Biomass and Carbon Neutrality

Putting in place an evaluation framework

Current State in Canada

December 2024

INSTITUT DE L'ÉNERGIE TROTTIER

The Transition Accelerator
L'Accélérateur de transition

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The list of stakeholders and experts that participated in the workshops and/or provided comments regarding the preliminary version of the white paper is in Appendix 10.

Linguistic revision and translation

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About the Institut de l’énergie Trottier (IET)

The creation of the IET was made possible, in 2013, thanks to an exceptional donation from the Trottier Family Foundation to Polytechnique Montréal. Since then, the IET has been involved in every energy debate in the country. At the source of major collective reflections, the team mobilizes knowledge, analyzes data, popularizes issues and recommends fair and effective plans. All this while contributing to academic research and training. Its independence gives it the neutrality essential to the collaborative approach it advocates, facilitating work with the players most likely to advance the energy transition, while allowing it to be freely critical when relevant.

As the initial ten-year mandate came to an end, the Trottier Family Foundation decided to renew its confidence in the IET and made a new donation. Given the scope of the IET’s activities and its status as a key player, it was decided to extend its mandate. The team will thus be able to continue offering science-based advice and enriching societal dialogue, in order to advance the way we produce, convert, distribute and use energy.

About the Transition Accelerator

The Transition Accelerator (the Accelerator) is a pan-Canadian charity organization that works with others to solve societal challenges through positive, transformational system change. The Accelerator works with innovative groups to create visions of what a socially and economically desirable net-zero future will look like and build out transition pathways that will enable Canada to reach it. The Accelerator’s role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground. Our four-step approach is to understand, codevelop, analyze and advance credible and compelling transition pathways capable of achieving societal and economic objectives, including driving the country towards net zero greenhouse gas emissions by 2050.

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Canada

Disclaimer

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Background

Given that biomass resources are expected to play a major role in the transition to net-zero, many studies have estimated the potential of biomass feedstocks for the deployment of bioenergy systems in Canada. Even though biomass resources are abundant and renewable, the portion that can be sustainably harvested each year and processed to meet a wide range of societal needs is limited. The recuperation of unmerchantable wood and harvest residues in the forestry and agricultural sectors could also be considered a way to valorize unused residual biomass. Feedstocks could be allocated to various applications, including combustion for heat and power, conversion to biofuels, renewable natural gas, biochar, wood composite products, biopolymers, and so on. However, the decarbonization pathways of several economic sectors are based on the same types of biomass feedstocks, which could lead to competition. For example, the decarbonization of the aviation sector and road transportation sectors involved are closely related through the technologies that can produce adjustable fractions of biojet and renewable diesel. Depending on how these projects develop, this competition could either accelerate decarbonization or create significant tensions.

With the development of numerous conversion technologies, competing demands from various economic sectors and a limited supply, which pathways would best contribute to carbon neutrality in Canada? The aim of this project is to co-develop, through several exchanges and workshops with stakeholders and experts in this domain, an evaluation and comparison framework for the use of biomass resources in Canada in the context of transition to carbon neutrality by 2050.

This report presents an overview of the current situation in Canada regarding the production of both biomass feedstocks and bioproducts. The analysis was performed by searching for publicly available information in the literature on quantities of biomass resources in Canada and the existing commercial or emerging technologies that are being developed worldwide to convert biomass resources to many valuable products for both energy and non-energy usages. This first analysis enables us to identify some key uncertainties tied to the use of biomass resources in the context of transition to net zero. This report will be shared with stakeholders and experts in the domain with a view to receiving comments from a wide variety of perspectives including industries, academia, governments, Indigenous communities, and non-profit organizations, to achieve the end objective of co-constructing an evaluation and comparison framework for biomass usages in a net-zero future.

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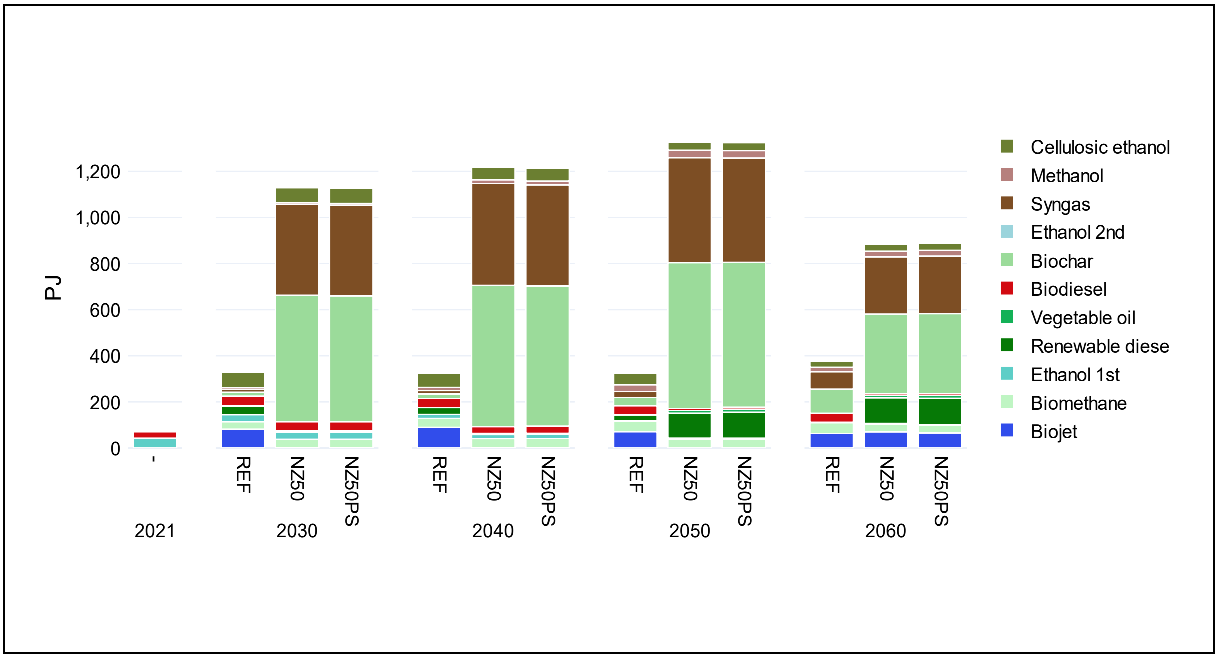
1. Overview

The use of bioenergy, traditionally one of the main energy sources for humans, has continued to expand with modern technologies to encompass numerous applications and a wide variety of biomass feedstocks. In a context of transition to a net-zero future, bioenergy occupies a significant place in scenarios of future energy mixes and is expected to play an important role in the decarbonization of many sectors, including transportation, buildings heating and industrial use.

1.1. The Net-Zero Challenge

The most recent Canadian energy modelling studies projecting transition to a net-zero future in 2050 include bioenergy in their resulting scenarios (Canadian Climate Institute 2021b; IEA 2021; Langlois-Bertrand et al. 2024). In the IET Canadian Energy Outlook 2024 (Figure 1), the use of bioenergy increases rapidly before 2030 for net-zero scenarios, for the decarbonization of the transportation sector, industrial use and in large part to produce negative emissions with biochar and bioenergy coupled with carbon capture and storage (BECCS). This narrow role is due to the lack of alternatives for producing negative emissions and to the blending mandates for biofuels. Such use is however limited by biomass availability, competing non-energy applications and the remaining emissions associated with biomass use (Langlois-Bertrand et al. 2024).

Figure 1: Primary biomass usages in net-zero scenarios

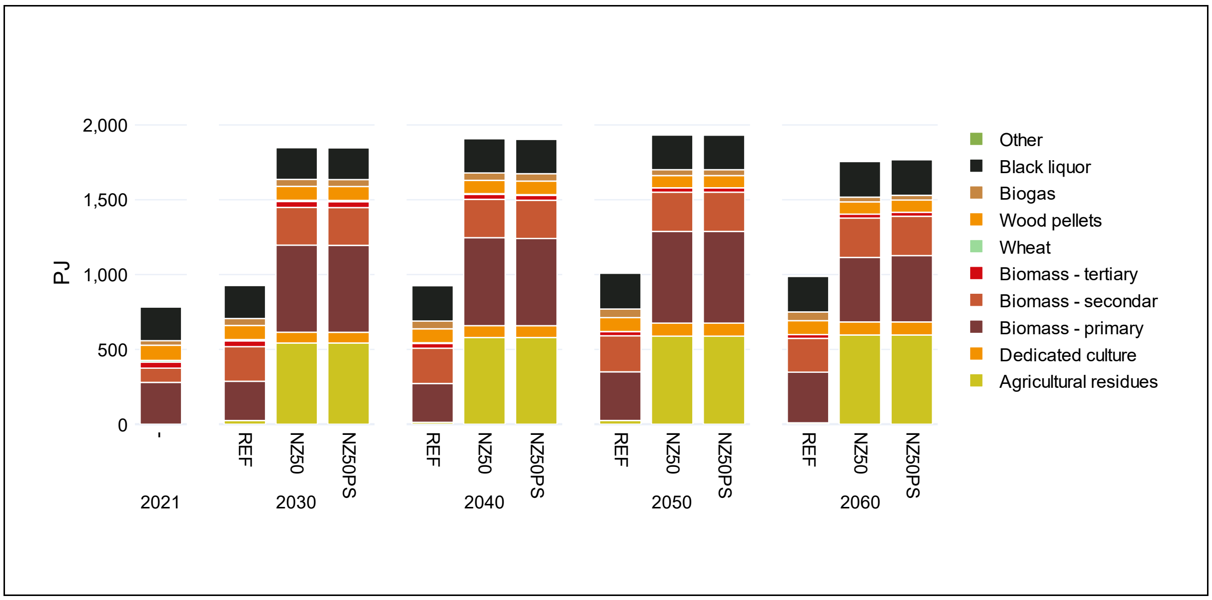


Source: Langlois-Bertrand et al. 2024.

Note: REF is the reference scenario using no constraining GHG reduction targets. NZ50 is a scenario that imposes a net-zero emissions target on total CO_2e by 2050, and a 40% reduction target by 2030, with respect to 2005. NZ50PS is a scenario identical to NZ50 except for cost projections for nuclear SMRs, which are higher.

Bioenergy can be produced from biomass resources from the following three key sectors: forestry, agriculture, and urban/rural waste. Note: REF is the reference scenario using no constraining GHG reduction targets. NZ50 is a scenario that imposes a net-zero emissions target on total CO2e by 2050, and a 40% reduction target by 2030, with respect to 2005. shows the type of biomass resources that have been included in the IET Canadian Energy Outlook net-zero scenarios. Based on a rich set of technologies, the quantity of forest waste used for bioenergy remains significant until 2060 in all net-zero scenarios. However, the use of agricultural crop residues grows rapidly before 2030. Other sources of biomass, such as dedicated culture, municipal organic waste, landfill gas, also contribute to the energy mix in these scenarios.

Figure 2: Bioenergy sources by type in net-zero scenarios



Source: Langlois-Bertrand et al. 2024.

Note: REF is the reference scenario using no constraining GHG reduction targets. NZ50 is a scenario that imposes a net-zero emissions target on total CO_2e by 2050, and a 40% reduction target by 2030, with respect to 2005. NZ50PS is a scenario identical to NZ50 except for cost projections for nuclear SMRs, which are higher.

1.2. Current Situation in the Biomass Sectors

The objective of this report is to summarize the key data and information the quantities of Canadian biomass resources indicated in the literature and to present the current situation respecting the harvest, production and collection of these resources in the agricultural, forestry and urban/rural waste sectors. The data search was primarily carried out on the data published by the Government of Canada on different platforms, including Statistics Canada, Environment and Climate Change Canada, and Natural Resources Canada. The information not available through these platforms was collected from published reports, scientific articles, industry websites, and so on.

Table 1 summarizes the quantities of different biomass feedstocks and bioproducts produced in Canada per year. The data for each type of feedstock are presented further in this report. No attempt was made to estimate the technical potential of the resources cited in this report for any type of biomass usage. However, the aim is to provide a clear overview of biomass resources in Canada, including those that are currently used for food, feed and construction, and the current production of major bioproducts.

Table 1: Summary of the quantities of the major biomass feedstocks and bioproducts produced in Canada per year

Description		Quantities produced per year	Energy content (PJ)	Carbon stock potential value @ \$65/t CO_2 (G\$)	Carbon stock potential value @ \$170/t CO_2 (G\$)
Biomass feedstocks					
Forestry sector	Wood volume harvested	143 Mm^3	1,216	2 to 11	6 to 29
	Logging residues *	21 Mt *(dry)*	390	1 to 2	3 to 6
Agricultural sector	Cereal crops	64.5 Mt	1,035	3 to 6	9 to 16
	Oilseed crops	25.3 Mt	729	1 to 2.5	3 to 7
	Corn stover *	13 Mt *(dry)*	234	-	-
	Straw and other harvest residues *	34 Mt *(dry)*	544	-	-
	Animal manure	21.4 Mt *(dry)*	185 to 401	-	-
Urban and rural waste	Wood and wood products	2.8 Mt	52	-	-
	Other organic waste	9.4 Mt	47 to 110	-	-
Bioproducts					
Solid biofuels	Wood pellets	3.5 Mt	65	-	-
Liquid biofuels	Bioethanol	1,750 M litres	41	-	-
	Renewable diesel	1,210 M litres	44	-	-
	Biodiesel	416 M litres	15		
	Biocrude and bio-oil	-	-	-	-
	Biomethanol	-	-	-	-
	Biojet	0	0	-	-
Biogas and RNG		-	22	-	-
Biohydrogen		0	0	-	-
Non-energy usages	Softwood lumber	56 Mm^3	476	-	-
	Structural panels	9 Mm^3	85	-	-
	Hardwood lumber	0.9 Mm^3	7	-	-
	Wood pulp	14.3 Mt	221	-	-
	Other (e.g., food & feed, biochar)	-	-	-	-

* Rough estimates for these biomass resources and precision are needed.
Notes: The list is not exhaustive. Only the quantities of the main categories of biomass for which values are available are presented in this table.
The values for the quantities of biomass used for food and feed are not included in this table, as they are not available.
This report offers references and additional data regarding the values in this table, in the corresponding sections.

Appendix 2, **Erreur ! Source du renvoi introuvable.** and Appendix 3 present the conversion factors used to estimate the energy content of the biomass resources in Canada. The method used to estimate the biogenic carbon stock value is set out in Section 5.4 of this report.

1.3. Uncertainties and Concerns

Many uncertainties remain about the integration of bioenergy systems in a net-zero future. The uncertainties and concerns respecting bioenergy raised in the literature primarily focus on the availability and sustainability of biomass resources, competition with essential non-energy usages such as food and animal feed, technology development and costs, supply chain emissions, assumption of the carbon neutrality of biomass, and the accounting rules for GHG reporting of bioenergy emissions in the United Nations Framework Convention on Climate Change (UNFCCC) (Bentsen 2017; Cowie et al. 2021).

The following is a list of the main uncertainties and concerns identified so far inassessing bioenergy's role in a net-zero future:

(a) *Land use*: It is recognized that the capacity of the managed forest and agricultural lands to supply biomass in a sustainable manner is limited. How will the increase in bioenergy demand impact forest management practices, the dedication of agricultural lands to biofuel production, and the increase of biomass residues recuperation from harvested lands?

(b) *Competition for the same resources by different bioproducts producers*: With limited feedstock availability and a rising demand for its use from different energy and non-energy producers, what will be the basis of the arbitration for the best usage? For example, many facilities have announced the production of renewable diesel and sustainable aviation fuel (SAF) in the near future in Canada. However, the producers' decision to focus on increasing the production of either renewable diesel or SAF would depend on the economics and the existence of proper incentives (Allan, Goldman, and Tauvette 2023).

(c) *Supply chain emissions:* The increase in bioenergy demand for different applications will require the implementation of supply chains in different regions. How will the harvest, processing and transportation of biomass impact the net GHG emissions of the entire system?

(d) *Alternatives:* If a specific bioenergy usage is not put in place, what will the alternative energy source be? Or, if a certain type of biomass residue is not collected and used for bioenergy, what will be the alternative destiny of that resource? What is the best way to compare options to ensure a complete assessment of the climate effects of the entire system put in place?

(e) *Assumption of carbon neutrality:* Bioenergy is often assumed to be carbon neutral since the biogenic carbon emitted at the time of combustion was previously sequestered or will be again during regrowth of the biomass resources. An important factor to consider in this assumption, is the temporality of these emissions which is referred to in the literature as "carbon debt" and "carbon parity time." How is the temporality of the climate effects of bioenergy systems taken into consideration in planning for a net-zero future by 2050?

(f) *Negative emissions:* Burning biomass for energy followed by recapturing and storing the carbon is one of the few ways to produce negative emissions. Technologies that lead to negative emissions will be necessary to reach net zero in the absence decarbonization solutions for all sectors in Canada by 2050. How—and where—will these technologies be prioritized in the upcoming years?

(g) *Value of biogenic carbon stock*: Biomass resources stock large quantities of carbon until it is released into the atmosphere through harvest and use for energy or their natural decomposition. At present, the carbon stock has no price value unless carbon offset credits are attributed. The carbon pricing system for emissions does not apply to bioenergy based on the assumption of carbon neutrality. If the current system were to be reevaluated, what would the carbon stock value be now and by 2050?

(h) *Reporting for bioenergy emissions:* Under UNFCCC countrywide reporting guidelines, CO_2 emissions from biomass combustion are not reported in the energy sector in order to avoid double counting the emissions that have already been reported in the land use, land-use change and forestry sector. How does the fact that emissions are counted at the place of harvest rather than according to combustion impact the sustainable practices of the reporting countries?

2. Biomass Feedstocks in Canada

2.1. Forestry Sector

Forest biomass resources are divided into three main categories according to where they are sourced, either as products and residues from forest management, wood processing industries or dedicated energy plantations (Table 2) (NRCan 2014; WSP Canada Inc. 2021).

This report presents the quantities of biomass from end-of-use products from construction, renovation, and demolition (CRD) in urban and rural waste (Section 2.3).

Table 2: Categories of biomass in the forestry sector

Categories	Examples
Forest management products or residues	Industrial roundwood
	Non-merchantable wood
	Trees affected by natural disturbances (fire or insect outbreaks)
	Logging residues (e.g., branches)
Wood processing industries	Sawmill residues (bark, sawdust, wood shavings, wood chips)
	Pulp & paper residues (e.g., black liquor)
Dedicated energy plantations	Short rotation woody crops (SRWC) such as hybrid poplar, hybrid aspen and willow

Sources: Natural Resources Canada 2014, WSP Canada Inc. 2021.

The area of forests harvested in Canada in 2020 represented around 0.2% of the country's total forest land (NRCan 2022) (Table 3). In 2020, the estimated total wood volume in Canada was **50,000 million m^3** (Table 4), while the wood supply level considered sustainable to harvest was **215.3 million m^3**. The total wood volume harvested in 2020 amounted to **143.1 million m^3**. The total industrial roundwood harvested that same year, including softwood and hardwood, was **141.1 million m^3** (NRCan 2022).

Table 3: Forest area in Canada

Forests in Canada (2020)	Area (hectares)
Forest land	361,732,641
Area of managed forests	225,516,062
Total area harvested in 2020	710,333

Source: NRCan 2022.

Table 4: Wood volume in Canadian forests

Wood volume in Canada (2020)	Quantity (Mm^3)
Total wood volume in Canada	50,000
Wood volume sustainable to harvest	215.3
Total wood volume harvested in 2020 (Includes industrial roundwood, fuelwood and firewood)	143.1
Industrial roundwood harvested in 2020 (Includes logs, pulpwood and other types of industrial roundwood)	141.1

Source: NRCan 2022.

Short-rotation woody crops (SRWC) plantations are considered one of the categories of potential biomass resources for bioenergy. Planting SRWC is a sylvicultural approach to establishing and managing fast-growing plantations on previously cleared lands. From 2002 to 2019, the Canadian Wood Fibre Center (CWFC) evaluated this approach for Canada at a technical development site in Edmonton, Alberta through research operations to develop tools for the implementation of large-scale afforestation programs in Canada (Canadian Forest Service 2023; Jensen 2021).

Logging operations generate a significant amount of residues, including branches and tops and low-quality logs or parts of logs. These resources are referred to as forest residuals or residual fibres that are left behind on-site after primary harvest operations. In certain areas and jurisdictions, residual biomass from logging operations is burned in "slash piles" near the harvesting site to reduce the fire risk. "Open burning" is carried out to meet requirements for the disposal of the residual slash and wood residues in order to reduce wildfire hazards. According to British Columbia's Open Burning Smoke Control Regulation, other reasonable alternatives, such as mulching and green waste recycling facilities must be explored before burning (*Environmental Management Act* 2019). Provinces also set limits for allowable waste to be left on site after logging operations (Ministry of Forests, BC n.d.).

Owing to the lack of a clear definition of what is included in the logging residues and consistency across jurisdictions. it is difficult to quantify these residues Canada-wide.

The annual national availability of logging residues is estimated around **21 million oven dry tonnes (ODT)** (Barrette et al. 2018).

The National Forest Inventory (NFI) is a collaboration between federal, provincial and territorial (FPT) governments to collect and report on the state and changes in forest measurements data. The biomass quantities of Canada's forestry sector can be estimated through the NFI's website, which provides some tools to estimate biomass quantities in Canada (NFI n.d.). However, to estimate the amount of biomass that could be used to produce bioenergy or other bioproducts, it is important to consider biomass feedstocks that would be economically accessible to collect and transport to different facilities.

A recent analysis by TorchLight Bioresources estimated the potential of renewable natural gas (RNG) development across Canada. This analysis found that because of "the absence of a Canada-wide, sub-regional wood fibre supply and flow analysis" the best approach for quantifying RNG potential from forest resources would be to assess the capacities of closed pulp mills and to use these capacities as indicators of wood fibre availability. Based on these assumptions, it was determined that Canada could support 13 facilities that consume each at least 500,000 dry tonnes, including pulpwood, mill residues and harvest residues (TorchLight Bioresources Inc. 2020).

2.2. Agricultural Sector

Biomass feedstocks in the agricultural sector include all types of agricultural and food products, however, in this report we will concentrate on the agricultural production and residue types which are also used as feedstocks for bioproducts (Table 5).

Table 5: Categories of biomass in the agricultural sector

Categories	Examples
Agricultural crops	Cereal crops, sugar crops, oilseed crops, forage crops
Harvest residues	Corn stover, straw and chaff from wheat, barley and oats
Animal manure	Livestock solid and liquid manure

2.2.1. Agricultural Crops

Canola crops constitutes the top acreage of all types of hay and field crops in Canada (22.3 million acres in 2021), followed by spring wheat (16.0 million acres in 2021) (S. C. Government of Canada 2022).

Grains and oilseeds grown in Canada are not only used for human food and animal feed, but also contribute to bioproducts. For example, corn and wheat are used to produce bioethanol. Oilseeds crops such as canola and soybeans are used for biodiesel production.

Farms classified as oilseeds and grain farms make up the largest share of farms in Canada (**34.3%** of total farms), followed by beef and feedlots (**20.9%** of total farms). In 2021, there were **65,135** oilseed and grain farms in the country. Grains and oilseeds accounted for **99%** of the volume of agricultural biomass used for bioproducts in 2015 (Government of Canada 2017). While corn for grain is primarily used for ethanol production and animal feed, it is also used to make bread, tortillas and other baked products (Statistics Canada 2022).

Corn is a suitable crop for the production of silage which is an animal feed that has been preserved by fermentation. Corn silage is commonly used as livestock feed in Canada and is one of the major forage components in dairy cow rations (Khan et al. 2015). It is also used as an important feedstock for bioenergy in biogas and RNG facilities in some countries (e.g., Germany) (TorchLight Bioresources Inc. 2020).

The following sections of this report present details on the current production of biofuels and other bioproducts in Canada. Table 6 shows Canada's agricultural crop production in 2022.

Table 6: Agricultural crop production in Canada in 2022

Types of crops		Production (kt)	Energy content (PJ)
Cereal crops	Corn for grain *(exclude sweet corn and corn silage)*	14,539	236
	Sweet corn (2)	201	3
	Wheat, all types	33,824	541
	Barley	9,987	159
	Oats	5,226	84
	Rye	520	8
	Mixed grains	203	3
	Total	64,500	1035
Sugar crops	Sugar beets	1,279	124
	Total	1,279	124
Oilseed crops	Canola	18,274	462
	Soybeans	6,543	134
	Flaxseed	473	132
	Total	25,290	729
	Tame hay	19,374	317

Forage crops	Corn silage	10,569	11
	Total	29,943	328

Sources: (1) Statistics Canada. Table 32-10-0359-01. Estimated areas, yield, production, average farm price and total farm value of principal field crops, in metric and imperial units. (2) *Table 32-10-0365-01. Area, production and farm gate value of marketed vegetables*.

Notes: Crops with production less than 200 kt were not included in the Table. The values are presented as reported in the source. No calculations were made for the dry mass yield in this Table.

2.2.2. Harvest Residues

Crop residues include corn stover, straw and chaff from wheat, barley and oats which are inedible crop by-products for humans. Some cereal straws and stover can be used as a low-cost animal feed source after dehydration and additional treatment by incorporating them into the animal diet with other high-quality feed (Agriculture Knowledge Centre of Saskatchewan n.d.).

Corn stover, the residue from corn harvest that remains in the field, includes leaves, stalks, husks and cobs. Corn grain represents around 40% to 50% of the dry matter of the corn plant; the rest of the corn plant material remains in the field after harvest. Corn stover has a higher feed value than straw from small grains.

Since no data were found on the exact total quantity of agricultural harvest residues in Canada, estimates were made based on the methods used in the literature.

Table 7: Harvest residues from the agricultural sector in Canada per year

Harvest residues	Quantities (dry Mt)
Corn stover	13
Straw and chaff from wheat, barley and oats	26 to 34

Sources: Province of Manitoba n.d.; Statistics Canada 2023; TorchLight Bioresources Inc. 2020.

According to the Government of Manitoba website, to estimate the tons per acre of dry matter material of corn stover remaining to be grazed or baled, the grain corn yield in bushels (bu) per acre (ac) can be multiplied by the bushel weight of the corn (56 lb/bu) with a cap of 4 tons/acre for fields yielding more than 140 bu/ac (Province of Manitoba n.d.). In 2022, the average yield of corn for grain was 160.4 bushels/acre and the total harvested area was 3,568,200 acres (Statistics Canada 2023). Therefore, if we assume 4 tons/acre of production, the corn stover yield would be 14,272,800 tons, which is equivalent to around **13 million metric tonnes (dry Mt)**. This estimation is consistent with other references that assume a ratio of 1:1 of harvested crops to stover in oven dry tonnes (M. Wood and B. Layzell 2003) or assume 3 to 4.5 dry tons of stover per harvested acre (Gould 2007).

The estimate for the residues consisting of straw and chaff from wheat, barley and oats, was based on the TorchLight Bioresources report (2020). According to this report, the annual availability of straw in the Prairie provinces varies substantially; in some very dry years almost no straw could be available owing to requirements for field retention (TorchLight Bioresources Inc. 2020).

The Torchlight Bioresources report assumes a biogas yield of 400 m^3 per dry tonne of straw; however, it does not specify the methane content of biogas, which we assumed to be around 50% to 65%. The report estimates the potential from these residues for RNG production to be 6,750 Mm^3 (250 PJ) with accounting for the residue retention quantity for soil carbon and moisture. The quantity of straw therefore obtained from wheat, barley and oats available would be around **26 Mt and 34 dry Mt.** If we assume a ratio of residues to grain of 1:1, as does WSP (WSP Canada Inc. 2021), the total quantity of straw would be higher (around 43 Mt). If we assume a straw to grain ratio for wheat of 1.3:1, as found in other references, the total amount would be even higher (M. Wood and B. Layzell 2003).

2.2.3. Animal Manure

Animal manure constitutes the third category of biomass in the agricultural sector that is currently used for both energy and non-energy purposes. Commonly used as a fertilizer, manure contains varying amounts of organic matter, water and nutrients including nitrogen and phosphorus (Statistics Canada 2011).

Daily manure production in Canada is estimated by coefficients determined by animal type. In 2018, Canada's total manure production was around **21.4 Mt** of dry manure or 19.8 Mt of volatile solids (VS). The energy content of the total quantities of animal manure is estimated to be around 146 PJ (**Erreur ! Source du renvoi introuvable.**). Some 1% to 2% of the total quantity is currently utilized for energy purposes (See Section 3 for more details).

Table 8 presents information on the number of animals in Canada, the manure production of the largest animal groups, and its energy content. It should be noted that not all the reported total quantity of manure would be easily available to be valorized in bioenergy systems.

Table 8: Manure production in Canada in 2018

Animal groups	Number of animals (2018)	Manure production (dry kt)	Energy content (PJ)
Beef cow	3,704,400	8,965	78 to 168
Calf	3,856,750	3,387	29 to 63
Dairy cow	971,000	2,404	21 to 45
Beef heifer-bred	615,750	1,056	9 to 20
Poultry: broiler	109,531,538	830	7 to 16
Hog (heavier than 60 kg)	4,517,500	697	6 to 13
Steer	1,381,800	682	6 to 13
Dairy heifer	434,400	618	5 to 12
Bull	218,900	557	5 to 10
Beef heifer slaughter	807,000	446	4 to 8
Horse	291,561	394	3 to 7
Turkey	8,423,900	257	2 to 5
Other	-	1,100	10 to 21
Total	180,960	21,400	185 to 401

Source: IEA BioEnergy Task 37 2021:37.

Note: This table includes the 12 largest animal groups according to manure volumes production.

2.3. Urban and Rural Waste

The data for municipal solid waste (MSW) is mainly divided according to the source of waste for residential and non-residential sources. The latter include Industrial, Commercial and Institutional (ICI), as well as Construction, Renovation and Demolition (CRD), which is sometimes categorized as Demolition, Land clearing and Construction (DLC).

In 2018, the total amount of solid waste generated in Canada was **35.6 Mt** (Environment and Climate Change Canada 2022b). A part of the country's total generated waste is diverted (28% in 2018) by recycling or composting, the rest being sent for disposal in landfills. Although waste is mainly disposed of in Canadian landfills, a small proportion is sent to the United States or incinerated (Table 9). Table 10 shows the total quantities of MSW (including organic waste) sent for diversion and disposal in Canadian provinces and territories.

Table 9: Quantities of municipal solid waste (MSW) in Canada

<table>
<tr><th colspan="3">Description</th><th>Quantities (Mt)</th><th>Quantities of potential biomass feedstocks (Mt)</th></tr>
<tr><td colspan="3">Total MSW generated</td><td>35.6 [b]</td><td rowspan="3">-</td></tr>
<tr><td colspan="3">Total MSW diverted by recycling or composting</td><td>9.8 [b]</td></tr>
<tr><td colspan="3">Total MSW disposed in landfills or by incineration</td><td>25.7 [b]</td></tr>
<tr><td rowspan="10">Disposed MSW</td><td rowspan="4">By main categories of biomass waste</td><td>Food</td><td>5.8 [a]</td><td rowspan="3">9.4 [a]</td></tr>
<tr><td>Paper</td><td>2.5 [a]</td></tr>
<tr><td>Yard and garden</td><td>1.1 [a]</td></tr>
<tr><td>Wood and wood products</td><td>2.8 [a]</td><td>2.8 [a]</td></tr>
<tr><td rowspan="3">by sector</td><td>Residential</td><td>10.2 [a]</td><td rowspan="6">-</td></tr>
<tr><td>Industrial, commercial and institutional (ICI)</td><td>11.5 [a]</td></tr>
<tr><td>Demolition, land clearing and construction (DLC)</td><td>3.2 [a]</td></tr>
<tr><td rowspan="3">by location of disposal</td><td>Disposed in landfills in Canada</td><td>20.3 [a]</td></tr>
<tr><td>Exported to the US</td><td>3.8 [a]</td></tr>
<tr><td>Incinerated (primarily to produce energy)</td><td>0.85 [a]</td></tr>
</table>

Sources: Environment and Climate Change Canada 2020, 2022b.
Notes: (a) 2016, (b) 2018.

Table 10: Disposal and diversion of municipal solid waste (MSW) in Canadian provinces and territories in 2020

Location	Quantities disposed (Mt)	Quantities diverted (Mt)
Canada	26.1	9.9
Newfoundland and Labrador	0.4	0.05
Prince Edward Island	0.06	0.06
Nova Scotia	0.4	0.3
New Brunswick	0.5	0.2
Quebec	5.8	2.6
Ontario	10.3	3.5
Manitoba	0.9	0.2
Saskatchewan	0.9	0.2
Alberta	4.0	0.9
British Columbia	2.8	1.8
Yukon, Northwest Territories and Nunavut	0.1	0.03

Sources: Statistics Canada. Table 38-10-0032-01 Disposal of waste, by source, 2023. Table 38-10-0138-01 Waste materials diverted, by type and by source, 2022.
Notes: Disposed and diverted quantities include residential and non-residential sources.

3. Biomass Usages for Energy and non-Energy Purposes

The multiple applications of biomass resources used in Canada encompass energy and non-energy usages. Major categories of biomass use for energy include solid biofuels, liquid biofuels, biogas, renewable natural gas and biohydrogen. The quantities produced for several categories were obtained from different publicly available sources and are presented in the sections below, along with examples of production facilities.

3.1. Solid Biofuels

Solid biofuels include biomass that is used directly or processed to be used as a fuel (e.g., wood chips, pellets, briquettes, biocoal). Biocoal, which is produced by torrefaction of biomass at high temperatures, can be manufactured in the form of torrefied wood pellets. It is used to replace coal in power plants or for energy in manufacturing industries (Airex Energy 2016).

To produce wood pellets, Canadian industries rely largely on sawmill residues, low-quality logs and harvest residues recovered from forests that cannot be used by sawmills or pulp and paper mills. According to a study conducted for the province of British Columbia, home to some 45% of Canadian pellet production, feedstocks used for pellet production are mainly direct by-products of sawmills and associated industries (over 85% of feedstocks used), as well as low-quality logs (11%) and ground-up fibre obtained from roadside piles containing branches, log trim ends, foliage and bio-logs (4%) (Bull et al. 2022).

These feedstocks are also used for heat production in community systems and industries (NRCan 2022). Wood pellet use for heat and power is primarily limited to small-scale industries and residences in Canada. The types of biomass feedstocks used for bioheat installations and the installed capacity and locations of these installations in Canada are presented in Appendix 7. In 2019, 516 community systems were using biomass for heating (NRCan 2022).

Suppliers of forest biomass for wood pellet production in Canada vary from large forest product companies to small harvesting contractors, and also include tenure holders and private landowners. Sellers and buyers in these sectors compete for the woody biomass in the free market (Bull et al. 2022; WSP Canada Inc. 2021). Many wood pellet mills in Canada are third-party certified under the Sustainable Biomass Program (32 in total), which ensures that woody biomass is sourced from legal and sustainable sources and that facilities demonstrate compliance with regulatory requirements (Bull et al. 2022; Sustainable Biomass Program n.d.; Watters 2023).

Table 11 presents the data for wood pellet production and use in Canada. Most of the pellets are produced in BC (45% of Canada's production) and Quebec (21%).

Table 11: Canadian wood pellets industry in 2021

	Wood pellets (kt)
Production	3,500
Imports	29
Exports	3,153
Consumption	500

Source: USDA Foreign Agricultural Service, Global Agricultural Information Network (Report CA2023-0002), January 2023.

The majority of the wood pellets produced in Canada are exported (USDA Foreign Agricultural Service 2023) to the United Kingdom and Japan for use in heat and power plants (C. E. R. Government of Canada 2021; Hayes and Bradford 2019). For instance, Drax Group, which has large Canadian pellet production operations in BC and Alberta, exports wood pellets to the UK (Drax n.d.-b). Most of the power production of the Drax Power Station in the UK, which has a capacity of 3,906 MW, uses compressed wood pellets (Drax n.d.-a).

In Canada, wood pellets have been used to replace coal in the Atikokan Generating Station in Ontario in 2014 and Thunder Bay Generating Station in 2015 (C. E. R. Government of Canada 2021). In the coming years, the growth of the pellet industry could be impacted by the reduction of the allowable annual cut (AAC) in BC and the change in harvesting practices resulting from the mountain pine beetle attacks in the same province (USDA Foreign Agricultural Service 2023).

3.2. Liquid Biofuels

This section describes the current production and use of five categories of liquid biofuels in Canada and examines the technologies being used or developed. Table 12 summarizes their production and the feedstocks used.

Table 12: Feedstocks used for yearly production of bioethanol and other renewable fuels in Canada

Description	Biomass feedstocks	Production
Cereal grains *Include corn, wheat, rye, barley, oats, and triticale.*	4,353 kt	
Vegetable oils *Include canola oil, soybean oil and other vegetable oils.*	338 kt	
Other feedstocks *Include agricultural residues, forestry residues, other biomass residues, MSW, animal fats, used cooking oil, methanol.*	82 kt	
Total plant feedstocks used	4,772 kt	
Bioethanol		1,642 M litres
Renewable fuels except bioethanol *Most of the production consists of biodiesel.*		431 M litres
Total renewable fuels produced		2,073 M litres
Total co-products *Include distiller grains that can be used as livestock feed*		1,752 kt

Source: Statistics Canada. Table 25-10-0082-01. Renewable fuel plant statistics, supply and disposition, monthly.
Note: Quantities were calculated from monthly data starting from January 2021 until December 2021 (Appendix 8).

Table 13: Canadian liquid biofuel industry in 2021

	Bioethanol (M litres)	**Biodiesel** (M litres)	**Renewable diesel** (M litres)	**Biocrude, bio-oil and biomethanol**	**Biojet**
Production	1,750	416	0	Quantities not found	0
Imports	1,254	380	480		0
Exports	108	440	0		0
Consumption	2,928	356	480		0

Source: Danielson 2022a.

3.2.1. Bioethanol

Bioethanol is one of the major liquid biofuels produced in Canada. In 2022, twelve facilities were producing it across the country (Table 14). Canada's bioethanol production is based on the agricultural sector, using mainly corn (**3.7 Mt** in 2022), followed by wheat and other grains such as barley (**560 kt** in 2022) (Danielson 2022b).

Bioethanol is primarily used in low concentrations for blending with gasoline as an oxygenate or octane enhancer. It can be used in high concentrations as a fuel for alternative-fuel vehicles that are specifically designed for ethanol use (US Energy

Information Administration n.d.). Bioethanol plants produce co-products such as distillers grains and corn oil. For example, GreenField Global in Varennes (QC) purchases 16.8 million bushels of corn locally each year to produce 190 million litres of bioethanol, along with 135 kt of distillers grain and 4 kt of corn oil (Greenfield Global 2023). Greenfield Global also capture 55000 tons of CO_2 at their Chatham plant in Ontario and makes it available to Linde and Truly Green (Greenfield Global n.d.).

Another production pathway for bioethanol is through lignocellulosic biomass such as agricultural and forestry waste biomass. The bioethanol produced in this way is known as cellulosic ethanol (NRCan 2011a). Thermochemical and biochemical are the two processes used to produce bioethanol through cellulosic biomass.

Since 2016, Enerkem has been using the thermochemical process pathway to convert MSW in Alberta, where it uses their patented and owned technology. It is currently constructing a plant in Varennes, Quebec (Government of Canada 2020) that will produce biofuels and renewable chemicals from waste, including wood waste and non-recyclable or non-compostable residual materials from MSW (Government of Canada 2020). The Varennes plant will incorporate a 90-megawatt electrolyzer for the use of green hydrogen in its proprietary thermochemical process.

The biochemical process for producing bioethanol has been demonstrated for agricultural and forestry feedstocks. The first step consists of breaking down the lignocellulosic feedstocks into sugars, then bioethanol is produced by enzymatic fermentation of sugars. The Iogen Corporation in Ottawa, Ontario built the first full-scale demonstration plant, which has a capacity to process around 25 tonnes of wheat straw per week (NRCan 2011a). Raizen built Iogen's first commercial biofuel facility in Brazil to produce cellulosic ethanol from sugarcane bagasse and straw, starting production in 2014. The technology Iogen uses is based on enzymes to convert cellulosic biomass to ethanol (Iogen Corporation 2015; Tolan 2002). CRB Innovations Inc., in Sherbrooke, demonstrated in their in Westbury facility their FIRSST deconstruction and hydrolytic fractionation technology by producing 3.6 tonnes of sugars per day from coniferous wood residues that were then fermented by Greenfield Global in their commercial first generation ethanol plant to produce bioethanol (Bioenergy International 2018).

Table 14: Bioethanol facilities in Canada in 2022

Province	Company	Types of feedstocks used	**Ethanol production capacity** (M litres)
Saskatchewan	Co-op Ethanol Complex	Wheat	150
	Husky Energy – Lloydminister	Wheat and Corn	150
	Northwest Bioenergy Ltd.	Wheat	25
	Poundmaker Agventures Ltd.	Wheat	14
Alberta	Enerkem Alberta Biofuels	Municipal solid waste	38
	Permolex	Wheat	48
Ontario	GreenField Global – Johnstown	Corn	260
	Integrated Grain Processors Co-operative Ethanol Inc.	Corn	380
	Suncor	Corn	396
	Kawartha Ethanol Inc.	Corn	80
Manitoba	Husky Energy – Minnedosa	Wheat and Corn	150
Quebec	GreenField Global – Varennes	Corn	190
Total Nameplate Capacity			1,881

Source: Danielson 2022a.

3.2.2. Biodiesel

Biodiesel, which is derived from biomass and also known as fatty acid methyl ester (FAME), has a different chemical composition than petroleum diesel. It is produced using vegetable oil or animal fat and adding an alcohol (typically methanol) through a process called transesterification, yielding glycerol as a by-product. Biodiesel is not fully compatible with diesel engines and is usually blended with petroleum diesel.

Canola oil is the agricultural feedstock most commonly used in Canada to produce biodiesel (FAME) (**265 kt** in 2020), although animal fats, waste oils and soybean oil feedstocks are also used in its production. Canada uses little yellow grease or tallow as feedstocks for biofuel production compared to the US, where soybean oil is mainly used to produce biodiesel.

Some biodiesel producers in Canada situated close to the US border import animal fat and yellow grease feedstocks from the US to use as feedstocks because of smaller supplies in Canada (Danielson 2022a). Most of the biodiesel produced in Canada is exported to the US (Hayes and Bradford 2019).

3.2.3. Renewable Diesel

Renewable diesel is a term commonly used for hydrogenated vegetable oil (HVO) or hydrogenation-derived renewable diesel (HDRD) that is produced by hydrotreating fat or oil-based feedstocks similar to those used for biodiesel. However, since biodiesel (FAME) and renewable diesel (HVO/HDRD) have different processing pathways and different chemical compositions, they have different requirements for their use as substitutes for petroleum diesel. Because renewable diesel has the same chemical composition as petroleum diesel, it is fully compatible with diesel engines.

Other emerging technologies, such as Gasification and Fischer-Tropsch synthesis process for Biomass-to-Liquid fuels (BtL), are being developed to convert cellulosic biomass to renewable diesel (ETIP Bioenergy 2023; NRCan 2011b).

To fulfill the renewable content requirements for liquid biofuels, Canada imports most of its renewable diesel from Singapore and Europe (Hayes and Bradford 2019).

The first commercial stand-alone renewable diesel (HDRD/HVO) facility in Canada, built by Tidewater Renewables's in Prince George, British Columbia, is expected to yield around 3,000 barrels per day (170 million litres per year) at full capacity and started commercial operations in November 2023 with approximately 1,500 barrels per day (Government of British Columbia 2023b; Tidewater Renewables n.d.). Braya Renewable Fuels's refinery in Come By Chance, Newfoundland and Labrador, converted from a former oil refinery plant, also started the production of renewable diesel with a capacity of 18,000 barrels per day (1040 million litres per year) (Braya Renewable Fuels n.d.; Canada Energy Regulator 2024; Khan 2024).

Other new projects have been announced or under way. In January 2023, Imperial Oils approved an investment of roughly $720 million (US$ 560 million) in a new renewable diesel facility at its Strathcona refinery near Edmonton. The estimated production is more than one billion litres of renewable diesel per year, using fats and oils such as canola. Production is expected to start in 2025 (ExxonMobil 2023; Imperial 2023).

In May 2022, the Calgary-based firm, Parkland Corporation, announced a planned investment of around $600 million to build a stand-alone renewable diesel complex project in its Burnaby, BC facility (Parkland Corporation 2022). However, in March 2023, the firm stated that it would not move forward with this project, a decision based on numerous factors impacting its competitiveness, such as project costs, lack of market certainty and the US *Inflation Reduction Act,* which advantages US producers and affects the demand (Voegele 2023).

3.2.4. Biocrude and Bio-Oil

Biocrude is a concentrated bio-oil made from biomass that can substitute petroleum crude oil. Canada's Renewable Fuels Regulations defines biocrude as follows:

> A liquid feedstock that is derived from renewable fuel feedstocks and that is used as a feedstock, with petroleum-derived feedstocks, in a production facility in Canada in the production of gasoline, diesel fuel, heating distillate oil or other liquid petroleum fuels (biobrut) (Government of Canada 2022b).

Biocrude can be used in conventional commercial and industrial grade boilers for heating and cooling applications. It can also be used as a low-carbon co-processing feedstock for petroleum refineries in fluid catalytic cracking (FCC) units to produce low-carbon transport fuels such as diesel and gasoline (Ensyn 2015b).

Biocrude or bio-oil can be produced from lignocellulosic biomass by using direct thermochemical liquefaction (DTL) technology. Commercially proven pyrolysis and fast pyrolysis technologies are used by commercial plants, which primarily use wood to produce bio-oil.

In Canada, Ensyn Technologies Inc., Arbec Forest Products Inc. and Groupe Rémabec partnered to expand the production of biocrude in BioÉnergie AE Côte-Nord. This facility converts approximately 65,000 dry metric tons of woody biomass per year (Ensyn 2015a). In May 2022, BioÉnergie AE Côte-Nord announced it had signed a three-year agreement with ArcelorMittal to deliver 16 million litres of pyrolytic oil per year to the ArcelorMittal pellet plant (ArcelorMittal 2022).

Hydrothermal liquefaction (HTL), another technology in the demonstration or pilot stage, can be applied to wet biomass such as pulp mill residues, manure, food processing waste and sewage sludge. In April 2023, Steeper Energy announced that it had signed a Memorandum of Understanding (MOU) with Invest Alberta to develop a commercial plant based on the firm's proprietary technology called Hydrofaction. This technology is used to convert biomass to biocrude oil using HTL method. As mentioned in the firm's announcement, feedstocks that will be used in Alberta will specifically focus on forestry waste that would otherwise be burned (Steeper Energy 2023).

3.2.5. Biomethanol

Biomethanol is an important raw material that can be used in the chemical industry to produce many other chemicals, solvents, dyes, plastics, and so on. It can also be blended with gasoline and used in the biodiesel production process or for the production of biodimethyl ether (DME) or bio-methyl tert-butyl ether (MTBE) for transportation fuels (Hobson 2018).

The process for producing biomethanol is based on biomass gasification to obtain crude syngas followed by syngas, followed by conditioning and conversion to biomethanol by a catalytic process. This is a well-known technology that can be applied to different biomass feedstocks: lignocellulosic forestry and agricultural biomass, agricultural waste, sewage sludge, and MSW. The challenge of this conversion pathway is to make it cost competitive (IEA-ETSAP 2013; IRENA 2021a).

In Canada, Alberta-Pacific Forest Industries refinery produces biomethanol (2,000 tonnes of biomethanol annually) derived solely from hardwood trees (Alberta-Pacific Forest Industries Inc. n.d.). Södra, a pulp mill company in Sweden, produces commercial grade biomethanol from pulp process residues (5,250 tonnes of biomethanol per year) (Södra n.d.).

It is also possible to produce biomethanol from MSW. The Edmonton firm Enerkem Alberta Biofuels produces biomethanol from MSW destined for landfills that can include wood residues, soiled food containers, textiles and non-recyclable plastics (Enerkem n.d.). The company started producing biomethanol in 2016 and added a unit in the facility to begin producing bioethanol in 2017.

3.2.6. Biojet

Sustainable Aviation Fuels (SAF) are currently blended with petroleum-based jet fuel prior to use in aircraft. SAF include fuels from biomass sources (called biojets) and renewable non-biological sources (e.g., power-to-liquids). This report will address biojet conversion pathways only.

As Table 15 shows, different types of feedstocks can be used to produce biojet. Since biojet fuels vary in chemical composition and characteristics, different blending percentages are permitted for different technology pathways for use in aircraft.

Many technologies have already developed for biojet production. The achievement of ASTM certification (ASTM D1655) typically indicates a Fuel Readiness Level (FRL) of seven (CAAFI 2023). Although eight certified biojet fuels can currently be used in commercial flights, global production remains limited. In 2019, Neste in Rotterdam in the Netherlands and World Energy in California in the US were the only two facilities producing biojet. Even though multiple facilities are under construction or planned to produce biojet worldwide, **Canada currently has no biojet facility**. It should be noted that the SAF+ Consortium announced the first production of SAF in North America at a pilot factory (ParaChem Industrial site, Montreal) through a power-to-liquid pathway that does not use any biomass feedstocks (SAF Consortium 2019).

One certified biojet technology, the Hydrotreated esters and fatty acids synthesized paraffinic kerosene (HEFA-SPK) process, is fully commercialized and produces the vast majority of the biojet fuel used today. According to IEA Bioenergy Task 39 report, this process is expected to remain the dominant pathway for biojet for at least 10 to 15 years (IEA Bioenergy Task 39 2021).

As Figure 3 shows, renewable diesel (default in the figure) is the main product of the HEFA process. Only about 15% of the total yield consists of biojet under common processing conditions. The IEA Bioenergy Task 39 (2021) article notes that due to the incentives and policy drivers targeted for renewable diesel production, the majority of HEFA producers sell this product as renewable diesel by diverting the biojet fraction to renewable diesel. The production of biojet fuel can be maximized by adding processing steps to the HEFA process (maximum jet in Figure 3) which also requires additional infrastructure and impacts its price compared to renewable diesel (IEA Bioenergy Task 39 2021).

The Alcohol-to-jet synthesized paraffinic kerosene (ATJ-SPK) is produced by a technology that has already provided numerous airports with demonstration quantities of biojet (IRENA 2021b). In 2022, Gevo Inc. announced a number sales agreements for its alcohol-based biojet produced from corn and converted through the ATJ-SPK pathway (Gevo Inc. 2022). The company's planned start-up of its commercial facility in Lake Preston, South Dakota, is expected in 2026.

Other emerging technologies, such as Fischer-Tropsch Hydroprocessed Synthesized Paraffinic Kerosene (FT-SPK), are close to producing biojet fuel commercially. This process, based on gasification of biomass, has been commercially demonstrated to turn syngas into FT products. The FT-SPK produced by from Velocys's FT reactor has been successfully used in commercial aircraft. BayouFuels biorefinery in Mississippi in the US is planning to start production in 2026 to convert forestry feedstocks (wood chips, slash and thinnings) to SAF and naphta by using Velocys' FT technology. The biorefinery will have a nameplate capacity of 35 million US gallons per year, including 25 million US gallons of SAF, plus renewable naphta (Bayou Fuels n.d.). In 2025, Velocys will begin the construction of a commercial scale waste-to-jet fuel facility in collaboration with British Airways at Altalto in the UK, in which it will use municipal and solid residual waste that would otherwise be destined for landfills or incineration (Velocys n.d.).

In 2014, the Synthesized Iso-Paraffins from Hydroprocessed Fermented Sugars (SIP) pathway was certified for feedstocks that include sugars from any source. In the same year, Total & Amyris announced that it would begin preparations to market the drop in jet fuel. However, we have been unable to find any updated information since that time (Total 2023).

Catalytic Hydrothermolysis Jet (CHJ), a technology pathway that converts fats, oils and greases feedstocks to biojet, was certified in 2020 for the ReadiJet by Applied Research Associates, Inc. (ARA) and Chevron Lummus Global LLC (CLG) (IEA Bioenergy Task 39 2021).

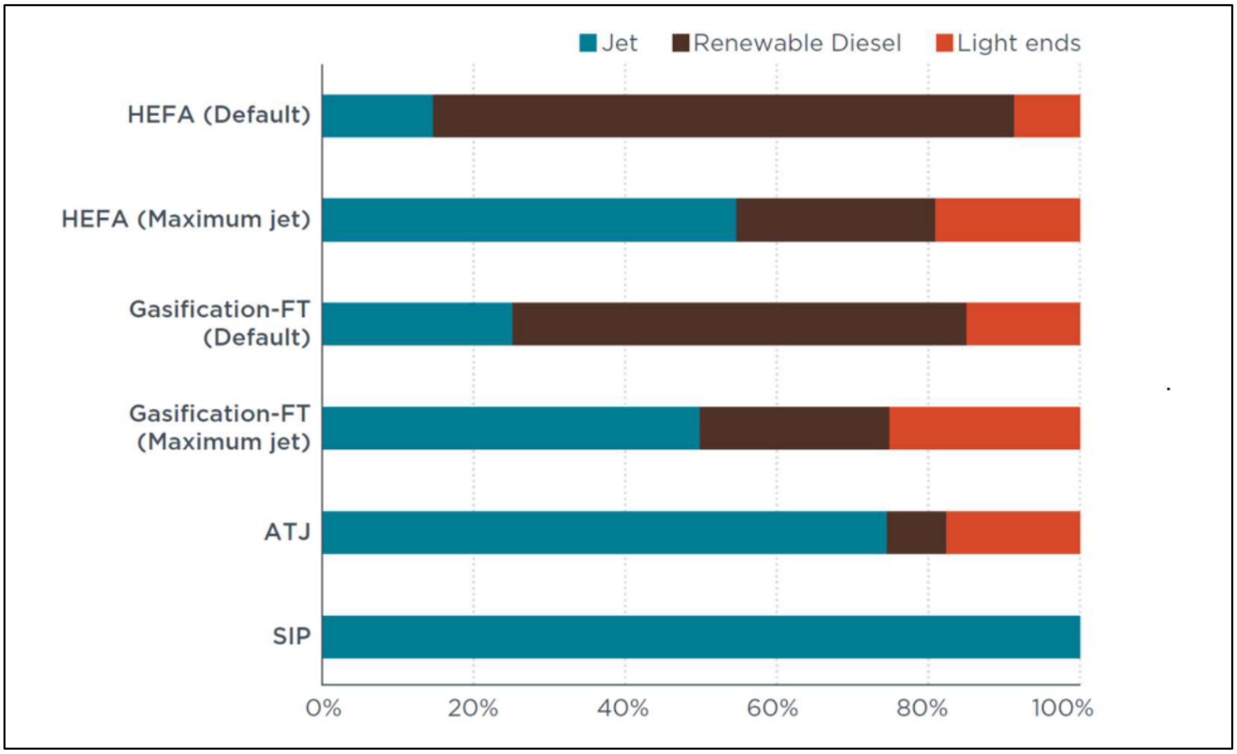
Table 15: Production technologies for biojet fuels developed worldwide

Biojet Technologies	HEFA-SPK	FT-SPK	ATJ-SPK	SIP	CHJ
Potential biomass feedstocks	Fats, oils, grease (FOGs)	Biomass from agriculture, forestry, energy crops and MSW	Alcohol from sugar or other sources such as MSW gasification	Sugars from any source	Triglyceride-based feedstocks (fats and oils)
Certification year by ASTM D7566	Certified for production using hydrogenation (2011)	Certified in 2009	Certified for isobutanol (2016) and ethanol (2018)	Certified in 2014	Certified in 2020
Blend with petroleum-derived jet fuel	Up to 50%	Up to 50%	Up to 50%	Up to 10%	Up to 50%

Sources: Green Car Congress 2020; IEA Bioenergy Task 39 2021; US Department of Energy 2020.

Notes: The other two biojets in ASTM D7566 are FT-SPK/A fuel which is FT-SPK combined with synthesized aromatics and HC-HEFA-SPK which is hydroprocessed hydrocarbons, esters and fatty acids from a species of algae.

Figure 3: Comparison of product slates for different biofuel conversion pathways



Source: IEA Bioenergy Task 39 2021.

3.3. Biogas and Renewable Natural Gas

Biogas typically consists of methane (45% to 75%), carbon dioxide and small amounts of other gases (such as hydrogen, nitrogen and hydrogen sulphide). Biomethane, which is also called renewable natural gas (RNG) is obtained either by upgrading biogas to RNG (greater than 97% content of methane) or through the gasification of biomass to obtain syngas (mainly carbon monoxide, hydrogen and methane) followed by a methanation process to obtain RNG (IEA 2020).

It should be noted that the term 'gas from renewable source' encompasses gases produced with organic materials or renewable energy whose properties allow for direct integration in the gas system, such as RNG, but also green hydrogen (Gouvernement du Québec 2023).

Anaerobic digestion (AD), the conventional method to produce biogas, is used commercially in Canada for feedstocks from agricultural waste, wastewater treatment facilities, source separated organics from MSW and pulp mills (IEA BioEnergy Task 37 2021). Biogas and RNG system production in Canada represent a total of **22 PJ**. Table 16 shows how the total energy from biogas produced in Canada was used in 2020.

Table 16: Biogas and RNG total production in Canada in 2020

Usage	Energy (PJ)
Electricity generation	11
Biogas conversion to RNG	6
Heat and powering on-site equipment and operations	5

Source: Canadian Biogas Association 2022b.

This report examines four different categories of biogas and RNG production based on their feedstock origin.

3.3.1. Agricultural Sector

The majority of the biogas systems used in Canada are based on the utilization of manure. The use of crop residues, which are sometimes employed as co-substrates with other feedstocks such as urban organics, is limited because of soil health concerns (TorchLight Bioresources Inc. 2020).

Manure is mainly used in Canada as a fertilizer by applying it directly to soils. A smaller proportion is converted to biogas by anaerobic digestion (AD) or composted. In 2020, **45** operational anaerobic digesters in Canada were using manure input to a certain extent. Most of the country's agricultural AD facilities are located in the province of Ontario. The technical capacity of these facilities totals around **1.1 Mt** of feedstocks, which is equivalent to some **94.6 million m^3** of biogas if assuming 86 m^3 of biogas per tonne of fresh waste (Canadian Biogas Association 2022a; IEA BioEnergy Task 37 2021). Co-substrates, such as food processing residues, fats, oils and greases are often added to the digesters even if the systems are manure-based (IEA BioEnergy Task 37 2021). In 2020, **779 kt** of manure and co-substrates combined produced approximately **67 million m^3** of biogas in Canada. This is equivalent to about **1.5 PJ** if assuming 65% methane content and 36 MJ/m^3 of methane (Hallbar Consulting Inc. and Research Institutes of Sweden 2020).

Most of the agricultural anaerobic digesters in Quebec, apart from Coop Agri-Énergie Warwick, which uses manure, treat cheese production waste. Several projects are under development in the province, including those launched by Nature Energy in Farnham, Groupe Bio Énertek in Sainte-Sophie-de-Lévrard, Agriméthane in Saguenay and Coop Carbone in Victoriaville (Canadian Biogas Association 2022a).

Farm sizes in Canada vary significantly and economies of scale for biogas facilities are achieved by larger farms or by co-digestion with feedstocks from outside the farms (IEA BioEnergy Task 37 2021). Canadian farms that have AD systems typically convert their biogas into electricity and sell it to the utility for a premium. Other opportunities for AD producers include using biogas for heat or upgrading biogas to RNG and selling it to natural gas utilities or local users.

3.3.2. Forestry Sector

Different projects are underway worldwide to develop and commercialize technologies used to convert woody biomass from the forestry sector to RNG.

GoBiGas in Sweden was the first to convert woody biomass to RNG by gasification in a demonstration scale facility (20 MW) (TorchLight Bioresources Inc. 2020). The plant faced challenges to produce continuously high purity syngas and was only able to operate by using wood pellets. The project was terminated after that phase.

In Canada, REN Energy announced in November 2022 that it had received site development approval, and would be building a facility to produce RNG from wood waste near Fruitvale in BC. The RNG produced will be purchased by FortisBC (REN Energy 2022).

G4 Insights in BC, which developed a technology called PyroCatalytic Hydrogenation (PCH), conducted trials on a pilot scale to convert lignocellulosic biomass to RNG. In 2020, it announced that the pilot demonstration phase had been successfully completed. The demonstration project used wood particles and forest residues supplied by FPInnovations. The RNG was injected into ATCO's natural gas distribution system in Edmonton, Alberta (NGIF Capital 2020).

In the forestry sector, pulp mills utilize AD technology to produce biogas from their pulp and paper mill sludge. In 2020, Canada had three in total (TorchLight Bioresources Inc. 2020).

3.3.3. Municipal Solid Waste and Wastewater Treatment Facilities

Part of the organic municipal solid waste (MSW) generated in Canada is treated by AD to produce biogas. There are around **9** AD **facilities** in the country that treat diverted food and organic waste from MSW as well as from business, institutional and industrial waste streams. Canada has some **126** wastewater treatment **facilities** with biogas and RNG systems including **108** municipal and **18** manufacturing **facilities** (Canadian Biogas Association 2022b).

The Disco Road Organics Processing Facility and Dufferin Organics Processing facility in the city of Toronto are two examples of organic waste processing facilities with AD systems in Canada. The Dufferin Organics Processing Facility has a capacity to treat around **55 kt** of waste per year. The biogas has been upgraded to RNG and injected in the natural gas grid since 2021 (City of Toronto 2021b). At the Disco Road Organics

Processing Facility, the equipment for biogas upgrading to RNG began installation in 2022. It is estimated that **75 kt** of organic waste will be treated to produce about **7.3 million m^3** of biogas and that Enbridge Gas will produce an output of **4.6 million m^3** of RNG (City of Toronto 2022).

Other examples include the city of Saint-Hyacinthe in the province of Quebec, which started producing RNG in 2014 and injecting it in the Énergir gas network in 2018 (Énergir n.d.). The Quebec Agglomeration Biomethanation Centre began operations in April 2023 (Monquartier 2023). In 2019 , the municipality of Laval announced a call for tenders for the construction of a biomethanation centre; however, in 2023 it indicated that it would not take this project any further due to high estimated costs (La Presse 2023).

Table 17: Examples of projects producing RNG from organic waste in MSW and wastewater treatment facilities in Canada

Facilities	Estimated or current production capacity per year				Project status
	Feedstocks		Production		
	MSW	Biosolids	Digestate	RNG	
Dufferin Organics Processing Facility (Ontario)	55 kt of MSW		9.5 kt	3.3 Mm^3	Started injecting RNG in the natural gas grid in 2021
Disco Road Organics Processing Facility (Ontario)	75 kt of MSW		Unknown	4.6 Mm^3	Started installation of the biogas upgrading equipment in 2022
Centre de biométhanisation de la ville de Saint-Hyacinthe (Québec)	More than 149.3 kt of MSW and biosolids combined		Unknown	13 Mm^3	Operational since 2014. Started injecting the RNG in the Énergir network in 2018
Centre de biométhanisation de l'agglomération de Québec (Québec)	Around 182.6 kt including 86.6 kt of MSW and 96 kt of biosolids		73 kt	10 Mm^3	Operational since April 2023

Sources: City of Toronto 2021a; Énergir n.d.; Le Soleil 2022; Monquartier 2023.

3.3.4. Landfill Sites

Methane is emitted at landfill sites from the anaerobic decomposition of organic waste, which includes waste from food, gardens, paper, wood and other materials. Food waste is a major contributor to methane generation. Landfill gas (LFG) is a mixture of gases comprised primarily of methane (CH_4), carbon dioxide (CO_2) and other compounds in low concentrations. LFG can be captured and flared or treated to be used as an energy resource. These commercial methods are already in use in Canada (Environment and Climate Change Canada 2022c), where there are over **100 landfills** with systems to recover LFG (Government of Canada 2023e) and around **50 facilities** that have LFG systems for biogas and RNG production (Canadian Biogas Association 2022b). Some **418 kt** of methane was recovered from about **1.4 Mt** of methane generated in 2020 at landfill sites. The recovered methane is used to generate electricity (52%), to produce RNG (17%) and to be used directly at nearby facilities (30%) (Government of Canada 2023e).

Canada has more than 3,000 landfills overall, although only over half are currently active. Of these, only 270 are considered large landfills with a waste capacity of more than 100,000 tonnes for open landfills and more than 450,000 tonnes for closed landfills (Environment and Climate Change Canada 2022f). These **270** large landfills have the most impact on GHG emissions since they receive around **90%** of country's generated waste. In 2019, they represented over **85%** of the methane generated from Canadian landfills. Regulations are currently in place requiring the capture of LFG by installing LFG recovery and destruction systems. However, existing LFG regulations do not require the utilization of the recovered LFG (Environment and Climate Change Canada 2022f) (Appendix 9).

According to an ECCC discussion paper, it is possible, technically speaking, to recover higher percentages of the methane generated from Canadian landfills and to use it as an energy source. However, the limited quantity of methane generated from each landfill impacts the economic viability of the projects (Environment and Climate Change Canada 2022f).

In 2022, the federal government began consultations on strengthening Canadian landfill methane regulations and increasing the number of landfills that recover methane (Environment and Climate Change Canada 2022a). In April 2021, a partnership was announced between Enbridge, Walker Industries and Comcor Environmental to jointly develop RNG projects at landfills throughout the country (Enbridge 2021).

3.4. Biohydrogen

This report defines biohydrogen as hydrogen produced from biomass resources. Canada **currently has no commercial production** facilities for biohydrogen.

Several projects have been announced for the production of biohydrogen in Canada in the upcoming years. The H2V Energies plant in Bécancour, Quebec, will convert MSW and residual biomass from the forestry sector and end-of-use wood to biohydrogen, bioammoniac and biomethanol. The process to be used is based on the conversion of biomass to hydrogen-enriched syngas through OMNI CT GPRS technology. This first step in the conversion of residual biomass is followed by a plasma treatment as a refining process to obtain biohydrogen and carbon dioxide. Production is expected to start in 2026 (H2 V Energies 2022).

Viridity Hydrogen Inc. (VHI) is a company in Northwestern, Ontario that developed a gasification technology for hydrogen production optimized for hardwood biomass feedstocks. The construction of its demonstration plant in Thunder Bay, Ontario will begin in 2023 with commissioning and production expected in 2025 (Canadian Hydrogen Association 2016; VIRIDITY Hydrogen Inc. n.d.).

Other projects to produce biohydrogen from biomass are being developed worldwide. For example, in May 2022, Mote in California announced that it had obtained commercial validation and was moving forward with facility planning. The firm's technology is based on biomass gasification to convert wood waste into biohydrogen and carbon capture to utilize or to store CO_2. Mote has secured feedstock supply for over 450 kt and the facility is expected to be operational in 2025 (Businesswire 2022).

In January 2023, Raven SR Inc., Chevron New Energies and Hyzon Motors Inc. announced that they were collaborating to commercialize hydrogen production from green and food waste. Raven SR's technology is a non-combustion steam/CO_2 reforming process that converts organic waste to biohydrogen. The facility in Richmond, California is expected to start commercial operations in 2024 and to use the biohydrogen produced in local transportation fuel markets (Chevron 2023).

In addition to MSW and forest biomass, sewage sludge has also been used for conversion to biohydrogen by demonstration plants abroad. TOSYNFUEL, a demonstration plant in Germany, ended its pilot project in September 2022, successfully converting sewage sludge to biohydrogen and synthetic fuels (TOSYNFUEL 2022).

3.5. Non-Energy Usages

Biomass resources can be used to produce several bioproducts for non-energy usages. Table 18 shows different categories of non-energy usages for biomass feedstocks.

Table 18: Examples of non-energy usages of biomass feedstocks

Categories	Examples
Food & Feed	Human food products, vegetable oils for cooking, etc.
	Animal feed products
Conventional and non-conventional wood products	Lumber
	Engineered wood products
	Pulp & paper
	Furniture & flooring
Biochemicals	Aromatics, amino and organic acids, phenols, polyols
	Cellulose, hemicellulose, lignin
	Biochar
	Bio-oils, lubricants
	Solvents, adhesives, paints, coatings
	Biopolymers and resins
	Biopesticides
	Biostimulants
	Additives and catalysts
	All other biochemicals
Biomaterials	Mats, cellulose products
	Bio-based auto parts, building materials, panels, cross-laminated timber
	Plastics, films, foams, hydrogels
	Nanomaterials and nanocomposites
	Nanocrystalline cellulose
	All other biomaterials

Source: Statistics Canada 2017.

3.5.1. Food and Feed

Food and animal feed are major categories of usage of biomass feedstocks from the agricultural sector.

The total quantities of each type of agricultural crop that is specifically used for food and feed were not found in the literature. However, the quantities of cereal crops and vegetable oils that were used as feedstocks for liquid biofuels are presented in Table 12 in Section 3.2. We could thus estimate that most of the remaining quantities would be used for food. Since exact quantities were not found, this category was explored no further in this report.

According to an estimate by the Animal Nutrition Association of Canada, Canadian livestock feed consumed approximately **28.9 Mt** of feed (not including forages) in 2021. Beef cattle, dairy cattle and sheep in Canada consume forages in addition to feed that is prepared in feed mills. In 2021, they consumed forages of **27 Mt, 6 Mt and 0.4 Mt**, respectively (quantities are presented on dry basis) (Animal Nutrition Association of Canada 2021).

3.5.2. Conventional and Non-Conventional Wood Products

Softwood lumber, wood pulp and structural panels make up Canada's main forestry sector products. In fact, Canada is the world's leading exporter of softwood lumber. Table 19 shows the quantities of the main wood products produced and consumed in Canada.

Table 19: Production and consumption of wood products in Canada in 2021

Wood products	Production in Canada	Consumption in Canada
Hardwood lumber	873,500 m^3	1,038,494 m^3
Softwood lumber	55,950,700 m^3	19,963,049 m^3
Structural panels (plywood and OSB)	8,938,385 m^3	4,111,910 m^3
Wood pulp	14,266 kt	6,644 kt
Printing and writing paper	2,418 kt	937 kt
Newsprint	1,888 kt	-91 kt

Source: NRCan 2022.

Wood logs harvested from Canadian forests are transported to different types of process facilities (lumber mills, chip mills, veneer and OSB plants) or exported. It is estimated that the log volume consumption by manufacturing plant type, as reported for BC in 2019, is around 68% for lumber mills, 11% for veneer and oriented strand board (OSB) plants and 10% for chip mills (including wood rooms in pulp mills). The remaining 8% of logs are exported and 3% are used for small operations.

Chips, sawdust and shavings obtained from sawmill process residues can be used as feedstocks for other usages (e.g., wood pellets). It is estimated that the product recovery in sawmills consists of 46% lumber, 35% chips and 17% sawdust and shavings. This estimate varies according to sawmill type and lumber processing dimensions. For example, in BC (2019) the province's 69 large mills produced **15.1 million m^3** of lumber by consuming around **32 million m^3** of logs (Bull et al. 2022).

Section 3.1 of this report explains the use of biomass feedstocks for wood pellets production in Canada and other energy use.

3.5.3. Biochemicals and Biomaterials

Bioproducts also include intermediary biochemicals and biomaterials (e.g., bioplastics) that are being developed globally to reduce the use of petroleum-based products. Bio-based plastics or bioplastics produced by using biomass feedstocks can be used to substitute conventional petroleum-based plastics in packaging, bottles, containers and many other applications.

One of the most common bio-based plastics is polylactic acid (PLA) which is made by extracting sugars from plants such as sugarcane or corn (Alfa Laval n.d.). In 2018, the Government of Canada launched the Plastics Challenge to encourage businesses to improve the biodegradability of bio-based plastics derived from agricultural or wood-based biomass and suitable for use as replacements for single-use plastics (I. Government of Canada 2021). In April 2021, it also announced a $1 million investment to BOSK Bioproducts Inc. to install a small-scale production line for prototyping formulations of compostable bioplastics made from forest biomass such as paper mill sludge (NRCan 2021a).

Biochar used for agricultural land applications is another non-energy usage of biomass. It is produced through the same process as biocoal, that is, the carbonization or pyrolysis of biomass at high temperatures. Biochar can be used for a variety of non-energy applications including soil amendments by blending it with compost or other nutrient-rich soil supplements (Airex Energy 2016).

Although there are several biochar producers in Canada, the total quantity produced per year was not found in the literature. Some examples of Canadian biochar producers include Airex Energy which has an industrial scale commercial plant at Bécancour in Quebec, and Canadian Agrichar industry in Maple Ridge, British Columbia. BC Biocarbon, based in Robson Valley, BC, uses pyrolysis to convert forest wood residues to many products as well as biochar.

4. GHG Emissions and Removal from the Biomass Sectors

Land and biomass use for energy or non-energy purposes is responsible for both carbon emissions and their removal from the atmosphere. Canada's National Inventory Report (NIR) track and report emissions from the forestry, agriculture and waste sectors and submits them to the UNFCCC. This section summarizes the emissions from these sectors for 2022.

4.1. Land Use, Land-Use Change and Forestry Sector (LULUCF)

In the above-mentioned NIR, the LULUCF sector reports anthropogenic GHG fluxes between the atmosphere and Canada's managed lands, including those associated with land-use change.

The net GHG fluxes in the LULUCF sector are reported for the following different categories of managed lands: forest land, cropland, grassland, wetlands, and settlements as well as the Harvested Wood Products (HWP) category. The reported net emissions from the LULUCF sector in the NIR published in 2024 were **14 Mt** of CO_2e in 2021 **and 51 Mt** in 2022 (Table 20).

It is to be noted that the NIR submission of 2024 included significant recalculations of the LULUCF emissions which shifted the entire time series from net removals reported in the 2023 inventory report to a net source of emissions in the report of 2024 (Government of Canada 2024).

Table 20: GHG emissions and removal from the LULUCF sector in Canada in 2022

Sectoral category	**Net GHG Flux (Mt CO_2e)**
Forest land	-110
Cropland	22
Grassland	1.3
Wetlands	3.3
Settlements	2.2
Harvested Wood Products	130
LULUCF total	51

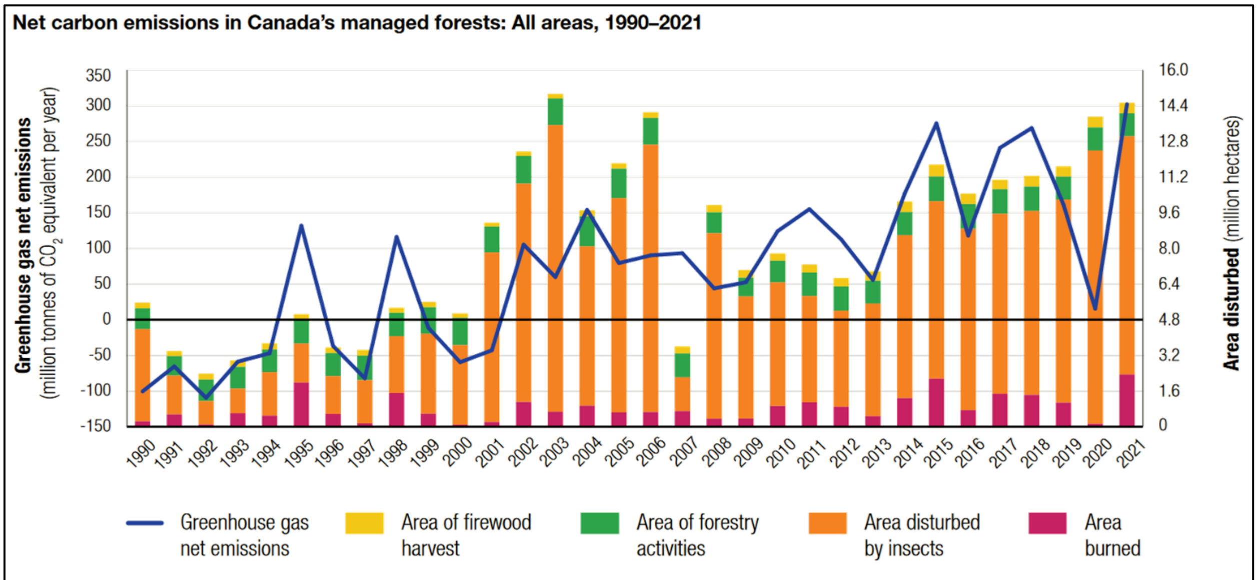
Source: Government of Canada 2024.

The GHG emissions in managed forests are also published in The State of Canada's Forests report (NRCan 2023). Figure 4 shows the net GHG emissions in managed forests from 1990 until 2021. Canada's managed forests have been a source of GHGs since

2002. Their total net GHG emissions, together with those from forest products, totalled **302.1 Mt** CO_2e in 2021.

The greater the area affected by the wildfires, the higher the GHG emissions will be. Since forests also sequester carbon during their growth, depending on the balance between the emissions and removal, Canadian forests can be either a sink or a source of GHGs every year.

Figure 4: Net carbon emissions in Canada's managed forests (all areas including areas of human activities and natural disturbances)



The total net emissions and removals from Canada's managed forests (line, left axis) and area affected by disturbance types (stacked bars, right axis), considering both human activities and natural disturbances, were approximately 302.1 Mt CO_2e in 2021, making the forests a net source in 2021.

Source: NRCan 2023.

Table 21: GHG emissions inventory of Canadian forests

Canadian forest contributions to the GHG inventory in 2021		**GHG inventory** (CO_2e/year, Mt)
Managed forests *(225 Mha)*	Total net emissions or removal to the atmosphere, all causes (a + b)	302.1
	(a) Net emissions or removal due to natural disturbances (not a reporting category in the NIR)	*310.1*
	(b) Net emissions or removal due to human forest management activities and from harvested wood products	*-8.0*
Forest lands affected by land-use change	Emissions due to afforestation	0.2
	Emissions due to deforestation	11.5

Source: NRCan 2023.

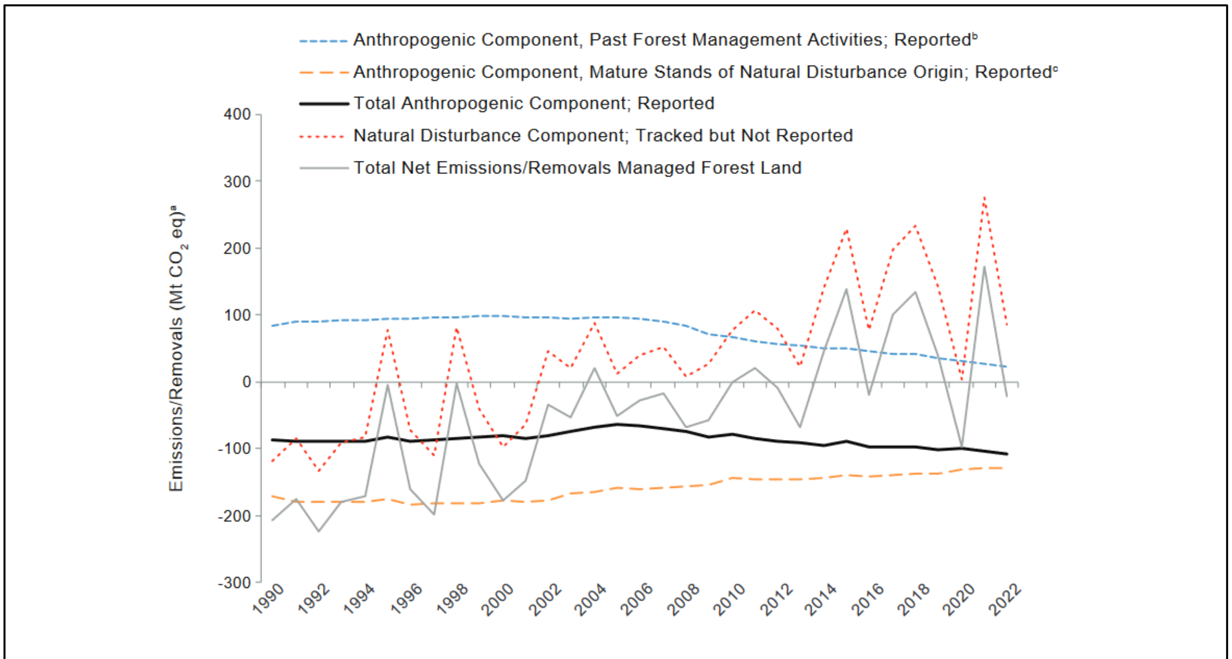
Note: Canada's managed forests are forest lands managed for timber production, conservation or fire suppression.

In the approach used to quantify the GHG emissions from Canada's forests, emissions stemming from natural disturbances and removal due to the regrowth of these forest stands (referred to as the natural disturbance component) are separated from those from the other stands in managed forests (referred to as the anthropogenic component). The anthropogenic component represents the stands for which the growth trajectory was primarily modified by human intervention (associated with forest management activities) and are considered mature enough to be eligible to harvest. Stands in managed forests that are affected by natural disturbances (such as wildfires) are separated until the trees have regrown back to maturity. Only then are they reported back in the first category. Therefore every year, the stands that were affected by natural disturbances are eliminated from the reported categories, and the previously removed stands that reached maturity in that year are added back to the reported category.

Although the NIR (Figure 5) tracks and presents all emissions and removal, the GHG reporting is based on the anthropogenic component only. GHG inventory values come only from ***"all forest stands in the managed forest land base that have attained commercial maturity or have had their growth trajectory modified by a direct anthropogenic management action in the forest"*** (Government of Canada 2024).

As mentioned in the NIR, the reason for that approach is to separate the emissions linked to land management from natural disturbances and to better inform stakeholders in the forest sectors (Environment and Climate Change Canada 2022e).

Figure 5: Emissions and removal in "Forest Land Remaining Forest Land" by stand component (not including emissions from HWP).



Notes:

a. Not including indirect CO_2 or emissions from HWP.

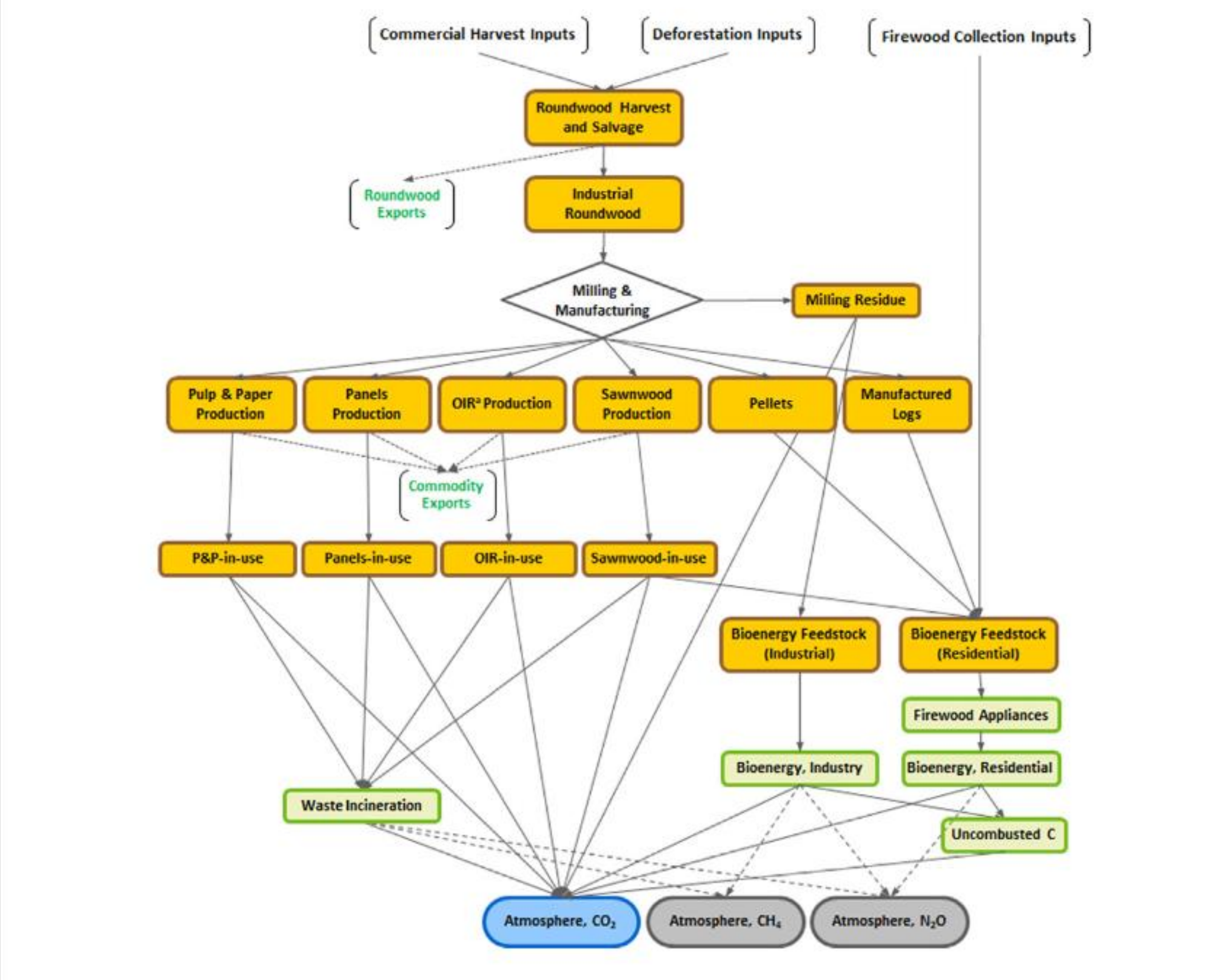
b. Clear-cut and partial harvests, commercial and pre-commercial thinning, and salvage logging.

c. Stands that have reached minimum operable age (either commercial maturity or pre-disturbance biomass threshold) and are eligible to be scheduled for harvest.

Source: Government of Canada 2024.

HWP are considered a transfer of carbon and the CO_2 emissions related to the use and disposal of wood products are estimated and reported in the LULUCF sector of the NIR. The CH_4 and N_2O emissions from the combustion of HWP or decomposition are reported in the Energy and Waste sectors of the NIR. The fate of the woody biomass is estimated by including the emissions at the end of life of products. Figure 6 shows a simplified schematic that was published in the NIR representing the carbon fluxes after harvesting wood.

Figure 6: Simplified schematic of carbon fluxes after forest harvesting.



Note:
a. OIR = Other Industrial Roundwood

Source: Environment and Climate Change Canada 2022e.

4.2. Agricultural Sector

In 2022, the agricultural sector's contribution to the total GHG emissions in Canada was **56 Mt** (excluding energy emissions) (Government of Canada 2024). The major share of these emissions comes from enteric fermentation (27 Mt) followed by the impact of applying nitrogen fertilizers to annual and perennial cropland agricultural soils (12.4 Mt). Emissions from crop residue decomposition depend on the impact of weather conditions on crop yields and changes in the proportion of annual and perennial crops. Cropland soils, which were a source of CO_2 removals in previous years (-23 Mt in 2021), switched to a source of emissions of 18 Mt in 2022 due to a significant drought event in 2021.

CO_2 emissions and removal by agricultural lands are reported in the LULUCF sector under the cropland category (Environment and Climate Change Canada 2023a).

4.3. Waste Sector

Canada's waste sector, which includes emissions from the treatment and disposal of wastes (solid waste disposal, composting, biological treatment, incineration, open burning of waste, wastewater treatment and discharge, contributed to the total GHG emissions in the country by **23 Mt** in 2022 (Government of Canada 2024).

The major contribution of this sector to emissions comes from the disposal of solid waste in MSW landfills (**19 Mt** CO_2e). In 2022, 42% of the LFG generated by MSW landfills were captured and flared or used for energy or oxidized. Waste diversion practices and landfill gas capture have been increasing over time and offsetting the increase of emissions arising from population growth.

It is important to note that emissions in the waste sector are produced by the anaerobic decomposition of disposed organic waste in landfills which generate mostly methane emissions. However, the CO_2 that is also emitted is not reported as part of the sector's total emissions.

5. Regulations in Canada Impacting the Demand for Biomass Harvest and Use

Many Canadian regulations and programs to reduce carbon pollution from fossil fuels have been announced in previous years. Numerous programs have also been introduced to encourage the use of biomass resources and reduce GHG emissions in the energy sector. This section summarizes key regulations and programs in Canada that impact (or could impact) the demand for biomass harvest and use in the transition to carbon neutrality.

5.1. Carbon Pricing System in Canada

The Pan-Canadian Approach to Pricing Carbon Pollution was announced in October 2016. The federal benchmark is the minimum national stringency standard applicable to all provinces and territories lacking carbon pricing systems that are at least at the level of the federal benchmark. The *Greenhouse Gas Pollution Pricing Act (GGPPA)* established two components of the federal carbon pollution pricing systems: a regulatory charge on fossil fuels (federal fuel charge) and a regulatory trading system for large emitting industries (output-based pricing system or OBPS).

In 2021, the Government of Canada announced that the carbon pollution price will be $65 per tonne of CO_2e in 2023 and will increase $15 each calendar year until 2030 to reach $170 per tonne of CO_2e (Government of Canada 2022a).

The federal fuel charge and the OBPS apply to many fossil fuels covered under the GGPPA, not including CO_2 emissions from combustion of biomass (Canada Revenue Agency 2022).

Some provinces apply their own pricing systems, such as the carbon tax in BC and Cap-and-Trade system in Quebec, that replace the federal fuel charge and OBPS systems. Other provinces have chosen to apply the federal backstop system only (e.g., Manitoba) or to apply one of the Federal Fuel Charge or OBPS and replace the other by their own carbon pricing system (e.g., Alberta).

It should be noted that emissions relating to land use and non-energy-related agricultural emissions are not covered by the carbon pricing systems in any jurisdiction in Canada (Canadian Climate Institute 2021c).

5.2. Carbon Intensity of Fuels

Canada's Clean Fuel Regulations require liquid fossil fuel primary suppliers to reduce the carbon intensity (CI) of the fuels they produce and sell for use in Canada by establishing CI requirements. A fuel's CI depends on the feedstocks (extraction), as well as its refining process, distribution and use (2020).

The CI reduction requirement started at 3.5 g CO_2e/MJ in 2023 and will increase by 1.5 g CO_2e/MJ each year to reach 14 g CO_2e/MJ in 2030.

The Government of Canada developed a Fuel Life Cycle Assessment (LCA) model as a tool to calculate the life cycle carbon intensity of fuels and energy sources used and produced in Canada (Environment and Climate Change Canada 2022d). According to its website, this model is used to determine the carbon intensity of fuels, material inputs and energy sources for credit creation for the Clean Fuel Regulations, and to provide transparent and traceable carbon intensity calculations. The last formal publication of the model was published in June 2024 (Environment and Climate Change Canada 2022d).

Table 22: Summary of clean fuel standards in Canada

Jurisdiction	Policy name	Requirements for renewable content blending with gasoline	Requirements for renewable content blending with diesel
Quebec	Integration of low-carbon-intensity fuel content into gasoline and diesel fuel	10% (2023) 12% (2025) 14% (2028) 15% (2030)	3% (2023) 5% (2025) 10% (2030)
Alberta	Renewable Fuels Standard	Min annual average of 5%	Min annual average of 2%
Manitoba	Ethanol Mandate, Biodiesel Mandate	At least 10%	5%
Ontario	Cleaner Transportation Fuels Regulation	10% (2020) 11% (2025) 13% (2028) 15% (2030)	4%
Saskatchewan	Renewable Diesel Act	7.5%	2%
British Columbia	Renewable and Low Carbon Fuel Requirements regulations	Min annual average of 5%	Min annual average of 4%

Sources: Gouvernement du Québec, n.d., Government of Alberta 2020, Government of Manitoba 2009, Government of Manitoba 2007, Government of Ontario 2020, Government of Saskatchewan 2012, Government of British Columbia, 2023a.

5.3. Carbon Market and Offset Credits

Carbon markets correspond to selling and buying credits obtained by reducing GHG emissions or by increasing GHG removal from the atmosphere. Typically, 1 GHG offset credit represents 1 tonne of reduced CO_2e emissions or removal from the atmosphere. In general, there are two types of carbon markets: compliance (credits used for compliance with regulations) and voluntary markets (credits used to meet voluntary objectives).

Canada's Clean Fuel Regulations established a credit market, from which a primary supplier of a fossil fuel can receive credits by further reducing the fuel's CI or can acquire credits from other parties to be able to comply with the requirements.

Canada has also put in place the ***Federal GHG Offset Credit System*** that generates credits for new projects to reduce GHG emissions compared to the business-as-usual case. These offset credits can be sold and used to comply with the requirements of the OBPS or be bought to comply with voluntary climate targets.

Only activities included in the published federal offset protocols will be eligible to generate offset credits in Canada's GHG Offset Credit System. The Compendium of Federal Offset Protocols currently includes only three systems: « Landfill Methane Recovery and Destruction », « Reducing GHG Emissions from Refrigeration Systems » and « Improved Forest Management on Private Land » (Environment and Climate Change Canada 2025).

ECCC is developing offset protocols to be included in the federal Offset Credit System for the following project types: Improved Forest Management on Public Land, Livestock Feed Management, Direct Air Carbon Dioxide Capture and Sequestration, Enhanced Soil Organic Carbon, Avoidance of Manure Methane Emissions through AD and other treatments. Bioenergy Carbon Dioxide Capture and Sequestration are currently under consideration by ECCC.

Other than the federal regulatory carbon markets that are used to comply with GHG emissions requirements, many provincial offsetting markets have already given credits for forest carbon sequestration. For example, offset projects that are managed through the BC Carbon Registry include the protection of forest areas and the reduction of harvest levels across the project area. BC is developing a new version of the Forest Carbon Offset Protocol (FCOP) for which public consultation on the last draft closed in April 2023. This protocol encompasses 3 types of projects: (1) afforestation and reforestation, (2) conservation and improved forest management and (3) avoided conversion of forest lands to a non-forest land use (Province of British Columbia 2023).

5.4. Biogenic Carbon Stock Potential Value

Biomass, including trees, agricultural crops and residues, currently stocks large amounts of carbon. When biomass is used for bioenergy, carbon is released into the atmosphere and will only be sequestered after several years of vegetation regrowth, provided that no disturbances occur during that period. The sequestered carbon in biomass currently has no value unless offset credits have been granted to enhance the carbon stock compared to a baseline scenario or for avoided emissions. As indicated in the 2020 expert report assessing carbon pricing systems, offsets do not automatically expand the coverage of carbon pricing programs, since the total quantity of compliance emissions (or emissions subject to a regulatory requirement) remains unchanged (Canadian Climate Institute 2021a).

The carbon pricing system for emissions does not apply to bioenergy based on the assumption of carbon neutrality. If the current system were to be reevaluated, what would the carbon stock value be now, and by 2050? Table 23 presents a proposal for estimating the biogenic carbon stock value for Canadian biomass resources at $65 and $170 per tonne of CO_2 in 2023 and 2030 respectively.

Estimations used for calculations:

[a, b] Wood basic density range used between 300 kg/m^3 and 700 kg/m^3 (Gonzalez 1990; UNECE n.d.). Moisture content of agricultural crops in Appendix 3.

[c] Carbon content by mass in biomass is between 44% and 50% for cereal and oilseed crops and 50% for forest biomass (Adetona and Layzell 2019; Greenhouse Gas Division Environment Canada 2002).

[d] The biomass emission factors range used is from 0.95 kg to 1.7 kg of CO_2 per 1 kg of dry biomass. (Germain 2005; Greenhouse Gas Division Environment Canada 2002).

Table 23: Biogenic carbon stock value estimations.

Categories of biomass	**Quantities produced** [a, b]		**Carbon content (Mt)** [c]	**CO_2 equivalent (Mt)** [d]	**Biogenic carbon stock value @ \$65/t CO_2 in 2023 (G\$)**	**Biogenic carbon stock value @ \$170/t CO_2 in 2030 (G\$)**
	Wet basis	Dry basis				
Cereal crops	64.5 Mt	56.1 Mt	25 to 28	53 to 95	3 to 6	9 to 16
Oilseed crops	25.3 Mt	22.8 Mt	10 to 11	22 to 39	1 to 2.5	3 to 7
Total harvested roundwood	143 Mm^3	42.9 to 100.1 Mm^3	21 to 50	40 to 170	2 to 11	6 to 29
Logging residues	-	21 Mt	10.5	20 to 36	1 to 2	3 to 6

5.5. Examples of Other Programs and Policies in Canada Impacting the Demand for Biomass for Heat and Energy

- Clean Fuels Fund: This fund aims to de-risk the capital investment required to build new or expand existing clean fuel production facilities. Support is also available for establishing biomass supply chains to improve the logistics of the collection, supply, and distribution of biomass materials as a feedstock in clean fuel production facilities (NRCan 2021b).

- Indigenous Forestry Initiative (IFI): The IFI provides financial support to Indigenous-led economic development projects in Canada's forest sector including biomass for heat and energy, pellet manufacturing, and use and management of forest resources. This initiative is not accepting applications at present (Government of Canada 2023b).
- Net Zero Accelerator (NZA) Initiative: Part of the Strategic Innovation Fund, this initiative could accept projects using biomass for energy if they show a potential of GHG reductions (Government of Canada 2023d).
- Low Carbon Economy Fund: Under the Low Carbon Economy Challenge, eligible projects could include those using biomass for energy if they could reduce GHG emissions in 2030 and If they align with Canada's goals for net-zero emissions by 2050 (Government of Canada 2023c).
- Sustainable Canadian Agricultural Partnership (CAP): This is a *$3.5-billion, five-year* agreement between the FPT governments designed to strengthen the competitiveness, innovation and resiliency of the agriculture, agri-food and agri-based products sector. Azure Sustainable Fuels Corp.'s SAF plant received funding from the Sustainable CAP program for its proposed project to be developed near Portage la Prairie. This project aims to produce 1 billion litres of SAF annually using Canadian feedstocks, including canola and soybean oils (Government of Canada 2023a).
- Quebec's Green Hydrogen and Bioenergy Strategy: One of the purposes of this strategy is to increase the role of bioenergy and green hydrogen in Quebec's energy portfolio (Government of Quebec 2023).
- Ontario's Forest Biomass Action Plan: This plan aims to encourage the integration of forest biomass into the province's various industrial sectors. The Ontario Forest Biomass Program supports the objectives of the provincial Forest Biomass Action Plan and supports initiatives that secure and increase long-term wood utilization across the province. (Government of Ontario 2022, n.d.).
- British Columbia's Residual Fibre Utilization Policy: This policy focuses on improving the use of lower-quality timber in Ministry of Forests areas where there is a demand for residual fibre and encourages increased business-to-business relationships between primary harvesters and secondary users (Ministry of Forests 2020).

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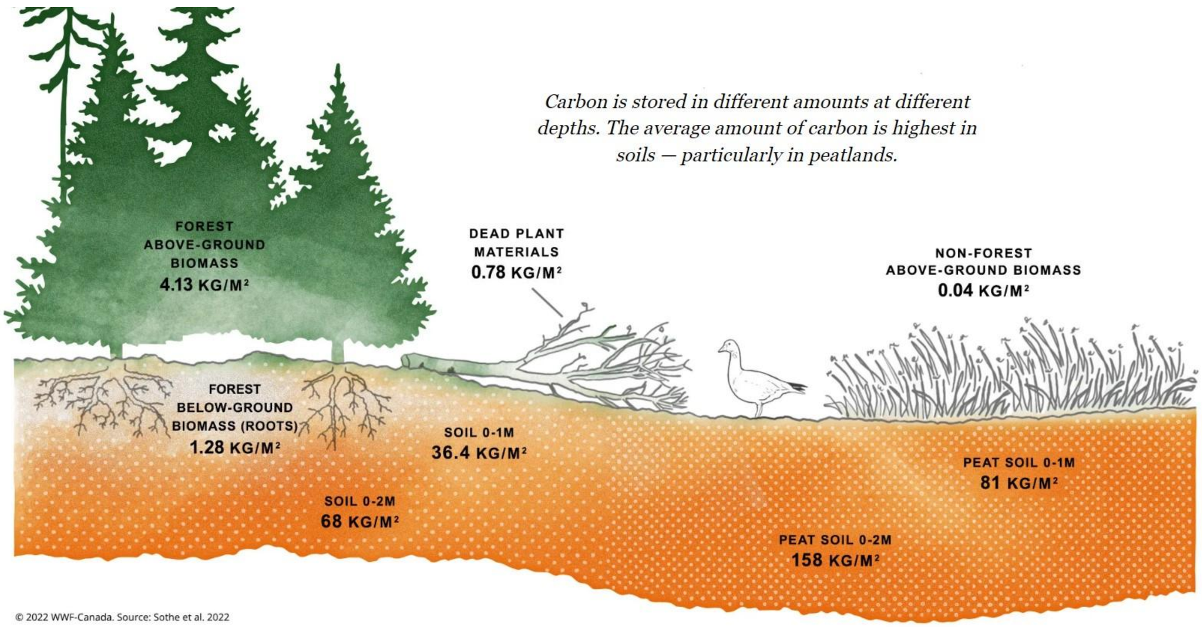
7. Appendices

Appendix 1: Canadian biogenic carbon stock in forest and non-forest ecosystems



Source: WWF 2022.

Biogenic carbon stock in Canada	**Mean ± SD** (kg/m^2)	**Total** (Billion tonnes of C)
Forest aboveground biomass	4.13 ± 1.80	14
Forest belowground biomass	1.28 ± 0.36	4.3
Forest dead plant materials	0.78 ± 0.02	2.6
Non-forest aboveground biomass	0.04 ± 0.01	0.2
Soil (0–0.3 m depth)	13.2 ± 10	111
Soil (0–1 m depth)	36.4 ± 37	306
Soil (0–2 m depth)	68 ± 75	572
Peat soils (0–1 m depth)	81 ± 67	98
Peat soils (0–2 m depth)	158 ± 134	190

Source: Sothe et al. 2022.

Appendix 2: Conversion factors used to estimate the energy content of the biomass resources cited in this report

Feedstock or fuel	Conversion factors for energy content	Sources
Ethanol	23.6 MJ/L	Navius Research Inc. 2023
Biodiesel (FAME)	35.4 MJ/L	Navius Research Inc. 2023
Renewable diesel (HDRD/HVO)	36.5 MJ/L	Navius Research Inc. 2023
Methane	36 MJ/m^3	Hallbar Consulting Inc. and Research Institutes of Sweden 2020
Green wood (35–58% MC)	3,000 MJ/m^3	IRENA 2019
Dry wood [a]	8,500 MJ/m^3 18.69 MJ/kg dry basis	Forest Research n.d.; WSP Canada Inc. 2021
Residual forest biomass (logging residues)	18.61 MJ/kg (dry basis)	WSP Canada Inc. 2021
Structural panels [b]	19 MJ/kg 9,500 MJ per m^3	Puettmann, Kaestner, and Taylor 2016; WSP Canada Inc. 2021
Wood pulp (paper)	15.5 MJ per kg	Kim, Park, and Yoshikawa 2017
Post consumer wood	8,500 MJ/m^3 18.69 MJ/kg (dry basis)	Forest Research n.d.; WSP Canada Inc. 2021
Wood pellets (8–10% MC)	18.6 MJ/kg	Natural Resources Canada 2013
Food waste (in MSW) [c]	16.73 MJ/kg (dry basis)	WSP Canada Inc. 2021
Agricultural crops (rye, oats, mixed grains)	18.3 MJ/kg (dry basis)	Adetona and Layzell 2019
Corn silage and tame hay	18.0 MJ/kg (dry basis)	Adetona and Layzell 2019
Wheat	18.4 MJ/kg (dry basis)	Adetona and Layzell 2019
Barley	18.2 MJ/kg (dry basis)	Adetona and Layzell 2019
Corn for grain	18.8 MJ/kg (dry basis)	Adetona and Layzell 2019
Oilseed meal of canola	27.8 MJ/kg (dry basis)	Adetona and Layzell 2019
Oilseed meal of soybean	23.4 MJ/kg (dry basis)	Adetona and Layzell 2019
Oilseed meal of flaxseed	30.8 MJ/kg (dry basis)	Adetona and Layzell 2019
Agricultural residues (corn stover)	18 MJ/kg (dry basis)	Helwig et al. 2002; US EPA 2015
Agricultural residues (straw)	16 MJ/kg (dry basis)	US EPA 2015; WSP Canada Inc. 2021
Cereal and oilseed crops	18.3 MJ/kg (dry basis)	Adetona and Layzell 2019
Animal manure (cattle)	8.7 to 18.7 MJ/kg (dry basis)	Font-Palma 2019

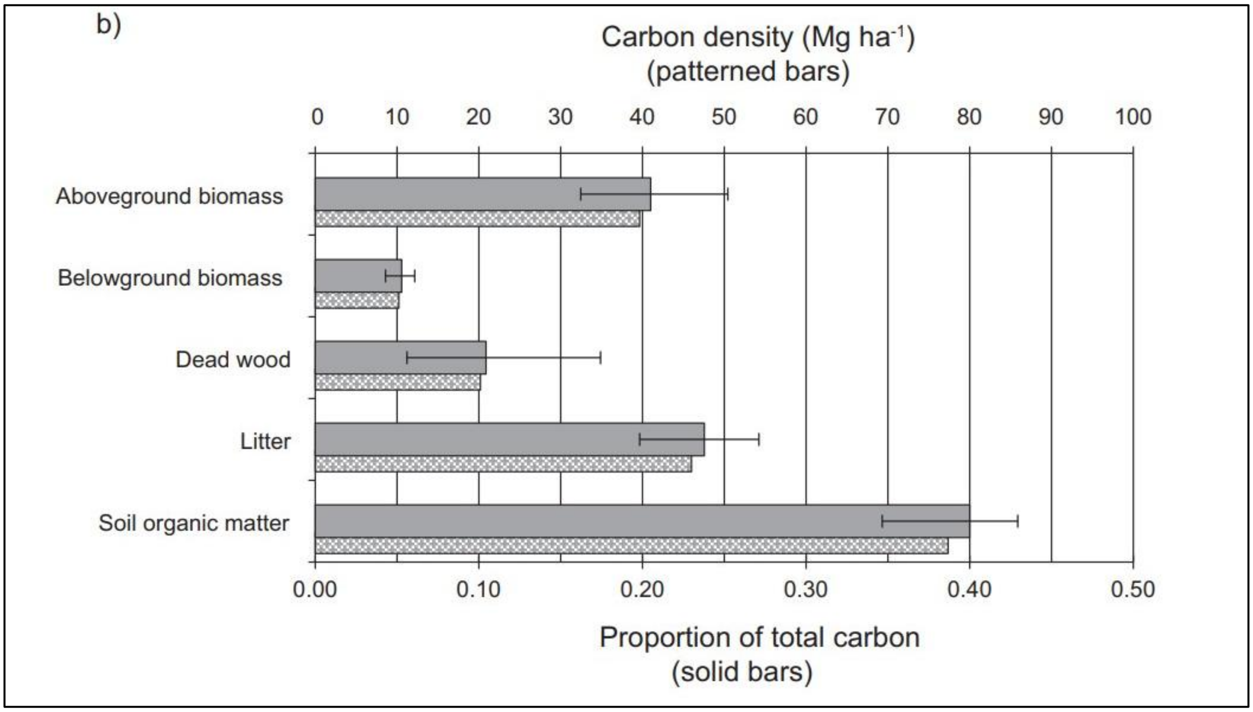
Notes: [a] The same value was used for all species of wood without differentiating hardwood and softwood species. [b] The assumption for structural panels was based on softwood plywood and by assuming the density of 500 kg/m^3. [c] We made the assumption for the total quantity of organic waste in MSW based on the data of energy content of food waste. Dry content of organic waste in MSW is between 30 and 50 %.

Appendix 3: Moisture content of the agricultural crops used to calculate the energy content on a dry basis

Agricultural crops	**Moisture content (kg H_2O/kg dry)**
Corn for grain	0.16
Fresh sweet corn	0.16
Wheat, all types	0.15
Barley	0.14
Oats	0.14
Rye	0.14
Mixed grains	0.13
Sugar beets	0.75
Canola	0.1
Soybeans	0.14
Flaxseed	0.1
Tame hay	0.1
Corn for silage	0.75

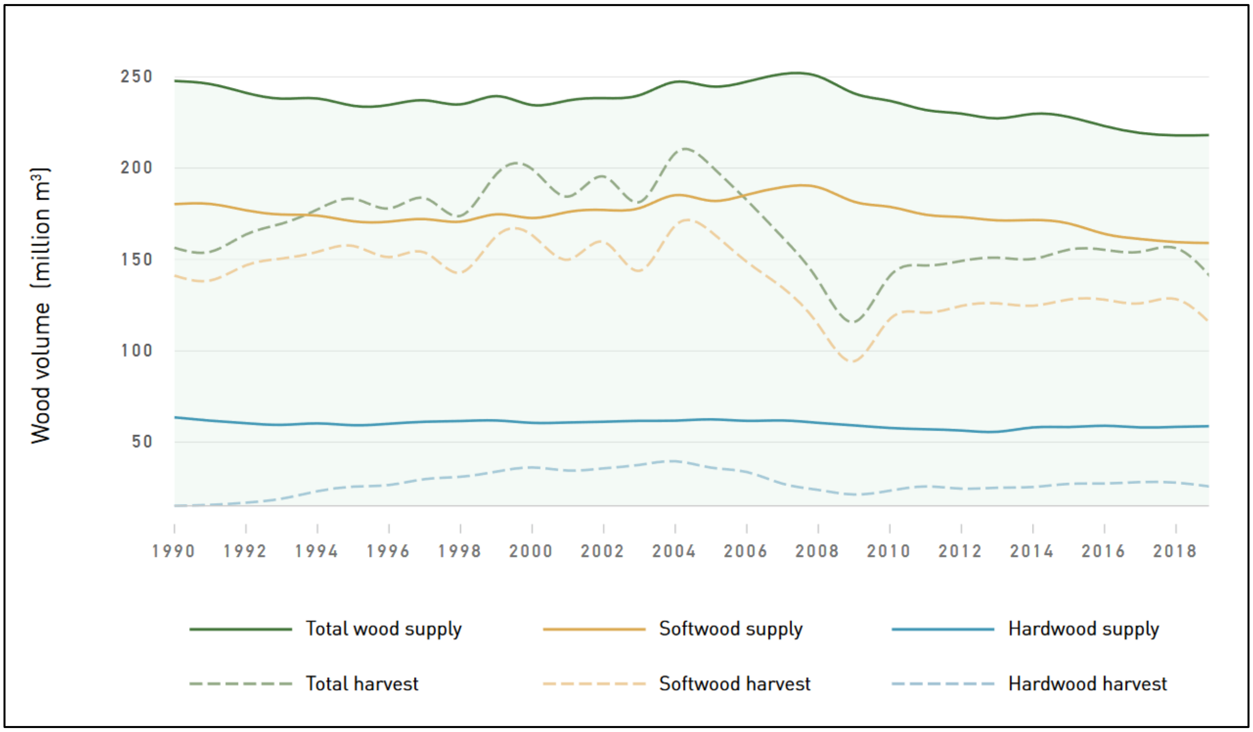
Source: Adetona and Layzell 2019.

Appendix 4: Carbon density and proportion of total carbon in biomass in Canadian forest lands



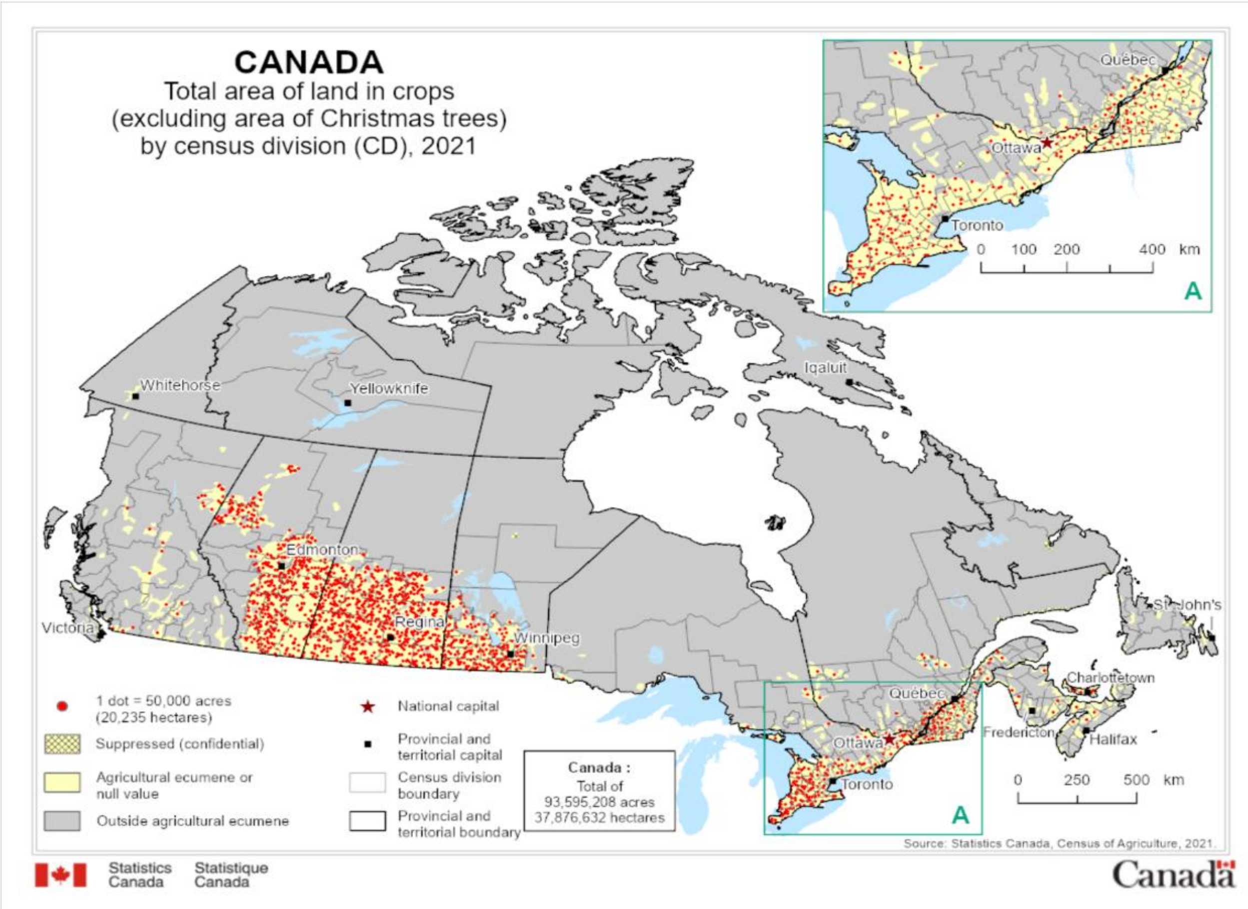
Source: Kurz et al. 2013.

Appendix 5: Comparison of wood volume that is considered sustainable to harvest and the volume that was harvested from 1990 until 2018 in Canada



Source: Forest Products Association of Canada 2022; Natural Resources Canada 2024.

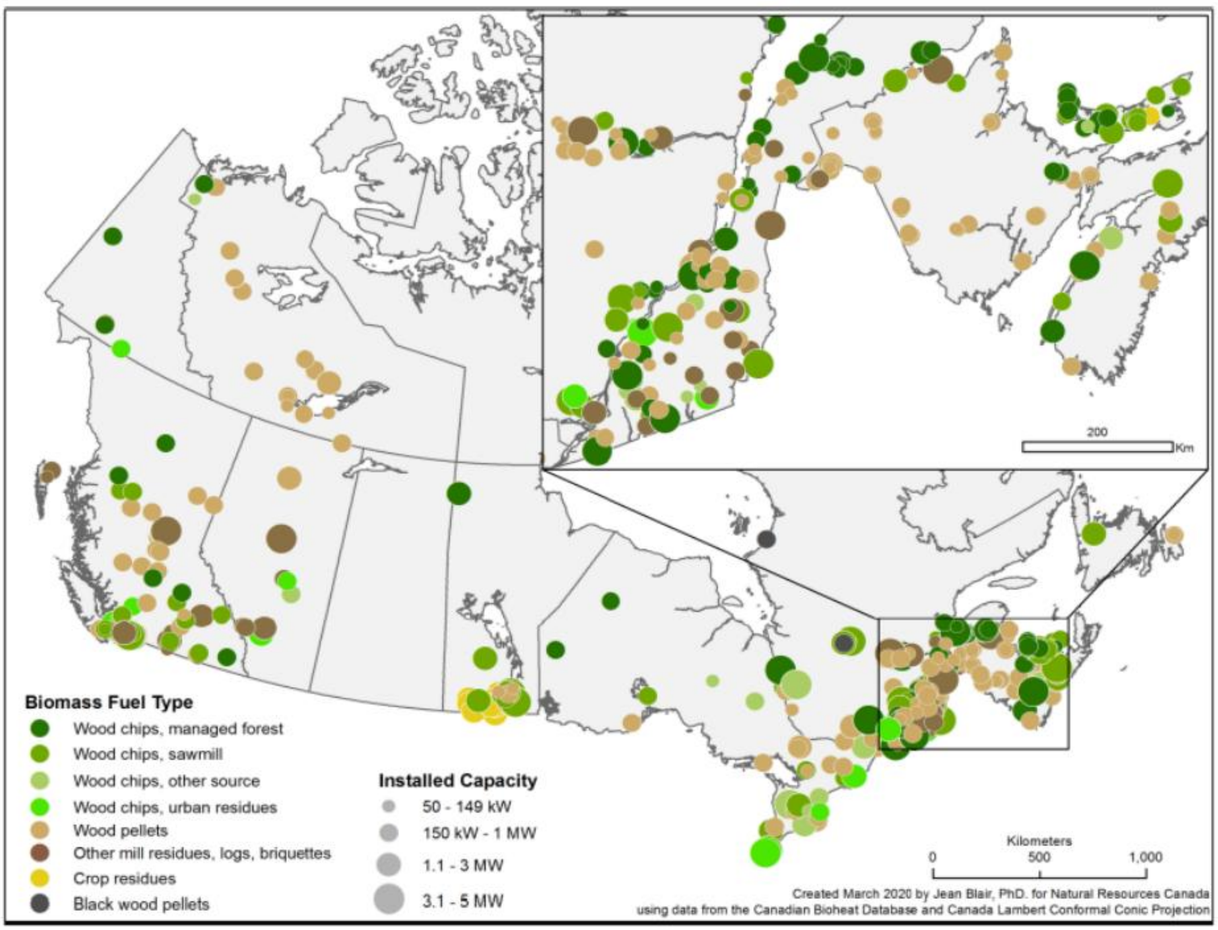
Appendix 6: Figure showing the total area of land in crops by census division in 2021



Source: Statistics Canada 2021.

Appendix 7: Locations of Bioheat installations in Canada by biomass type fuel and installed capacity

Bioheat systems are installed across Canada for use of solid biomass. Although multiple types of biomass feedstocks are used in bioheat systems (e.g., wood chips, wood pellets, other mill residues, crop residues), wood pellets and wood chips are the dominant feedstock of solid fuel bioheat installations in the country (USDA Foreign Agricultural Service 2023).



Source: USDA Foreign Agricultural Service, Global Agricultural Information Network (Report CA2023-0002) (January 2023)

Figure showing the locations of biomass installations in Canada per biomass type fuel and installed capacity.

Appendix 8: Monthly data for renewable fuel plant statistics

Products		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
Beginning stocks	Renewable fuel plant feedstocks, total *(metric tonnes)*	123,290	109,020	107,316	124,474	154,577	121,328	130,068	96,426	89,293	104,196	62,060	113,582
	Cereal grains, total *(metric tonnes)*	118,227	106,126	103,049	120,639	150,424	117,612	125,992	92,542	85,360	101,049	59,081	110,909
	Vegetable oils, total *(metric tonnes)*	1,070	832	1,190	764	774	908	840	662	765	724	1,254	898
	Other renewable fuel plant feedstocks, total *(metric tonnes)*	3,993	2,062	3,077	3,071	3,379	2,808	3,236	3,222	3,168	2,423	1,725	1,775
	Renewable fuels, total *(cubic metres)*	28,017	27,724	22,951	23,338	23,049	27,479	22,677	24,181	20,052	16,848	20,869	25,881
	Fuel ethanol (denatured) *(cubic metres)*	19,153	20,126	16,571	18,151	16,874	23,047	16,938	19,000	15,154	12,941	16,606	21,365
	Renewable fuels except fuel ethanol *(cubic metres)*	8,864	7,598	6,380	5,187	6,175	4,432	5,739	5,181	4,898	3,907	4,263	4,516
	Renewable fuel plant co-products, total *(metric tonnes)*	14,043	16,270	19,966	19,626	9,736	18,148	16,589	18,431	21,335	17,443	20,347	18,711
Receipts	Renewable fuel plant feedstocks, total *(metric tonnes)*	330,723	321,352	417,875	402,987	383,310	406,023	418,716	416,085	433,988	309,959	490,647	470,617
	Cereal grains, total *(metric tonnes)*	302,223	289,198	383,745	368,953	355,843	366,464	382,005	380,357	398,288	275,459	453,237	429,610
	Vegetable oils, total *(metric tonnes)*	22,450	25,305	28,078	26,142	20,756	31,071	29,020	29,208	30,327	29,496	31,355	34,941
	Other renewable fuel plant feedstocks, total *(metric tonnes)*	6,050	6,849	6,052	7,892	6,711	8,488	7,691	6,520	5,373	5,004	6,055	6,066

Inputs	Renewable fuel plant feedstocks, total *(metric tonnes)*	344,211	323,028	400,719	373,523	408,032	397,893	447,997	423,137	418,976	353,674	437,332	443,944
	Cereal grains, total *(metric tonnes)*	314,384	292,209	365,998	339,496	379,932	358,389	410,823	387,313	382,621	319,052	399,599	402,767
	Vegetable oils, total *(metric tonnes)*	22,686	24,930	28,507	26,132	20,622	31,139	29,199	29,104	30,370	28,965	31,711	34,853
	Other renewable fuel plant feedstocks, total *(metric tonnes)*	7,141	5,889	6,214	7,895	7,478	8,365	7,975	6,720	5,985	5,657	6,022	6,324
Production	Renewable fuels, total *(cubic metres)*	145,465	139,836	172,532	165,461	172,229	175,038	193,086	185,513	179,772	156,941	194,209	193,131
	Fuel ethanol (denatured) *(cubic metres)*	116,631	108,904	137,014	130,068	143,350	134,140	155,200	148,267	142,231	121,464	154,607	150,595
	Renewable fuels except fuel ethanol *(cubic metres)*	28,834	30,932	35,518	35,393	28,879	40,898	37,886	37,246	37,541	35,477	39,602	42,536
	Renewable fuel plant co-products, total *(metric tonnes)*	129,248	121,523	153,033	136,809	150,720	149,380	162,174	156,271	151,760	134,520	153,273	153,712
Ending stocks	Renewable fuel plant feedstocks, total *(metric tonnes)*	108,806	107,326	124,474	154,606	121,328	130,068	96,426	89,293	104,196	62,060	113,582	124,322
	Cereal grains, total *(metric tonnes)*	105,932	103,049	120,639	150,424	117,612	125,992	92,542	85,360	101,049	59,081	110,909	121,716
	Vegetable oils, total *(metric tonnes)*	832	1,200	764	774	908	840	662	765	724	1,254	898	986

	Other renewable fuel plant feedstocks, total *(metric tonnes)*	2,042	3,077	3,071	3,408	2,808	3,236	3,222	3,168	2,423	1,725	1,775	1,620
	Renewable fuels, total *(cubic metres)*	27,724	22,951	23,338	23,049	27,479	22,677	24,181	20,052	16,848	20,869	25,881	26,588
	Fuel ethanol (denatured) *(cubic metres)*	20,126	16,571	18,151	16,874	23,047	16,938	19,000	15,154	12,941	16,606	21,365	19,662
	Renewable fuels except fuel ethanol *(cubic metres)*	7,598	6,380	5,187	6,175	4,432	5,739	5,181	4,898	3,907	4,263	4,516	6,926
	Renewable fuel plant co-products, total *(metric tonnes)*	16,270	19,966	19,734	9,748	18,148	16,589	18,431	21,335	17,679	20,347	18,711	14,220

Source: Statistics Canada. Table 25-10-0082-01. Renewable fuel plant statistics, supply and disposition, monthly.

Appendix 9: Examples of requirements by certain governments to collect landfill gas to flare or utilize it

Provinces/states/territories	Requirements to install landfill gas recovery systems
Quebec and Ontario	Landfills larger than 1.5 million cubic metres of waste capacity
British Columbia	Landfills with greater than 100,000 tonnes of waste or greater than 10,000 tonnes disposed per year to evaluate their annual methane generation and install landfill gas systems if they exceed 1,000 tonnes of methane per year.
California	Landfills that generate landfill gas with a heat input capacity of more than 3.0 MMBtu/hr (~ 650 tonnes methane generation per year).

Source: Environment and Climate Change Canada 2022f

Appendix 10: List of stakeholders and experts that participated in the workshops and/or provided comments regarding the preliminary version of the white paper

Last Name	First Name	Organization
Adetona	Adekunbi	Canadian Forest Service, Natural Resources Canada
Aghabararnejad	Milad	CanmetENERGY in Varennes, Natural Resources Canada
Alward	Jonathan	Atlantica Centre for Energy
Beaumier	Louis	Institut de l'énergie Trottier
Bédard	Serge	CanmetENERGY in Varennes, Natural Resources Canada
Bédard	André	Quebec Wood Export Bureau
Bélanger	Normand	Fonds de solidarité Bioénergie (Fonds FTQ Bioénergie)
Bernier	Daniel	Union des producteurs agricoles
Bourdages	Alain	Produits forestiers Résolu
Bourque	Jean-Pierre	Ministère des Ressources naturelles et des Forêts
Brewin	Dan	Plant Protein Alliance of Alberta
Broda	Joey	FortisBC
Byatt	Justin	Forest Operations and Development Branch, Government of New Brunswick
Chenel	Jean-Philippe	Consortium de recherche et innovations en bioprocédés industriels au Québec
Clark	Dylan	Pacific Institute for Climate Solutions
Dagher	Roberta	Institut de l'énergie Trottier
Dickie	Chris	ResearchNB
Down	Sam	HEMPALTA
Downing	Melissa	Alberta and National Cattle Feeders' Association
Drevet	Tarra	The Simpson Centre
Durany	Gabriel	Plan A Capital
Edom	Éloïse	Institut de l'énergie Trottier
Ell	Wendy	Glacier FarmMedia
Mohammadi	Hana Fateme	University of British Columbia
Finet	Jean-Pierre	ROEÉ
Foxall	Ryan	BC Ministry of Energy, Mines and Low Carbon Innovation
Gagnon	Bruno	Canadian Forest Service, Natural Resources Canada
Gagnon	Yves	Université de Moncton
Germain	Louis	Conseil de l'industrie forestière du Québec (CIFQ)
Ghatala	Fred	Advanced Biofuels Canada
Goodison	Andrew	Canfor
Goulet	Nicole	Ontario Power Generation
Gulab	Sabrina	The Simpson Centre
Guy Adegbidi	Hector	Université de Moncton Campus d'Edmundston
Harvey	Jacques	J Harvey Consultant & Associés inc

Last Name	First Name	Organization
Hays	Fred	AB Beef
Hoffmann	Ron	SixRing
Holowaychuk	Will	Alberta Canola
Ishaque	Hanan	The Simpson Centre
Jazinaninejad	Mona	University of New Brunswick
Kehoe	Steve	BMO
Khennache	Lylia	Airex Énergie
Kiro	Ruth	Pollution Probe
Laframboise	Amélie	Ville de Montréal
Landry	Mathieu	Climate Change Secretariat, Government of New Brunswick
Langlois - Bertrand	Simon	Institut de l’énergie Trottier
Lee	Jason	Environment and Climate Change Canada
levesque	Jonathan	Biomass Solution Biomasse
Lhermie	Guillaume	The Simpson Centre
Liu	Daniel	Natural Resources Canada
Locoh	Ayaovi	Institut de l’énergie Trottier (IET)
Maghzian	Ali	University of British Columbia
Mambo	Tatenda	The Simpson Centre
Marois-Mainguy	Olivier	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation
Mathis	Chris	Viable Solutions
McGee	Michael	BioEnterprises
McKell	Brittany	HEMPALTA
Meisser	Janay	UFA Co-Operative Ltd.
Moss	David	Telus Agriculture
Moss	Riley	TC Energy
Mousseau	Normand	Institut de l’énergie Trottier
Afzal	Muhammad	University of New Brunswick
Müssenberger	Frank	Ministère de l'Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs
Naylor	Simon	Viridis Environnement
Niet	Taco	Simon Fraser University
Paré	Benoit	Centre de traitement de la biomasse de la Montérégie
Pauer	Stefan	Clean Energy Canada
Pinault	Eric	Université de Québec à Montréal
Prodan	Hugh	Bio Alberta
Rancourt	Emmanuelle	Vision Biomasse Québec - Nature Quebec
Sanguinetti	Lucia	The Simpson Centre
Sebaa	Nazim	Association des consommateurs industriels de gaz
Sharma	Mahima	Forest Products Association of Canada
Sieppert	Jackie	School of Public Policy, University of Calgary

Last Name	First Name	Organization
Sokhansanj	Shahab	University of British Columbia
Sorenson	Brian	Canary Biofuels
Tauvette	Geoff	Canadian Council for Sustainable Aviation Fuels
Thellen	Philippe	Ministère de l'Économie, de l'Innovation et de l'Énergie (MEIE)
Thiffault	Evelyne	Université Laval
Thomson	Ian	Advanced Biofuels Canada
White	Troy	BioComposites Group
Whitmore	Johanne	HEC
Wiskar	Shawn	The Simpson Centre
Wolinetz	Michael	Navius Research
Wong	Tammy	Ontario Power Generation
Xie	Sheng	Natural Resources Canada
Zhu	Hui	UBC Clean Energy Research Centre
Zuleta	Liliana	Emissions Reduction Alberta