beef, poultry and swine, while Table 3.5 demonstrates the biogas and heating potential for each industry. Energy derived from livestock waste is expected to supply on-farm requirements, although larger farms have the potential to supply some off-farm users as well.

Estimates show that typical household electrical demands could be met by the average Quebec dairy farm, which would offer a considerable savings to the farm owner/operator (Helwig *et al.,* 2002). While energy potential from manure wastes will not address a large

Table 3.4 Livestock Manure Production, Canada, 2001

Livestock	Number of Animals[1]	Average mass/animal[2]	Manure animal/day[3]	Daily total	Yearly total	% Recoverable[4]	Recoverable manure/yr
		Kg/animal	**Kg/animal**	**M kg**	**Mt**	**%**	**Mt**
Dairy (mature cows)	1,060,965	636	52	55	19	75	14
Beef (large animals)	6,533,500	568	34	222	81	25	20
Poultry	126,159,529	1	0.06	8	2	85	2
Swine	13,913,001	90	5	72	26	85	22
Totals	**147,666,995**	**-**	**-**	**357**	**128**		**58**

[1] Assumes the number of living animals at any time during the calendar year; poultry numbers are for the standing flock and are calculated by dividing yearly production by the number of flocks raised per year. Poultry numbers are for meat chickens only, and do not include laying hens or turkeys. Beef and dairy livestock numbers are based on mature animals and do not include calves. Statistics Canada livestock inventory numbers, used here, do not match provincial data; available provincial data are consistently higher.

[2] Assumes that average slaughter weight for steers and heifers is 400 kg, 500 kg for cows and 800 kg for bulls; average slaughter weight for swine is 120 kg.

[3] Mass of manure produced per animal per day (Helwig *et al.,* 2002). While these figures are not for oven dried residues and moisture content varies depending upon food source, and method of manure collection, they are within the scope of other sources, such as Klass, 1998 and Statistics Canada, when moisture content is calculated at 50% of mass.

[4] The percentage of recoverable manure depends on the growth environment of the livestock. Manure from field grazed animals is considered lost due to difficulties in collection. The percentages used are highly conservative and actual recovery rates could be much higher on individual farms.

proportion of Canada's total energy requirement, the possibility of meeting local need is significant.

Some technological hurdles associated with efficient function of digester systems in cold Canadian climates must be addressed, but recent nutrient management legislation designed to minimize the environmental impact of animal wastes will be a strong motivator for producers to consider digesters for their multiple advantages, and livestock wastes for their carbon potential.

Table 3.5 Biogas and Heating Potential from Livestock Wastes, 2001

Livestock	Recoverable manure/yr	Biogas Potential[1]		% methane[2]	Energetic heating value[3]	
	Mt	m^3/day	m^3/yr	%	GJ/day	GJ/yr
Dairy (mature cows)	14	1,504,086	548,991,590	54	29,808	10,880,015
Beef (large animals)	20	4,661,092	1,701,298,790	53	92,470	33,751,572
Poultry	2	515,061	187,997,626	60	11,445	4,177,725
Swine	22	2,003,269	731,193,287	58	43,108	15,734,539
Totals	**58**	**8,683,508**	**3,169,481,293**		**176,831**	**64,543,849**

[1] Assumes that conversion of ft^3 to m^3 = ft^3/35.315 (Klass, 1998), and conversion of lbs to kgs = lbs/2.205. Also assumes that biogass production per 493.8 kg body weight for beef is 0.62 m^3/day, for dairy is 1.10 m^3/day, for poultry is 1.44 m^3/day and for swine is 0.79 m^3/day, (Helwig *et al.,* 2002). Biogas calculated as livestock biogas production constant/493.8kg bodyweight X number of animals X average weight/animal.

[2] Percentage methane presented is specific for different livestock species and may vary according to available feeds. The values presented here are from Helwig *et al.,* 2002 and are consistent with values expressed in other sources such as Klass, 1998 where a variety of measurement techniques are compared.

[3] Energetic heating value calculated as per Helwig *et al.,* 2002, using derived constants for dairy, 0.021 GJ/493.8 kg bodyweight; beef 0.012 GJ/493.8 kg; poultry 0.032 GJ/493.8 kg; and swine 0.017 GJ/493.8 kg. Energetic heating potential presumes the combustion of dried wastes.

3.6. Summary of Biomass from Agricultural Sources

Farmland occupies 67.5 M ha (6.7% of Canada's total land mass) and this land is used for the annual production of crops and animals, primarily for food and feed (Table 3.1).

Crop production involves 36.4 M ha of land. Of this area, about 32 M ha are planted each year to produce a crop yield with a carbon content of about 33.5 Mt C/yr (Table 3.2). The total yield of the above ground biomass from these plants has a carbon content of roughly 55 Mt C/yr, with an energy content of about 2 EJ/yr (Table 3.2). This energy content is equivalent to about 24% of the annual fossil fuel energy use in Canada.

Agricultural residues were estimated to have a total of 56 M ODT/yr, but some of this residue must be incorporated into the soil to maintain soil fertility and carbon content. However, the recoverable portion contains 14.6 Mt C/yr, with an energy potential of 0.52 EJ/yr (Table 3.3). This represents about 25% of the energy content in the annual agricultural harvest in Canada, and is equivalent to about 6.3% of the fossil fuel energy use in Canada.

However, not all residue is likely to be available since there are some traditional uses for the straw and stovers, including animal bedding and mulching. When these amounts are considered, as well as a discount for variability in harvest success, agricultural biomass availability may be as low as 8.6 Mt C/yr, having a energy content of 0.31 EJ/yr (Table 3.3). This represents about 16% of the energy content in the annual agricultural harvest in Canada, and is equivalent to about 3.7% of the fossil fuel energy use in Canada.

Research to improve harvesting equipment to better gather crop residues, and to reduce handling costs is currently underway (PAMI). Considerable interest in innovative agricultural product development, and commitment of research and development funds has already been made (CARC, Pembina, BIOCAP).

Livestock wastes could produce over 3 billion m^3 of biogas annually through anaerobic digestion. This process could provide an energy source of 0.065 EJ/yr, an amount equal to 3.3% of the annual agricultural harvest, or 0.8% of the current fossil fuel energy use in Canada. As well as providing energy, digestion of livestock wastes mitigates odour and reduces the risk of surface and groundwater contamination and complies with "nutrient management" initiatives recently introduced. Digested livestock manure is an excellent soil amendment.

4. Biomass from Municipal Waste

4.1. Municipal waste as a source of biomass

Anthropogenic wastes contain discarded energy-containing biomass materials, often of virgin biomass origin. Because the disposal of wastes is costly, and has negative environmental impacts, it is advantageous to remove and recycle biomass from disposed materials. By doing so, the volume of solid waste may be dramatically reduced, nuisance odors controlled, bacterial pollution of water resources minimized and the opportunity for energy derivation optimized.

Municipal solid waste is highly abundant, particularly in regions of greatest population density, and is generated with a steady flow. The fact that wastes tend to be concentrated in production permits centralization of processing. In Canada, approximately 750 kg/person of municipal solid waste is generated each year (derived from Statistics Canada, 2000).

4.1.1. Generation of municipal solid wastes

In general, municipal solid wastes (MSW) may be considered to fall into three categories: urban or residential wastes, which are generally picked up at the curb or transported directly by the producer to landfill; industrial, commercial and institutional (I, C & I) wastes, which arise from commercial enterprises and are temporarily stored on-site in bulk-lift containers before haulage; and demolition, landscaping and construction (DLC) wastes, which are usually trucked directly to landfill. Canadian municipal waste generation data, as tabulated by municipalities on the basis of wastes for which tipping fees must be paid, is summarized by province and source in Table 4.1. A majority of municipal waste is disposed of by landfilling; some smaller communities have limited combustion programs as well.

4.1.2. Diversions of municipal solid wastes by recycling

Not all municipal solid wastes generated are disposed of through landfilling or combustion: an increasingly significant proportion of waste is diverted from landfill through recycling. Recycling may occur at residential, commercial or industrial sources, and diverts approximately 24% of generated wastes on a per capita basis as shown in Table 4.2. Other sources suggest that residential and IC&I source recycling occurs at a significantly lower level than reported (Chornet, 2002).

4.1.3. Biomass potential of recycled materials

Over 60% of recycled materials have biomass potential, and a carbon value totaling 2 Mt C/yr, as summarized in Table 4.3. Some recycled materials serve dedicated markets, but the extent of these markets varies widely geographically, leaving unused biomass suitable for energy production in every region. An accurate assessment of biomass availability is made more difficult by the variability in recycling strategies and capabilities. It is clear, however, that in all regions there is strong potential for extracting biomass materials from recycled wastes, and that commitment to recycling is an increasing trend.

Table 4.1 Generation of Municipal Solid Wastes, 2000

	Sources of Municipal Solid Wastes				
Region	Urban[1]	IC&I[2]	DLC[3]	Sum[4]	Per Capita[5]
	tonnes				kg/person
NL	**x**	**x**	x	x	842
PE	x	x	x	x	746
NS	266,503	287,025	24,561	578,089	615
NB	273,159	279,572	x	552,731	750
QC[6]	3,457,320	4,840,380	1,383,500	9,681,200	1,312
ON	3,807,311	5,080,065	975,281	9,862,657	925
MB	358,222	x	x	358,222	1,007
SK	380,851	x	x	380,851	1,074
AB	822,310	1,618,907	x	2,441,217	x
BC	1,168,668	x	x	1,168,668	x
YT, NT, NU	x	x	x	x	778
Canada	**10,869,156**	**15,814,967**	**3,802,440**	**25,023,634**	**1,021**

Source: Statistics Canada, 2000

Numbers may not add up due to rounding.

x - Provinces may choose non-disclosure of Provincial data under the Secrecy Act.

[1] Assumes amount of non-hazardous residential waste disposed of in public and private waste disposal facilities. Does not include wastes disposed in hazardous waste disposal facilities or wastes managed by the producer on site.

[2] Assumes Industrial, Commercial, and Institutional (IC&I) solid non-hazardous recyclable materials are those generated by all IC&I sources in a municipality, and are excluded from the residential waste stream. These include: industrial recyclable materials, which are generated by manufacturing and primary and secondary industries, and managed off-site from the manufacturing operation; commercial recyclable materials, which are generated by commercial operations such as shopping centres, restaurants, offices, etc; and institutional materials which are generated by institutional facilities such as schools, hospitals, government facilities, seniors homes, universities, etc.

[3] Assumes construction and demolition non-hazardous recyclable materials refer to materials generated by demolition, land-clearing and construction (DLC) activities. These generally include materials such as concrete, brick, painted wood, rubble, drywall, metal, cardboard, doors, windows, wiring, etc. but exclude materials from land clearing on areas not previously developed, asphalt and clean sand or gravel.

[4] Does not include net exports of garbage, which exceed 900,000 t in Ontario alone and are not disclosed by other provinces.

[5] All population data from Statistics Canada , CANSIM, Table 051-0001.

[6] Data derived from provincial survey.

Table 4.2. Diversions of Municipal Wastes by Recycling, 2000

Region	Diversions of Municipal Solid Wastes by recycling					Rate of diversion per capita
	Urban[1]	IC&I[2]	DLC[3]	Sum[4]	Per Capita[5]	
	tonnes				kg/person	%
NL	x	x	x	43,010	80	10
PE	x	x	x	x	x	x
NS	77,735	x	x	145,602	155	25
NB	44,697	x	x	114,896	152	20
QC	830,760	1,246,140	692,300	2,769,200	375	29
ON	876,259	1,361,743	133,073	2,371,076	203	22
MB	50,416	x	x	215,671	188	19
SK	52,141	x	x	268,830	263	25
AB	156,335	x	x	422,595	140	14
BC	402,209	x	x	1,128,115	278	30
YT, NT, NU	x	x	--	x	x	x
Canada	**2,519,080**	**4,016,210**	**977,254**	**7,501,536**	**244**	**24**

Notes as for Table 4.1

Table 4.3. Carbon Content of Recycled Materials

Recyclable Material	Amount Recycled	% Recycled Materials	C-Source Materials	C Yield
	tonnes/yr	%	ODT/yr	t C/yr[1]
Newsprint*	657,813	8.7	592,032	260,494
Cardboard and boxboard*	555,059	7.4	499,553	219,803
Mixed paper*	1,725,472	23	1,552,925	683,287
Glass	344,353	4.6		
Ferrous metals	1,904,616	25.4		
Copper and aluminum	42,596	0.6		
Other metals	327,557	4.4		
Plastics*	171,018	2.3	153,916	93,889
Construction and demolition*	501,624	6.7	451,462	225,731
Organics*	980,787	13.1	882,708	538,452
Other materials	290,641	3.9		
Total	**7,501,536**	**100.1**	**4,132,596**	**2,021,656**

Data Source: Statistics Canada, 2000

*Categories have biomass energy potential, if diverted from current usage. Together, these categories constitute 55.1% of recycled materials, or 4,132,596 tonnes.

[1] Assumes that recycled paper products have an average carbon content of 44%; wood products a carbon content of 50% and plastics and organics have a carbon content of 61% (Klass, 1998).

4.2. Energy potential of recycled materials

Assuming that 35.76 GJ of energy are produced per tonne of dried biomass carbon, a total of 0.07 EJ of energy are available from the recycled biomass components of MSW, with the best potential for mixed paper and organics. Direct derivation of heat energy from recycled materials may not be the most efficient approach for claiming this carbon source. More typically, recycled materials are processed into consumer products. Reclaimed paper, for example may be recycled into paper, or used for boxboard manufacture; the real energy saving in this instance comes from the reduction in energy used for primary manufacture along with the reduction in use of primary carbon resources, with savings evaluated on a case-by-case basis.

4.3. Energy potential of disposed municipal wastes

Despite diversions of specific waste components to recycling, MSW contains on average 85% combustible materials from which energy may be derived by a variety of methods. These technologies include combustion, pyrolysis, gasification and production of biogas through aerobic or anaerobic fermentation. The first three technologies listed require the removal of approximately 22.5% moisture from the raw garbage, but offer great potential both for the capture of energy and the production of specific bio-products.

Table 4.4 Energy Potential of Disposed Municipal Solid Wastes, 2000

	Total Disposed Wastes	**Combustible Fraction (CF)[1]**	**Dried CF[2]**	**Carbon Yield[3]**	**Energy Potential[4]**
Region	**tonnes**				**EJ/yr**
NL	409,599	348,159	269,824	110,628	0.004
PE	x	x	x	x	x
NS	432,487	367,614	284,901	116,809	0.004
NB	472,612	401,720	311,333	127,647	0.005
QC[6]	6,912,000	5,875,200	4,553,280	1,866,845	0.067
ON	7,491,581	6,367,844	4,935,079	2,023,382	0.075
MB	938,624	797,830	618,318	253,510	0.009
SK	828,359	704,106	545,682	223,730	0.008
AB	2,750,004	2,337,503	1,811,565	742,742	0.027
BC	2,592,191	2,203,362	1,707,606	700,118	0.025
YT, NT and NU	x	x	x	x	x
Canada	**22,985,027**	**19,403,339**	**15,037,587**	**6,165,411**	**0.224**

[1] Assumes that 85% of MSW is combustible (Klass, 1998).

[2] Assumes that average moisture content of MSW is 22.5% (Klass, 1998).

[3] Assumes that carbon yield from MSW averages 41% (Klass, 1998).

[4] Assumes 35.76 GJ/t dried biomass.

Concerns about the emission of particulates from combustion processes caused a shift to landfilling in Canada, and an overall decline in the support for incineration. Improvements in combustion technology have shown that particulate emission is manageable and that substantial energy capture, as well as a reduction in the need for landfilling sites, are measurable benefits.

A Japanese model has demonstrated long-term success, and modern co-generation facilities are now operational in Ottawa. Energy potential of disposed municipal wastes, based on carbon yield is presented in Table 4.4. The total energy potential is 0.22 EJ, which represents 2.7% of Canada's total annual energy use from fossil fuels (Table 1.1). With the addition of energy from recycled materials, combined MSWs could produce 2% of total energy consumption. In their document "Renewables in global energy supply, 2001", the International Energy Agency (www.iea.org) suggests that energy derived by combustion of biomass from municipal solid wastes is worthy of consideration in outlying, off-the-grid areas of Canada.

Clearly the potential for co-generation of energy using MSW as the carbon source, is real and most concentrated in areas of population density. Combustion of MSW using modern technology offers added benefits of environmental protection and waste management.

Derivation of energy from MSW is also possible without immediate combustion, as has been explored through a pilot project operated at the City of Sherbrooke, QC through the cooperative efforts of Universite de Sherbrooke, Enerkem Technologies Inc., and Groupe Kemestrie Inc.(Chornet, 2002). Residential and ICI MSWs brought to the pilot project site are sorted. Recyclable metals and glass are removed and sent to the appropriate recycling facilities, putrescent materials are composted and non-recyclable residues are gasified to produce syngas used for generation of heat, steam or electricity. Economic analysis shows that this method of garbage handling is cost effective when tipping charges for landfilling exceed $30 US/ tonne, with the added value of recovering energy for co-generation. Tipping charges are expected to rise as restrictions on landfilling are implemented.

4.4. Municipal biosolid generation and availability

A second source of municipal biomass is biosolids, or sewage sludge, that is the product of treatment of wastewater. Wastewater treatment facilities are used to remove excrement as well as particulate, organic, bacterial, chemical and toxic materials from residential and industrial effluent

Table 4.5 Biosolid Generation, 2001

Region	Population[1]	Population served by water treatment[2]	Available biosolid residues[3]		Combustion energy potential[4]
			kg/day	t/yr	GJ/yr
NL	531,595	414,644	26,122	9,534	181,160
PE	139,913	109,132	6,875	2,509	47,680
NS	944,765	736,917	46,425	16,945	321,962
NB	756,652	590,189	37,181	13,571	257,856
PQ	7,455,208	5,815,062	366,348	133,717	2,540,629
ON	12,068,301	9,413,275	593,036	216,458	4,112,706
MB	1,150,848	897,661	56,552	20,641	392,192
SK	1,011,808	789,210	49,720	18,147	344,809
AB	3,113,586	2,428,597	153,001	55,845	1,061,066
BC	4,141,272	3,230,192	203,502	74,278	1,411,287
YT, NT, NU	100,042	78,033	4,916	1,794	34,092
Canada	**21,585,857**	**16,836,968**	**1,060,729**	**387,166**	**7,356,155**

[1] Statistics Canada, CANSIM II 051-00001

[2] Assumes 78% of wastewater undergoes primary, secondary or tertiary treatment (Eco-research Chair of Environmental Law and Policy, 2002).

[3] Assumes biosolid production of 0.063 dry kg/person/day (Klass, 1998) and that all biosolids removed by wastewater treatment are available for energy production.

[4] Assumes lower heating value of 19 MJ/dry kg of sludge (Klass, 1998).

waters before these are returned to surface waters such as lakes and streams.

Although Canada has made good improvements in the proportion of the population served by municipal wastewater treatment, increasing from 64% to 78% of the population in the years between 1990 and 1997, over 90 municipalities including the cities of Victoria, Halifax and St, John's continue to dump raw untreated sewage into their local waterways (Eco-research Chair of Environmental Law and Policy, 2002). While the trend in Canada is clearly towards improving the extent of treatment of wastewater, only 33% of wastewater treatment is at the highest or tertiary level. All treatment levels remove the biosolids proportion, but may not inactivate the bacterial fraction or remove toxic chemicals.

As a consequence, disposal of biosolids is problematic. In most regions, the favoured approach is to spread the biosolids on agricultural land, where it acts as a fertile soil amendment. Sites are selected according to stringent criteria set out by provincial government environmental agencies; these criteria are intended to minimize contamination of surface or groundwater supplies, avoid nuisance odour complaints and select for lands where crops intended for animal consumption are grown (OMOE and OMAFRA, 1996). In fact, areas where all the criteria may be adequately met are in short supply, so that spreading sites may be heavily loaded. As well, biosolids are often not adequately stabilized and may contain high levels of contaminates (Ho, T. 2001).

Where disposal by land application has become a problem, disposal of biosolids in landfill is a favoured option. A better solution may be to subject biosolids to fermentative processes, which serve to stabilize the bacterial component, permit the time needed for precipitation of toxic chemicals, and produce a high-grade biogas that may be captured and used for co-generation. The resulting low-odour, lower volume and biologically inert sludge may be used as a soil amendment with fewer complications. This option may be economically beneficial for municipalities, as they currently must pay for the use of land as well as shipment to the site; sale of sludge as fertilizer is not currently permitted in Canada. Furthermore, co-generation may offset the energy cost of treating an increasing volume of sludge to a higher degree.

As with the production of MSWs, biosolids are produced with consistency and in greater concentrations where population density is highest. In non-urban areas, wastewater treatment tends to be simpler (primary) or non-existent. About 9% of the Canadian population has no available treatment for sewage, although the bulk of this fraction is captured by septic systems (Eco-research Chair, 2002). The trend for increasing attention to the extent of wastewater treatment is expected to ensure an increasing volume of biosolids, which may be viewed as biomass suitable for energy production. The extent of biosolids generation, based on population is shown in Table 4.5.

4.5. Energy potential of biosolids

Biosolids do not represent a huge biomass resource and energy potential through combustion represents only 0.5% of Canada's energy requirement. However, the treatment of biosolids will require an increasing proportion of municipal energy and finances over time. Biogas production from biosolids can meet the energy requirement for biosolid tertiary treatment with additional potential for contribution to the municipal grid.

An excellent example of the potential for energy production is the Edmonton Waste Management Centre of Excellence (EWMCE), which produces biogas from both MSW and biosolids in separate facilities. Capture and burning of biogas from biosolids produces sufficient energy to operate the treatment plant, with an excess of 40%, which will eventually be used for the production of electricity (www.ewmce.com/fac2.html).

In regions where total wastewater treatment capacity is relatively small, energy capture through combustion is also a realistic option, and the energy potential from combustion is presented in Table 4.5. It should be noted that the ash fraction from biosolid combustion is considered a suitable mineral amendment for agricultural soils and horticultural applications, providing that industrial effluents with high chemical loads do not contribute to pre-treatment wastewater.

4.6. Summary of biomass from municipal wastes

Municipal solid wastes (MSW) contain large quantities of biomass suitable for energy production. Carbon from disposed (6 Mt C/yr) and recycled materials (2 Mt C/yr) exceeds 8 Mt C per year. Energy potential of disposed MSW is 0.22 EJ/yr, with an additional 0.07 EJ/yr available from recycled biomass and 0.007 EJ/yr from biosolids. The combined energy potential of all fractions (0.29 EJ/yr) represents about 3.5% of Canada's current use of fossil fuel energy.

More efficient use of MSWs could significantly reduce emissions of GHG from landfill, while offering local solutions to waste management, and contributing to Canada's energy needs.

Technologies such as modern combustion, pyrolysis or gasification may be used to harvest energy from MSW. Such energy production has been proven to be cost effective in a pilot project by the City of Sherbrooke, QC.

Disposal of municipal biosolids is expensive, and currently poses health concerns in many parts of Canada. Digestion treatments offer the opportunity to harvest biogas, while stabilizing the sludge; where co-generation facilities are operating, a net surplus of energy (0.007 EJ/yr) is produced.

5. Summary of the Biomass – Bioenergy Inventory

5.1. Canada's Biomass Carbon and Energy Stock

Of the 418 M ha of forest in Canada, 245 M ha are considered part of the Timber Productive Forest. On this land base, there is an estimated 15,835 Mt C with an energy content of 566 EJ (Table 5.1). Given that fossil fuels provide Canada with about 8.24 EJ/yr, the biomass of the timber productive forest is sufficient to meet Canada's energy needs for about 69 years.

In most agricultural systems, the crops are annual, so there really is no standing biomass C stock on Canada cropland that differs from the annual harvest. The C content of the annual harvest will be discussed in the next section.

The situation is a somewhat different for municipal waste. Landfill sites have been collecting municipal waste for many years, and there certainly are large C stocks at these sites. This study has not considered the existing carbon stocks that now exist in landfill sites, and the potential to recover the energy from this biomass. Rather, we have only considered the energy content in the annual production of municipal waste streams and this will be considered in the next section.

It should be noted that the production of methane from existing landfill sites is an important source of biomass energy that is increasingly being tapped.

Table 5.1. Summary of the Biomass Sources in Canada and their Energy Content

	Units	Forestry	Agriculture		Municipal Waste			Total	Footnote
			Crops	Animal Prod'n	Recycling	Municipal Solid Waste	Bio-solids		
Standing Carbon Stocks									
- On Timber Productive Land	Mt C	15,835	-	-	-	-	-	15,835	1
	EJ	566	-	-	-	-	-	566	2
Annual Harvest									
- Yield of harvested product	Mt C/yr	47.7	33.5	-	-	-	-	81.2	3
- Total harvest (incl. residue)	Mt C/yr	88	54.9	-	-	-	-	142.9	4
	EJ/yr	3.1	2.0	-	-	-	-	5.1	2
Residual or Waste biomass									
- Available Unused biomass	Mt C/yr	43.1	8.6	-	2.0	6.17	-	59.9	5
	EJ/yr	1.54	0.31	0.065	0.07	0.22	0.007	2.2	2 & 6

Footnotes:

1. From Tables 2.2 & 2.4
2. Assumes 35.76 EJ/ tonne C in biomass (Layzell, 2001)
3. From Table 2.5 & 3.2
4. From Table 2.5 & 3.2
5. From Table 2.6, 2.7, 4.3
6. From Table 3.3, 3.5, 4.4, 4.5

5.2. Annual Biomass Production in Forestry, Agriculture and Municipalities

The potential for the conversion of carbon from agricultural and forest production to energy is excellent. Energy conversion processes could include combustion, pyrolysis, conversion to biofuels such as ethanol or biodiesel, anaerobic fermentation to produce methanol, and gasification.

The choice of conversion technology depends on the nature of the feedstock (cellulosic or lignocellulosic) and the degree of homogeneity of the biomass. The conversion efficiency for these potential processes varies widely, so energy potential is best measured on the basis of a carbon-based conversion factor.

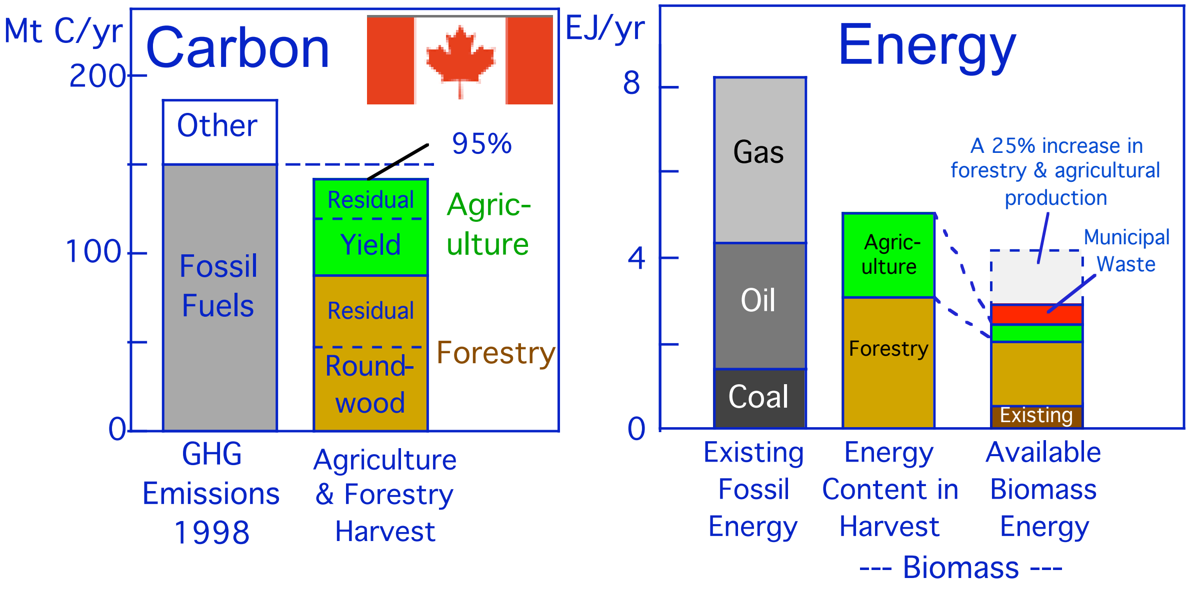
A conversion factor of 35.76 GJ/t C from dried biomass (Fig. 5.2) has been challenged against higher and lower heating values (theoretical and measured) and has been within 5.0% accuracy for a wide variety of biological feedstocks.

The annual production of forest and agricultural products in Canada has a C content of about 143 Mt C/yr, a value that is similar to the GHG emissions that are associated with fossil fuel combustion in Canada in 1998 (about 150 Mt C/yr, Table 5.1, Fig. 5.1). This comparison clearly illustrates the magnitude of the forest and agricultural production sectors in Canada.

The energy content of forest and agricultural production biomass is about 5.1 EJ (Table 5.1), equivalent to about 62% of the energy that Canada obtains from fossil fuels (Fig. 5.1). Note that the energy content of biomass is lower than that for coal, oil or natural gas (Fig. 5.2).

Approximately 54% of the forest harvest, and 61% of the agricultural harvest was removed from the land as roundwood or agricultural yield, respectively (Table 5.1). In some cases, uses have developed for the residual biomass, but in many cases it is either left to decompose or burned with little or no energy capture. The magnitude of the residual biomass from existing forestry and

Fig. 5.1. Comparison of Canada's annual fossil fuel use and biomass carbon yield (Left panel) and their energy content (right panel). The right panel also shows the energy content in the existing and available biomass resources, as well as the impact of a 25% increase in agricultural and forest production to provide biomass feed-stocks for bio-based energy. The values in Fig. 5.2 were used to calculate energy content.



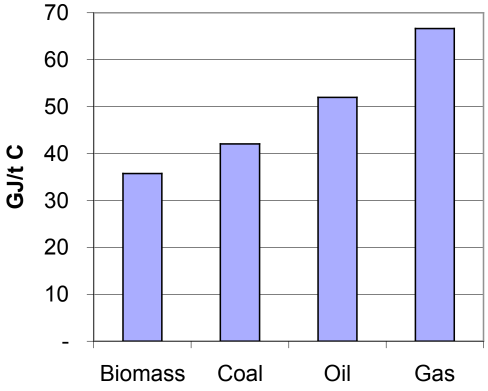
agriculture will be considered in section 5.3.

Figure 5.1 illustrates the potential an increase in forest and agricultural production in Canada could provide to the supply of renewable and sustainable energy. For example, a 25% increase in forestry and agricultural production could translate into a major contribution of about 1.25 EJ/yr, an amount equivalent to about 15% of the energy that Canada now derives from fossil fuels (Fig. 5.1).

5.3. Residual and Waste Biomass and Energy Resources

Residual or waste biomass can be obtained from a wide range of sources, in addition to the waste streams generated by forestry and agricultural production. Examples of these sources and the estimated energy content associated with each are summarized in Table 5.1. Note that the use of these biomass resources could provide as much as 2.2 EJ/yr, significantly more energy than that currently obtained from biomass (about 0.34 EJ/yr).

Fig. 5.2. Comparison of the energy content of different energy sources (From Klass, 1998)



Dried biomass is readily combustible although the combustion efficiency may vary dramatically with feedstock quality and the degree of homogeneity. For example, Table 3.3 shows the energy potential, totaling 0.523 EJ, of the major crop residues through combustion, assuming 50% combustion efficiency.

Alternatively, dried cellulosic biomass, such as cereal straws may be readily converted to ethanol by fermentation, at a rate of 300 litres of ethanol produced per tonne of dried biomass; if the entire agricultural residue currently available was converted to ethanol, 5,336 M litres of ethanol could be produced.

6. Hurdles

6.1. The Challenge of Using Biomass as an Energy Resource

It was not the goal of this study to identify all the barriers to the production, collection and use of biomass for energy and bio-products. Nevertheless, some common hurdles must be overcome to successfully optimize the use biomass from the forest or agricultural industries, or from municipal waste sources, for the production of bio-products and energy. In any specific geographic region, these problems could include: distribution and availability of biomass resources; economic viability; social acceptance and public perception; technological and processing bottlenecks; and competition from the petroleum based sector.

6.1.1. Distribution and availability of biomass resources

Biomass residues tend to be neglected during the harvest process because of their traditionally lower value. Tops and branches, or slash, of harvested trees may be left at the harvest site, or along the roadside where logging trucks are loaded. Similarly, agricultural residues are widely dispersed as a result of harvest techniques that focus on the "crop" fraction. In order to be used for purposes other than soil amendment, residues must, at the very least, be removed from the field to some processing facility.

Costs associated with this first simple step include equipment, consumables (such as baling twine), labour, transportation and storage or weather protection and together, these costs may be quite substantial. Straw hauling to processing sites in Manitoba has been carefully examined, with projected and actual costs evaluated using a variety of techniques and equipment (Agricultural Fibre in Manitoba, 2000).

Costs of baling and transportation within a 50 km radius of a processing facility average approximately $33.00/t, with an additional $1.65 /t for protective covering, should storage be required. These figures do not include the purchase cost of the straw.

In contrast, biomass from municipal sources is typically collected and taken to a common facility (landfill or incinerator), and the cost of collection is fixed whether the biomass fraction is withdrawn for energy production or not. In general, greater concentrations of waste are produced in regions where energy demand is highest.

6.1.2. Economic viability

The cost of biomass procurement and processing is directly dependant upon the costs of energy and labour, and the status of world markets. One of the potential hurdles of using agricultural residues is that they tend to be widely dispersed and in relatively low abundance, so careful planning for harvesting and transportation strategies is vital to ensure strong economic success.

Estimating residue production and evaluating the economic issues of collection and transportation to central facilities has been aided by the development of interactive models based on biophysical analysis and GIS reports of agronomic activity (Huffman *et al.,* 2000). Such models have been used to determine the economic feasibility of developing residue-handling facilities and have powerful potential for estimating availability of residues in any growing season (see, http://192.197.71.108/ims/addboard15/maps.html).

As well as interactive modeling, remote sensing is useful for assessing biomass accumulation within specific fields, or areas of fields, throughout the growing season (see, http://www.ccrs.nrcan.gc.ca/ccrs/learn/tour/25/25scene2_e.html). Both remote sensing and interactive modeling serve to reduce economic risk, and optimize biomass utilization.

Although markets for forest products and agricultural commodities may be described as "dedicated", general consensus suggests that commodity use is market-driven. Thus, while corn is predominantly grown for food and feed, a significant proportion could be drawn away from these traditional uses if a strong market emerged for the use of corn for energy production. Likewise, roundwood intended for lumber could be redirected for energy purposes if market conditions were favourable.

Similarly, it must be noted that some crops with strong bio-product potential, including horticultural species, non-forestry products from forests, and silviculture species have not been included in this study because they do not have significant economic impact at the current time. Their potential, along with that of marine biomass may become significant with changing market pressures.

A cost point assessment would be a logical next step arising from the current study, along with assessment of specific regional sites where potential is highest.

6.1.3. Public perception and acceptance

From a traditional viewpoint, agricultural land should be used for the production of food and animal feeds and there has been some resistance to the notion of using agricultural lands for the production of bio-products and biomass for energy.

This trend seems to be changing, with better acceptance for example, of the growing of "flax for fibre" rather than flax seed in the agricultural sector (Braun, 2003). In contrast, the idea of using trees for non-roundwood, non-pulping has been largely ignored. With declining demand for softwood in the USA, it would seem reasonable to divert a portion of the potential Canadian harvest to bio-energy production, rather than to scale back harvest operations.

6.1.4. Technological and processing requirements

There is a need for technological advancement to improve efficiency of materials handling, and biological conversion. Fermentation of cellulose to produce ethanol fuels has been well developed, however, fermentation of ligno-cellulosic feedstocks, such as wood residues, is not yet available on a commercial scale. Research focused on translating laboratory or pilot-project successes to field applications must be a top priority.

6.1.5. Changing weather patterns

Projections of biomass availability presume continued favorable growing conditions. Yet recent drought conditions in the Canadian West, coupled with a prediction of continued climate change, have some producers reevaluating the viability of traditional agricultural production systems.

This situation may have negative impacts on the availability of agricultural residues from traditional sources; alternatively, it may present an excellent opportunity for an adjustment towards cultivation of crops, such as switchgrass, intended specifically for their biomass potential.

6.2. Some Concluding Thoughts

Despite the large potential that residual or waste biomass offers to Canada's energy needs, there are significant hurdles that must be overcome before we will see large scale use of biomass as an energy, chemical and material resource. For example, harvest residues from the forest industry, as well as crop residues may be difficult to collect, dispersed over a wide region, costly to transport, seasonally available and variable in quality. These factors all pose economic, technological or logistical problems.

Moreover, there is inevitably resistance to adopting new management strategies until an economic advantage is proven. However, precedents that show that the manufacture of bio-energy and bio-products are economically successful and offer excellent potential for stimulation of the rural economy have already been made.

With strong economic incentives, movement towards a bio-based economy using currently available waste biomass could happen quickly and efficiently resulting in positive outcomes for the forest industry, rural economy, manufacturing sector as well as an improved ability to meet GHG reduction targets while strengthening the Canadian economy.

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