Biomass and carbon neutrality: putting in place an evaluation framework

# Current State in Canada

*Preliminary version*

***Institut de l'énergie Trottier*** and ***Transition Accelerator***

## About the *Institut de l'énergie Trottier* (IET)

The IET was created in 2013 thanks to a generous donation from the Trottier Family Foundation and is based at Polytechnique Montréal. Its mission is to train a new generation of engineers and scientists with a systemic and transdisciplinary understanding of energy issues, to support the search for sustainable solutions to help achieve the necessary transition, to disseminate knowledge, and to contribute to discussions of energy issues. This diversity of expertise allows IET to assemble work teams that are transdisciplinary, an aspect that is vital to a systemic understanding of energy issues in the context of combating climate change.

## About the Transition Accelerator

The Transition Accelerator (The Accelerator) exists to support Canada's transition to a net zero future while solving societal challenges. 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 get there. 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.

## Disclaimer



## Funding

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Institut de l'énergie Trottier
Polytechnique Montréal
2900, Boul. Édouard-Montpetit
2500, chemin de Polytechnique
Montréal (Québec) H3T 1J4
Web: iet.polymtl.ca
Twitter: @EnergieTrottier

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## Authorship team

**Roberta Dagher, PhD – Research Associate**
*Institut de l'énergie Trottier and the Transition Accelerator*
Roberta Dagher holds a PhD in wood and bio-based materials engineering from Université Laval. She completed her doctoral thesis and a postdoctoral fellowship at the university's *Centre de recherche sur les matériaux renouvelables* (centre for research on renewable materials, known by its French acronym CRMR). After an academic background specialized in chemistry, her research experience was acquired in the fields of wood chemistry, material characterization and evaluation of the fire resistance of wood.

**Ayaovi Locoh, PhD – Research Associate**
*Institut de l'énergie Trottier*
Ayaovi Locoh is an economist with a PhD specialized in energy economics from Université Laval. As a previous member of the *Centre de recherche sur les matériaux renouvelables* (CRMR) and the *Institut d'Innovations en Écomatériaux, Écoproduits et Écoénergies à base de biomasse* (I2E3), he has developed his expertise in renewable energy, energy transition and decision-making processes.

**Louis Beaumier, M.A. Sc – Executive director**
*Institut de l'énergie Trottier*
A graduate of Polytechnique Montréal, Louis Beaumier has worked for several years in software development. He has worked in a variety of application fields, from distributed systems of immersive simulations to speech recognition interfaces. The experience he has acquired over the years and through his various assignments – from developer to R&D manager – has led him to realize that a poorly presented solution, is often the main source of difficulties in a project. After several years in product management, during which he honed his ability to understand problems and present solutions, he joined the IET. His work at the Institute adds a sense of commitment that was lacking in his previous roles.

**Normand Mousseau, PhD – Scientific director**
*Institut de l'énergie Trottier and the Transition Accelerator*
Normand Mousseau is a professor of physics at Université de Montréal, scientific director of the Institut de l'énergie Trottier and research director at the Transition Accelerator. After completing his doctoral thesis at Michigan State University, he worked as a postdoctoral researcher at Oxford University in England and at the Université de Montréal. He is a world-renowned researcher in complex materials and biophysics, with over 150 scientific articles to his credit. He is actively involved with energy and climate policy, having co-chaired the Quebec Commission on Energy Issues in 2013, and published several books in this field.

## Background

Biomass resources are expected to play a major role in the transition to net-zero and many studies estimate 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 or 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 bioethanol, biojet fuels, renewable natural gas, biochar, wood composite products, biopolymers, etc. However, the decarbonization pathways of several economic sectors are based on the same types of biomass feedstocks. For example, the decarbonization of the aviation sector and road transportation sectors involved are closely related due to technologies that can produce adjustable fraction of biojet and renewable diesel. Depending on how these projects develop, this competition can either accelerate decarbonization or create important tensions.

**With the development of multiple conversion technologies, competing demands from various economic sectors and a limited supply, which pathways would contribute best 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.

In this report, we present an overview of the current situation in Canada concerning the production of both biomass feedstocks and bioproducts. The analysis was done 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 including both energy and non-energy usages. This first analysis allows us to identify some key uncertainties related 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 to receive comments from a wide variety of perspectives including industries, academia, governments, indigenous communities, non-profit organizations, for the end objective of co-constructing an evaluation and comparison framework for the biomass usages in a net-zero future.

## Note to Readers

This version of the report is still a work in progress. Although the authors invite the readers to add their comments and/or suggestions on any element in the report, some have been already identified by them as of particular interest. They are highlighted as following:

This icon identifies notes from the authors. These notes raise specific hypotheses, ideas or elements to discuss.

This icon identifies questions from the authors about topics that need further exploration.

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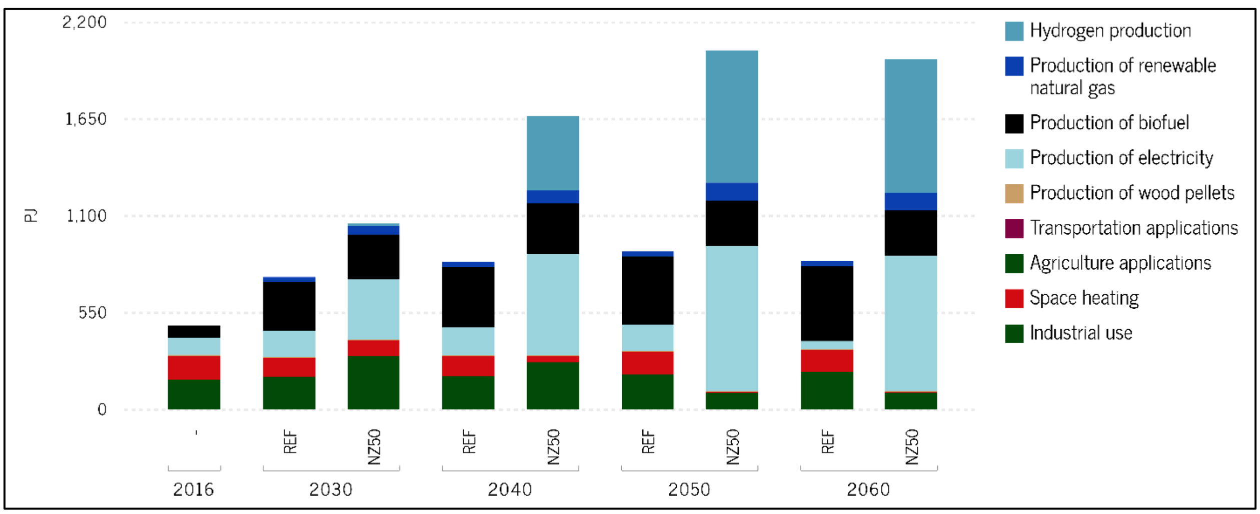
# 1. Overview

Bioenergy has been traditionally one of the main energy sources for humans and its use continued to expand with modern technologies to include numerous applications and a large variety of biomass feedstocks. In a context of transition to a net-zero future, bioenergy is occupying 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, space heating and industrial use.

## 1.1. The Net-Zero Challenge

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

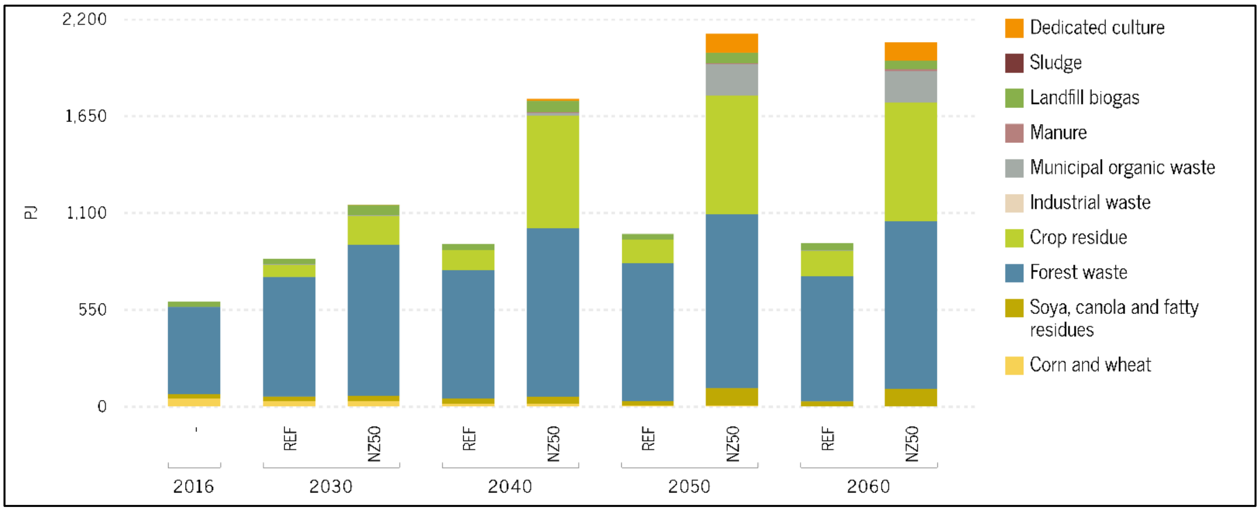



Source: (Langlois-Bertrand et al. 2021)
Note: REF is the reference scenario using no constraining GHG reduction targets. NZ50 is a scenario which imposes a net-zero emissions target on total $CO_2e$ by 2050, and a 40% reduction target by 2030, with respect to 2005.

**Figure 1: Primary biomass usages in net-zero scenarios of the Canadian Energy Outlook published by IET in 2021**

Bioenergy can be produced from biomass resources from 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 which imposes a net-zero emissions target on total CO2e by 2050, and a 40% reduction target by 2030, with respect to 2005.

Figure 2 shows the type of biomass resources that were included in net-zero scenarios of the IET Canadian Energy Outlook. Based on a rich set of technologies, the quantity of forest waste that is used for bioenergy remains significant until 2060 in all net-zero scenarios; however, the use of agricultural crop residues grows rapidly and reaches more than 30% of the total biomass sources in 2050. Other sources of biomass, such as dedicated culture, municipal organic waste, landfill gas, soya, canola and fatty residues, also contribute to the energy mix in these scenarios.




Source: (Langlois-Bertrand et al. 2021)
Note: REF is the reference scenario using no constraining GHG reduction targets. NZ50 is a scenario which imposes a net-zero emissions target on total $CO_2e$ by 2050, and a 40% reduction target by 2030, with respect to 2005.

**Figure 2: Bioenergy sources, shown by type, in net-zero scenarios of the Canadian Energy Outlook published by IET in 2021**

## 1.2. Current Situation in the Biomass Sectors

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

Table 1 shows the summary of the quantities produced in Canada of different biomass feedstocks and bioproducts. The data for each type of feedstock are presented further in this report.

*There was no attempt to estimate the technical potential of the resources cited in this report for any type of biomass usage. However, the aim is to have a clear overview of the biomass resources in Canada (including those that are currently used for food, feed and construction) and the current production of major bioproducts.*

*The conversion factors used to estimate the energy content of the biomass resources in Canada are presented in Appendix 2, Appendix 3 and Appendix 4. The method used to estimate the biogenic carbon stock value is presented in section 5.4 of this report.*

**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 $CO_2$ (billion \$) | Carbon stock potential value @ \$170/t $CO_2$ (billion \$) |
|---|---|---|---|---|---|
| ***Biomass feedstocks*** | | | | | |
| **Forestry sector** | Wood volume harvested | 143 million $m^3$ | 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)* | 146 | - | - |
| **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 | 59 | - | - |
| **Liquid biofuels** | Bioethanol | 1,642 million litres | 35 | - | - |
| | Renewable diesel | 0 | 0 | - | - |
| | Biodiesel | 431 million litres | 15 | | |
| | Biocrude and bio-oil | | | - | - |
| | Biomethanol | | | - | - |
| | Biojet | 0 | 0 | - | - |
| **Biogas and RNG** | | - | 22 | - | - |
| **Biohydrogen** | | 0 | 0 | - | - |
| **Non-energy usages** | Softwood lumber | 56 million $m^3$ | 476 | - | - |
| | Structural panels | 9 million $m^3$ | 85 | - | - |
| | Hardwood lumber | 0.9 million $m^3$ | 7 | - | - |
| | Wood pulp | 14.3 Mt | 221 | - | - |
| | Other (e.g., food & feed, biochar) | - | - | - | - |

* Rough estimates for these biomass resources and precision are needed.
Note: REF is the reference scenario using no constraining GHG reduction targets. NZ50 is a scenario which imposes a net-zero emissions target on total $CO_2e$ by 2050, and a 40% reduction target by 2030, with respect to 2005.

## 1.3. Uncertainties and Concerns

There are many uncertainties related to the integration of bioenergy systems in a net-zero future. Uncertainties and concerns related to bioenergy in the literature mainly include the availability and sustainability of the biomass resources, competition with essential non-energy usages such as food and animal feed, technology development and costs, supply chain emissions, assumption of "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 while assessing bioenergy role in a net-zero future:

**(a)** ***Land use:*** It is known that the capacity of the managed forest and agricultural lands to supply biomass in a sustainable manner is limited. How will the increase of bioenergy demand impact the 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 energy producers*****:** With limited feedstock availability and a rising demand for its use by different energy producers, on which basis will the arbitration for the best usage occur? For example, many facilities announced the production of renewable diesel and sustainable aviation fuel (SAF) in the near future in Canada, however, the decision of producers 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 of 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 whole system?

**(d)** ***Alternatives:*** If a certain 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 the alternative destiny of that resource be? What is the best way to compare options to ensure a complete assessment of the climate effects of the whole system that is put in place?

**(e)** ***Assumption of "carbon neutrality":*** Bioenergy is often assumed to be carbon neutral since biogenic carbon that is being 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 “payback 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 are stocking large quantities of carbon until it gets released to the atmosphere through harvest and use for energy. Presently, the carbon stock does not have a 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:*** In the UNFCCC countrywide reporting, $CO_2$ emissions from biomass combustion are not reported in the energy sector in order to avoid double counting of the emissions which are already reported in the “land use, land-use change and forestry sector.” How does this approach of counting emissions at the place of harvest instead of combustion impact the sustainable practices of the reporting countries?

# 2. Biomass Feedstocks in Canada

## 2.1. Forestry Sector

Forest biomass resources are divided in three main categories according to where they are sourced either as products and residues from forest management, from wood processing industries or from dedicated energy plantations (Table 2) (NRCan 2014; WSP Canada Inc 2021). In this report, the end-of-use products from construction, renovation, and demolition (CRD) were considered in the 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 total forest land (NRCan 2022) (Table 3). In 2020, the estimated total wood volume in Canada was **50,000 million m$^3$** (Table 4). However, wood supply level that is considered sustainable to harvest was **215.3 million m$^3$**. The total wood volume that was harvested in 2020 totalled **143.1 million m$^3$**. The total industrial roundwood that was harvested in 2020, including softwood and hardwood, totalled **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 that is sustainable to harvest | 215.3 |
| Total wood volume harvested in 2020<br>(Industrial roundwood, fuelwood and firewood) | 143.1 |
| Industrial roundwood harvested in 2020<br>(logs, pulpwood, other) | 141.1 |

Source: (NRCan 2022)

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

Logging operations generate a lot of residues which include branches and low-quality logs or parts of logs. These resources are referred to as forest residuals or residual fibre which are left behind on-site after primary harvest operations. Residual biomass from logging operations is usually burned in “slash piles” near the harvesting site. “Open burning” is done due to requirements for disposal of the residual slash and wood residues to reduce wildfire hazards. The Open Burning Smoke Control Regulation in British Columbia (BC) mentions that other reasonable alternatives such as mulching and green waste recycling facilities must be explored before burning (Environmental Management Act 2019). There are also limits set by provinces for allowable waste to be left on site after logging operations (Ministry of Forests, BC n.d.).

It is difficult to quantify the logging residues on a Canada-wide level due to lack of a clear definition of what is included in the logging residues and lack of consistency across jurisdictions. It is estimated that the annual national availability of logging residues to be 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 obtained through the NFI’s website which provides some tools to estimate the biomass quantities in Canada (NFI n.d.). 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 to transport to different facilities.

*A recent analysis by Torchlight Bioresources estimated the potential of renewable natural gas (RNG) development across Canada. They mentioned that due to "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, they determined that Canada could support facilities that consume **at least 500,000 dry tonnes** including pulpwood, mill residues and harvest residues (TorchLight Bioresources Inc. 2020).*

*What will be the impact of the wildfires of 2023 on sustainable wood volumes estimation?*

## 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

Among all types of hay and field crops, canola represents the top acreage 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 the production of bioproducts. For example, corn and wheat are used for the production of bioethanol. Oilseeds crops such as canola and soybeans are used for biodiesel production.

Farms classified as oilseeds and grain make up the largest proportion 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 Canada. Grains and oilseeds accounted for **99%** of the volume of agricultural biomass that was used for bioproducts production in 2015

(Government of Canada 2017). Corn for grain is primarily used for ethanol production and animal feed, but 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 the ration of dairy cows (Khan et al. 2015). It is also used as an important feedstock for bioenergy in some countries (e.g., Germany) in biogas and RNG facilities (TorchLight Bioresources Inc. 2020).

The details about the current production of biofuels and other bioproducts in Canada are discussed in the following sections of this report. As for the production of agricultural feedstocks, the quantities produced per year are shown in Table 6.

**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 |
| Forage crops | Tame hay | 19,374 | 317 |
| | 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 treatments by incorporating them to the animal diet with other high-quality feed (Agriculture Knowledge Centre of Saskatchewan n.d.).

Corn stover is the residue from corn harvest that remains in the field and includes leaves, stalks, husks and cobs. Corn grain represents around 40 to 50% of the dry matter of the corn plant and 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.

No data was found for the exact total quantity of agricultural harvest residues in Canada; therefore, estimates were made based on the methods found 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).

***Estimation method:*** *According to the website of the government of Manitoba, to estimate the tons per acre of dry matter material of corn stover remaining to be grazed or baled, we can multiply the grain corn yield in bushels (bu) per acre (ac) 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 a 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).*

As for the residues consisting of straw and chaff from wheat, barley and oats, the estimate was based on the report of Torchlight Bioresources (2020). It is mentioned in the report of Torchlight Bioresources that the annual availability of straw in the prairie provinces varies substantially and in some very dry years there could be almost no straw available due to requirements for field retention (TorchLight Bioresources Inc. 2020).

***Estimation method:*** *In the report of Torchlight Bioresources, they assumed biogas yield of 400 $m^3$ per dry tonne of straw; however, they did not specify the methane content of biogas. We assumed that the methane content of biogas would be around 50 to 65%. They estimated 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. Therefore, the quantity of straw 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 done in the assessment of WSP (WSP Canada Inc 2021), the total quantity of straw would be higher (around 43 Mt) and 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. Manure contains varying amounts of organic matter, water and nutrients including nitrogen and phosphorus and is commonly used as a fertilizer (Statistics Canada 2011).

The daily manure production in Canada is estimated by coefficients determined by animal type. The total manure production in Canada was around **21.4 Mt** of dry manure in 2018 or 19.8 Mt of volatile solids (VS). The energy content of the total quantities of the animal manure is estimated to be around 146 PJ (Appendix 3) and currently around 1 to 2% of the total quantity is utilized for energy purposes (details are discussed further in section 3).

The number of animals in Canada, manure production of the largest animal groups and their energy content are presented in Table 8. It is important to note that not all the total quantity of the reported 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 | 59.8 |
| Calf | 3,856,750 | 3,387 | 22.6 |
| Dairy cow | 971,000 | 2,404 | 16.0 |
| Beef heifer-bred | 615,750 | 1,056 | 7.0 |
| Poultry: broiler | 109,531,538 | 830 | 6.5 |
| Hog (heavier than 60 kg) | 4,517,500 | 697 | 5.8 |
| Steer | 1,381,800 | 682 | 4.5 |
| Dairy heifer | 434,400 | 618 | 4.1 |
| Bull | 218,900 | 557 | 3.7 |
| Beef heifer slaughter | 807,000 | 446 | 3.0 |
| Horse | 291,561 | 394 | 3.9 |
| Turkey | 8,423,900 | 257 | 2.0 |
| Other | - | 1,100 | 7.3 |
| Total | 180,960 | 21,400 | 146 |

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 by the source of waste for either residential or non-residential sources. Non-residential include Industrial, Commercial and Institutional (ICI) as well as Construction, Renovation and Demolition (CRD) or 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 small part of the total generated waste in Canada is diverted (28% in 2018) by recycling or composting and the rest of the waste is sent for disposal. Waste is mostly disposed in Canadian landfills and a small proportion of that waste in sent to the United States (US) 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**

| Description | | | Quantities (Mt) | Quantities of potential biomass feedstocks (Mt) |
|---|---|---|---|---|
| Total MSW generated | | | 35.6 [b] | - |
| Total MSW diverted by recycling or composting | | | 9.8 [b] | |
| Total MSW disposed in landfills or by incineration | | | 25.7 [b] | |
| Disposed MSW | by categories of biomass waste | Food | 5.8 [a] | 9.4 [a] |
| | | Paper | 2.5 [a] | |
| | | Yard and garden | 1.1 [a] | |
| | | Wood and wood products | 2.8 [a] | 2.8 [a] |
| | by sector | Residential | *10.2* [a] | - |
| | | Industrial, commercial and institutional (ICI) | *11.5* [a] | |
| | | Demolition, land clearing and construction (DLC) | *3.2* [a] | |
| | by location of disposal | Disposed in landfills in Canada | 20.3 [a] | |
| | | Exported to the US | 3.8 [a] | |
| | | Incinerated (primarily to produce energy) | 0.85 [a] | |

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 |
| Québec | 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

Biomass resources are used in multiple applications in Canada including energy and non-energy usages. The 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 found in different publicly available sources.

## 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 is produced by carbonization or pyrolysis of biomass at high temperatures and can be produced in the form of torrefied wood pellets. It is used to replace coal in power plants or for energy in manufacturing plants (Airex Energy 2016).

To produce wood pellets, Canadian industries rely mostly on sawmill residues as well as low-quality logs and harvest residues recovered from forests and that cannot be used by sawmills or pulp and paper mills. According to a study conducted for BC which represents around 45% of the Canadian pellet production, feedstocks used for pellet production are mostly 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 including branches, log trim ends, foliage and bio-logs (4%) (Bull et al. 2022).

These feedstocks are also used for heat production in community systems (NRCan 2022). Wood pellet use for heat and energy is mostly limited to small-scale industrial and residential use in Canada. The types of biomass feedstocks used for Bioheat installations as well as the installed capacity and locations of the Bioheat installations in Canada are included in Appendix 8. There was 516 community systems using biomass for heating in 2019 (NRCan 2022).

Suppliers of forest biomass for wood pellet production in Canada vary from large forest product companies to small harvesting contractors, and from tenure holders to 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). This program 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).

The data for wood pellet production and use in Canada are presented in Table 11. Most of the pellet production is in BC (45% of Canada's production) followed by 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).

Most of the wood pellets produced in Canada are exported (USDA Foreign Agricultural Service 2023). Export goes mainly to United Kingdom and Japan for use in their heat and power plants (C. E. R. Government of Canada 2021; Hayes and Bradford 2019). Drax group has large Canadian pellet production operations in BC and Alberta and export wood pellets to the UK (Drax n.d.-b). The Drax Power Station in the UK has a capacity of 3,906 MW and the power it produces is almost all using compressed wood pellets (Drax n.d.-a).

In Canada, wood pellets were used to phase out coal for example in the Atikokan Generating Station in Ontario (in 2014) and Thunder Bay Generating Station (in 2015) (C. E. R. Government of Canada 2021). The growth of the pellet industry could be impacted in the upcoming years by the reduction of the allowable annual cut (AAC) in BC and the change of harvesting practices due to the mountain pine beetle attacks in BC (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 as well as technologies that are being used or developed. Table 12 shows the summary of their production and feedstocks used.

**Table 12: Feedstocks used for yearly production of liquid biofuels in Canada**

| **Description** | **Biomass feedstocks** | **Production** |
|---|---|---|
| Cereal grains<br>*Include corn, wheat, rye, barley, oats, and triticale.* | 4,353 kt | |
| Vegetable oils<br>*Include canola oil, soybean oil and other vegetable oils.* | 338 kt | |
| Other feedstocks<br>*Include agricultural residues, forestry residues, other biomass residues, MSW, animal fats, used cooking oil, methanol.* | 82 kt | |
| Total of plant feedstocks used | 4,772 kt | |
| Bioethanol | | 1,642 million litres |
| Liquid biofuels except bioethanol<br>*Most of the production consists of biodiesel.* | | 431 million litres |
| Total of liquid biofuels produced | | 2,073 million litres |
| Total of co-products<br>*Include distiller grains which 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 9).

**Table 13: Canadian liquid biofuel industry in 2021**

| | **Bioethanol** (million litres) | **Biodiesel** (million litres) | **Renewable diesel** (million 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

In Canada, one of the major liquid biofuels produced is bioethanol. In 2022, there were 12 refineries producing bioethanol in Canada (Table 14). The bioethanol production in Canada is based on the agricultural sector by using mostly corn (**3.7 Mt** in 2022) followed by wheat and other grains such as barley (**560 kt** in 2022) (Danielson 2022b).

Bioethanol is used mostly for blending with gasoline as an oxygenate or octane enhancer in low concentrations. 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 locally 16.8 million bushels of corn 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).

Another production pathway for bioethanol is through lignocellulosic biomass such as agricultural and forestry waste biomass. The bioethanol produced is known as “cellulosic ethanol” (NRCan 2011a). There are two ways to produce cellulosic ethanol: thermochemical and biochemical.

The thermochemical process pathway is used by Enerkem to convert MSW (they use their patented and owned technology) in Alberta since 2016. They are constructing a plant in Varennes, Quebec (Government of Canada 2020). The facility 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 plant in Varennes will incorporate a 90-megawatt electrolyzer for the use of green hydrogen in its proprietary thermochemical process.

The biochemical process of producing bioethanol was demonstrated for agricultural feedstocks. The first full-scale demonstration plant was built by Iogen Corporation in Ottawa, Ontario with a capacity to process around 25 tonnes of wheat straw per week (NRCan 2011a). The first commercial biofuel facility of Iogen was built in Brazil by Raizen to produce cellulosic ethanol from sugarcane bagasse and straw (started in 2014). The technology that is used by Iogen corporation is based on enzymes to convert cellulosic biomass to ethanol (Iogen Corporation 2015; Tolan 2002).

**Table 14: Bioethanol facilities in Canada in 2022**

| **Province** | **Company** | **Types of feedstocks used** | **Ethanol production capacity** (million 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 |
| Québec | GreenField Global – Varennes | Corn | 190 |
| Total Nameplate Capacity | | | 1,881 |

Source: (Danielson 2022a)

### 3.2.2. Biodiesel

Biodiesel is known as Fatty Acid Methyl Ester (FAME). Biodiesel is derived from biomass and has a different chemical composition than petroleum diesel. Biodiesel is produced by using either vegetable oil or animal fat with the addition of an alcohol (typically methanol) through a process called "transesterification." Glycerol is obtained as a by-product of this process. Biodiesel is not fully compatible with diesel engines and is usually blended with petroleum diesel.

Biodiesel (FAME) is currently produced in Canada and canola oil is the most used agricultural feedstock for biodiesel production (**265 kt** in 2020). Animal fats, waste oils and soybean oil feedstocks are also used for biodiesel production. Canada's does not use a lot of yellow grease and tallow as feedstocks for biofuel production compared to the US. In the US, the production of biodiesel is mostly done by using soybean oil.

Some biodiesel producers in Canada that are close to the border with the US, count on the imports of animal fat and yellow grease feedstocks from the US to use as feedstocks due to smaller supplies in Canada (Danielson 2022a). Most of the biodiesel produced in Canada is exported to the US. In order to fulfill the renewable content requirements for liquid biofuels, Canada imports most of its biodiesel also from the US (Hayes and Bradford 2019).

### 3.2.3. Renewable Diesel

Renewable diesel term is used commonly for Hydrogenated Vegetable Oil (HVO) or Hydrogenation-Derived Renewable Diesel (HDRD) which is produced by hydrotreating similar fat or oil-based feedstocks as biodiesel. However, biodiesel (FAME) and renewable diesel (HVO/HDRD) have different processing pathways and different chemical compositions. Therefore, they have different requirements for their use in substitution of petroleum diesel. Renewable diesel has the same chemical composition as petroleum diesel and therefore is fully compatible with diesel engines.

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

In order to fulfill the renewable content requirements for liquid biofuels, Canada imports most of its renewable diesel from Singapore and Europe (Hayes and Bradford 2019). There is **currently no production** of renewable diesel (HDRD/HVO) in Canada; however, new projects have been announced or under way to produce renewable diesel:

Imperial Oils approved in January 2023 an investment of about $720 million (USD 560 million) in a new Renewable Diesel facility at Imperial's Strathcona refinery near Edmonton. The facility will be the largest in the country with an estimated production of more than one billion litres of renewable diesel annually. The start of the production is expected to be in 2025 (ExxonMobil 2023; Imperial 2023).

Parkland, based in Calgary, had announced in May 2022 a stand-alone renewable diesel complex project in its Burnaby facility with an investment of around $600 million (Parkland Corporation 2022). However, in March 2023, they announced that they won't move forward with this project due to multiple factors that impacted the competitiveness of the renewable diesel complex including, project costs, lack of market certainty and the US Inflation Reduction Act which advantages the US producers and impacts the demand (Voegele 2023).

### 3.2.4. Biocrude and Bio-Oil

Biocrude is a concentrated bio-oil produced from biomass and that can substitute petroleum crude oil. In the Renewable Fuels Regulations in Canada, biocrude is defined as:

> "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 further 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. Pyrolysis and fast pyrolysis technologies are proven commercially and used by commercial plants. Pyrolysis can be virtually applied to a large variety of biomass feedstocks; however, wood is mostly used by commercial plants to produce bio-oil.

In Canada, Ensyn Technologies Inc. and 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 signing a 3-year agreement with ArcelorMittal to deliver 16 million litres of pyrolytic oil per year to the ArcelorMittal pellet plant (ArcelorMittal 2022).

Other technologies that are in demonstration or pilot stages include hydrothermal liquefaction (HTL) which can be applied to wet biomass such as pulp mill residues, manure, food processing waste and sewage sludge. Steeper Energy recently announced in April 2023 signing a Memorandum of Understanding (MOU) with Invest Alberta to develop a commercial plant based on the proprietary technology of Steeper Energy called "Hydrofaction." This technology is used to convert biomass to biocrude oil by using HTL method. As mentioned in their 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, etc. It can also be blended with gasoline, used in the biodiesel production process or for the production of bio-dimethyl ether (DME) or bio-methyl tert-butyl ether (MTBE) for transportation fuels (Hobson 2018).

The production process of biomethanol (from biomass) is based on biomass gasification to obtain crude syngas followed by syngas conditioning and conversion to biomethanol by a catalytic process. It is a well-known technology and can be applied to different biomass feedstocks: lignocellulosic forestry and agricultural biomass, agricultural waste, sewage sludge, MSW. The challenge with this conversion pathway of biomass 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 only from hardwood trees (Alberta-Pacific Forest Industries Inc n.d.). A pulp mill company in Sweden (Södra) is producing commercial grade biomethanol from the pulp process residues (5,250 tonnes of biomethanol per year) (Sodra n.d.).

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

### 3.2.6. Biojet

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

Different types of feedstocks can be used to produce biojet as shown in Table 15. Since biojet fuels differ in their chemical composition and characteristics, there are different blending percentages permitted for different technology pathways for use in an aircraft.

There are multiple technologies that are already developed for the biojet production. The achievement of ASTM certification (ASTM D1655) typically indicates a Fuel Readiness Level (FRL) of seven (CAAFI 2023). There are currently eight certified biojet fuels that can be used in commercial flights. However, global production is still limited and in 2019 there were only 2 facilities that produce biojet: Neste in Rotterdam and World Energy in California. There are multiple facilities that are under construction or planned to produce biojet worldwide; however, there is **no biojet facility currently in Canada**. To note that the SAF+ Consortium announced the first production of SAF in North America in a pilot factory (ParaChem Industrial site, Montréal) through Power-to-liquid pathway which doesn't use any biomass feedstocks (SAF Consortium 2019).

Among the certified biojet technologies, the *Hydrotreated esters and fatty acids synthesized paraffinic kerosene* (HEFA-SPK) process is fully commercialized and is used to produce the vast majority of the biojet fuel that is used today globally. According to IEA Bioenergy Task 39 report, it is anticipated that the HEFA-SPK process will remain the dominant pathway for biojet for at least 10 to 15 years (IEA Bioenergy Task 39 2021).

As shown in *Figure 3*, the main product of the HEFA process is renewable diesel (default in the figure). Only about 15% of the total yield consists of biojet under common processing conditions. In the article of IEA Bioenergy Task 39 (2021), it is noted that due to incentives and policy drivers that are targeted for renewable diesel production, the majority of HEFA producers sell the HEFA 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 a technology that already provided numerous airports with "demonstration quantities" of biojet (IRENA 2021b). The planned start-up of the commercial facility of Gevo in Lake Preston (South Dakota) is expected for 2026 and Gevo announced in 2022 multiple sales agreements for their biojet based on alcohol produced from corn and converted through the ATJ-SPK pathway (Gevo Inc 2022).

Other technologies are close to producing biojet fuel commercially such as *Fischer-Tropsch Hydroprocessed Synthesized Paraffinic Kerosene* (FT-SPK) based on gasification of biomass. The technology was commercially demonstrated to turn syngas to FT products. The FT-SPK produced by the FT reactor from Velocys was successfully used in commercial aircraft. BayouFuels biorefinery is planned to start production in 2026 in Mississippi, USA 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.). Velocys will start in 2025 the construction of a commercial scale waste-to-jet fuel facility in collaboration of British Airways in Altalto, the UK, in which they will use municipal and solid residual waste that would otherwise be destined for landfills or incineration (Velocys n.d.).

The *Synthesized Iso-Paraffins from Hydroprocessed Fermented Sugars* (SIP) was certified in 2014 for feedstocks that include sugars from any source. It was announced by Total & Amyris in 2014 that they will begin to prepare to market the drop in jet fuel. However, we didn't find any updated stories since then (Total 2023).

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

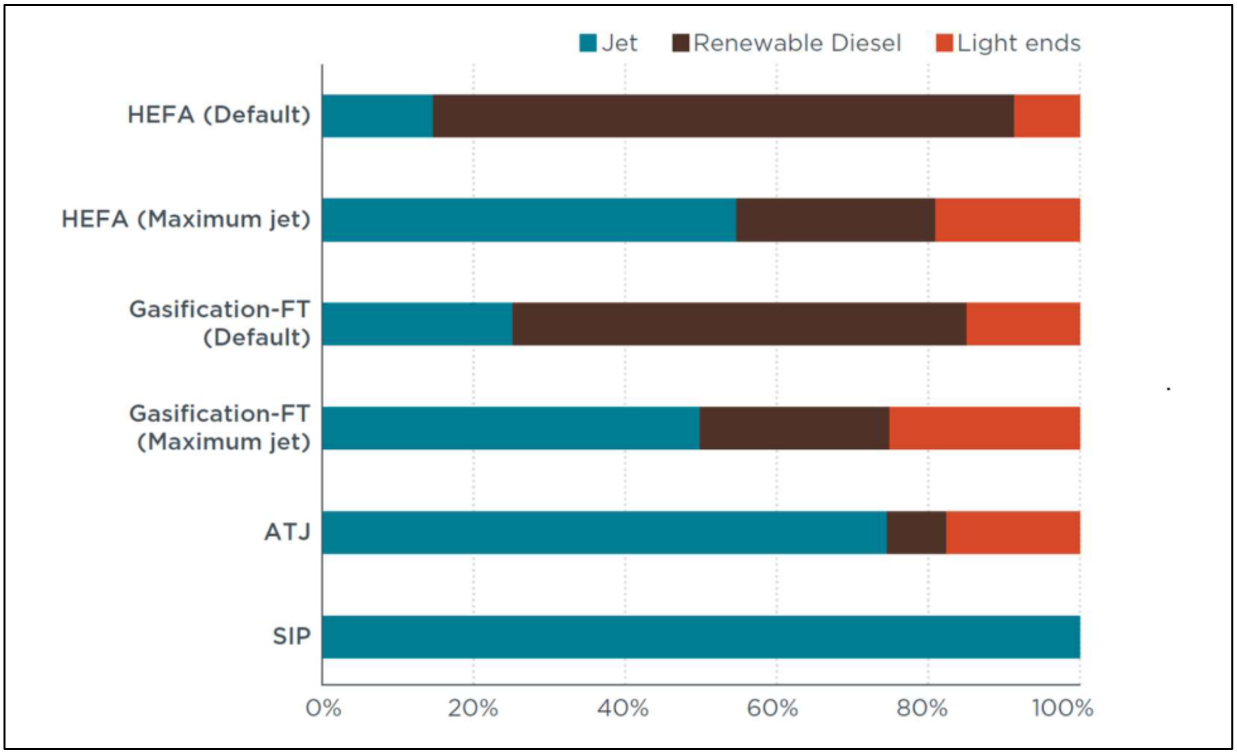
**Table 15: Production technologies for biojet fuels developed worldwide**

| **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 2 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 specie of algae.*

*In addition to biomass feedstocks, other input requirements in biojet production processes (such as hydrogen) should be taken into account during the evaluation of biojet production technologies.*




Source: (IEA Bioenergy Task 39 2021).

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

## 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 is also called "*renewable natural gas*" (RNG) and is either obtained by upgrading biogas to RNG (greater than 97% content of methane) or through gasification of biomass to obtain syngas (mainly carbon monoxide, hydrogen and methane) followed by a methanation process to obtain RNG (IEA 2020).

Anaerobic digestion (AD) is the conventional method to produce biogas and 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). In Canada, biogas and RNG system production represented a total of **22 PJ**. Table 16 shows how the total energy from biogas produced in Canada was used.

**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)

Four different categories of biogas and RNG production are discussed in this report based on their feedstock origin.

### 3.3.1. Agricultural sector

The majority of the biogas systems used in Canada are based on manure utilization. Crop residues are sometimes used as co-substrates with other feedstocks such as urban organics and their use is limited due to concerns related to soil health (TorchLight Bioresources Inc. 2020).

Manure is mostly used in Canada as a fertilizer by applying it directly to soils and a smaller proportion is converted to biogas by anaerobic digestion (AD) or composted. In 2020, there were **45** operational anaerobic digesters in Canada that use manure input to a certain extent. Most of the agricultural AD facilities are located in the province of Ontario. The technical capacity of the agricultural AD facilities in Canada is a total of around **1.1 Mt** of feedstocks which is equivalent to around **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 around **1.5 PJ** if assuming 65% methane content and 36 MJ/m$^3$ of methane (Hallbar Consulting Inc and Research Institutes of Sweden 2020).

In Quebec, most of the agricultural anaerobic digesters treat cheese production waste and only Coop Agri-Énergie Warwick uses manure. There are several projects in development in Quebec including projects of Nature Energy in Farham, Groupe Bio Énertek in Sainte-Sophie-de-Lévrard, Agriméthane in Saguenay and Coop Carbone in Victoriaville (Canadian Biogas Association 2022a).

In Canada, farm sizes vary a lot and economies of scale for biogas facilities are achieved by larger farms or by co-digestion with feedstocks from outside of the farms (IEA BioEnergy Task 37 2021). Farms in Canada 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 either natural gas utilities or a local user.

### 3.3.2. Forestry sector

There are different projects worldwide for the development and commercialization of technologies that are used to convert woody biomass from the forestry sector to RNG.

GoBiGas in Sweden was the first plant 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 they received site development approval, and they will build a production facility of RNG from wood waste near Fruitvale in BC. The RNG produced will be purchased by FortisBC (REN Energy 2022).

Another company, G4 Insights in BC (Canada) developed a technology called PyroCatalytic Hydrogenation (PCH) and conducted trials on a pilot scale to convert lignocellulosic biomass to RNG. It was announced in 2020 that the pilot demonstration phase was 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 & paper mill sludge. Currently, there are around three pulp mills in Canada that use their pulp & paper mill sludge as feedstocks to produce biogas by AD process (TorchLight Bioresources Inc. 2020).

### 3.3.3. Municipal Solid Waste and Wastewater Treatment Facilities

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

Examples of organic waste processing facilities with AD systems in Canada are the Disco Road Organics Processing Facility and Dufferin Organics Processing facility in the city of Toronto. The Dufferin Organics Processing facility has a capacity to treat around **55 kt** of waste per year and the biogas is 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 around **7.3 million m$^3$** of biogas and Enbridge Gas will produce an output of **4.6 million m$^3$** of RNG (City of Toronto 2022).

Other examples include the city of Hyacinthe in the province of Quebec that started producing RNG in 2014 and injecting it in the gas network of Énergir in 2018 (Énergir n.d.). The Quebec Agglomeration Biomethanation Centre started operations recently in April 2023 (Monquartier 2023).

*The municipality of Laval announced in 2019 a call for tenders for the construction of a biomethanation centre; however, the municipality announced in 2023 that they would not go through this project any further due to high estimated costs (La Presse 2023).*

**Table 17: Examples of projects producing RNG in treatment facilities of MSW and wastewater in Canada**

<table>
<tr><th rowspan="3">Facilities</th><th colspan="4">Estimated or current production capacity per year</th><th rowspan="3">Project status</th></tr>
<tr><td colspan="2">Feedstocks</td><td colspan="2">Production</td></tr>
<tr><td>MSW</td><td>Biosolids</td><td>Digestate</td><td>RNG</td></tr>
<tr><td>Dufferin Organics Processing Facility (Ontario)</td><td colspan="2">55 kt of MSW</td><td>9.5 kt</td><td>3.3 million m$^3$</td><td>Started injecting RNG in the natural gas grid in 2021</td></tr>
<tr><td>Disco Road Organics Processing Facility (Ontario)</td><td colspan="2">75 kt of MSW</td><td>Unknown</td><td>4.6 million m$^3$</td><td>Started installation of the biogas upgrading equipment in 2022</td></tr>
<tr><td>Centre de biométhanisation de la ville de Saint-Hyacinthe (Québec)</td><td colspan="2">More than 149.3 kt of MSW and biosolids combined</td><td>Unknown</td><td>13 million m$^3$</td><td>Operational since 2014. Started injecting the RNG in the Énergir network in 2018</td></tr>
<tr><td>Centre de biométhanisation de l'agglomération de Québec (Québec)</td><td colspan="2">Around 182.6 kt including 86.6 kt of MSW and 96 kt of biosolids</td><td>73 kt</td><td>10 million m$^3$</td><td>Operational since April 2023</td></tr>
</table>

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

### 3.3.4. Landfill sites

Methane is emitted at landfill sites due to the anaerobic decomposition of the organic waste which includes food, garden waste, 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 methods are commercial and already used in Canada (Environment and Climate Change Canada 2022c). There are over **100 landfills** in Canada that have systems to recover LFG (Government of Canada 2023e). There are around **50 facilities** in Canada that have LFG systems for biogas and RNG production (Canadian Biogas Association 2022b). In Canada, **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).

In Canada, there are more than 3,000 landfills but only over half are currently active. Among those landfills, only 270 are considered “large landfills” with 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 largest impact on the GHG emissions compared to the rest of the landfills since they receive around **90%** of the waste generated in Canada. They represented in 2019 over **85%** of the methane generated from Canadian landfills. There are currently regulations in place that require 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 10).

According to a discussion paper published by ECCC, 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).

The federal government started consultations in 2022 on strengthening the landfill methane regulations in Canada 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

Biohydrogen is defined in this report as hydrogen produced from biomass resources. In Canada, there are **currently no commercial production** facilities for biohydrogen.

A couple of projects were announced for production of biohydrogen in the upcoming years in Canada. The H2V Énergie, Inc plant in Bécancour (Quebec) is a project that will convert MSW and residual biomass from the forestry sector and end-of-use wood to biohydrogen, bio-ammoniac and biomethanol. The process that will be used in this project is based on the conversion of biomass to hydrogen-enriched syngas by using OMNI CT GPRS technology. The first conversion step of residual biomass is followed by a plasma treatment as a refining process to obtain biohydrogen and carbon dioxide. The production is expected to start in 2026 (H2 V Énergies 2022).

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

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

Raven SR. Inc., Chevron New Energies and Hyzon Motors Inc. announced recently in January 2023 that they are collaborating to commercialize hydrogen production from green and food waste. The Raven SR. 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).

Other than MSW and forest biomass, sewage sludge was also used for conversion to biohydrogen by demonstration plants abroad. A demonstration plant in Germany called *To-syn-fuel* ended its pilot project in September 2022 and converted sewage sludge to biohydrogen and synthetic fuels successfully (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 crops that are 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 were presented in Table 12 in section 3.2. Therefore, we could estimate that most of the remaining quantities would be used for food. Since exact quantities were not found, this category was not explored further in this report.*

Canadian livestock feed consumption was estimated by the Animal Nutrition Association of Canada. Their results showed that approximately **28.9 Mt** of feed (not including forages) was consumed by Canadian livestock in 2021. In addition to feed that is prepared in feed mills, forages are consumed by beef cattle, dairy cattle and sheep in Canada. The quantities of forages consumed by beef cattle, dairy cattle and sheep in

2021 were **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

The main products from the forestry sector in Canada are softwood lumber, wood pulp and structural panels. Canada is the world's leading exporter of softwood lumber. Table 19 shows the quantities produced and consumed in Canada for the main forest products.

**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 that are harvested from Canadian forests are transported to different process facility types (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 that are obtained from the sawmills 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 by sawmill type and lumber processing dimensions. For example, in BC (2019) the 69 large mills of the province produced **15.1 million $m^3$** of lumber by consuming around **32 million $m^3$** of logs (Bull et al. 2022).

The use of biomass feedstocks for wood pellets production in Canada and other energy use are explained in section 3.1 of this report.

### 3.5.3. Biochemicals and Biomaterials

Bioproducts also include intermediary biochemicals and biomaterials (e.g., bioplastics) which are being developed worldwide to reduce the use of petroleum-based products. Bio-based plastics or bioplastics are produced by using biomass feedstocks and 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 like sugarcane or corn (Alfa Laval n.d.). 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). The Government of Canada announced in April 2021, a $1 million investment to BOSK Bioproducts Inc. that will install a small-scale production line for prototyping formulations of compostable bioplastics that are made from forest biomass such as paper mill sludge (NRCan 2021a).

Another non-energy usage of biomass is biochar for agricultural land applications. Biochar is produced by using the same process as biocoal, which consists of 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).

There are several biochar producers in Canada, however, the total quantity produced per year was not found in the literature. Some examples of Canadian biochar producers include Airex Energy industry that has an industrial scale commercial plant at Bécancour (Quebec) and Canadian Agrichar industry that is located in Maple Ridge (BC). BC Biocarbon, based in Robson Valley (BC), uses the technology of pyrolysis to convert forest wood residues to many products including biochar.

# 4. GHG Emissions and Removal from the Biomass Sectors

Land and biomass use for energy or non-energy purposes are responsible for both carbon emissions and removal from the atmosphere. Emissions from the forestry, agriculture and waste sectors are tracked and reported in Canada's National Inventory Report (NIR) submitted to the UNFCCC. This section summarizes the emissions from these sectors for the year of 2021.

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

In Canada's NIR submitted to the UNFCCC, 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 different categories of managed lands: forest land, cropland, grassland, wetlands, and settlements plus the Harvested Wood Products (HWP) category. The reported net emissions from the LULUCF sector were **-13 Mt** of $CO_2$e in 2020 **and** -**17 Mt** in 2021 (Table 20).

*In Canada's Energy Future 2023, the assumptions for the LULUCF sector's emissions in Global and Canada Net-Zero scenarios were **-30 Mt** in 2030 and **-50 Mt** by 2050 (Canada Energy Regulator 2023).*

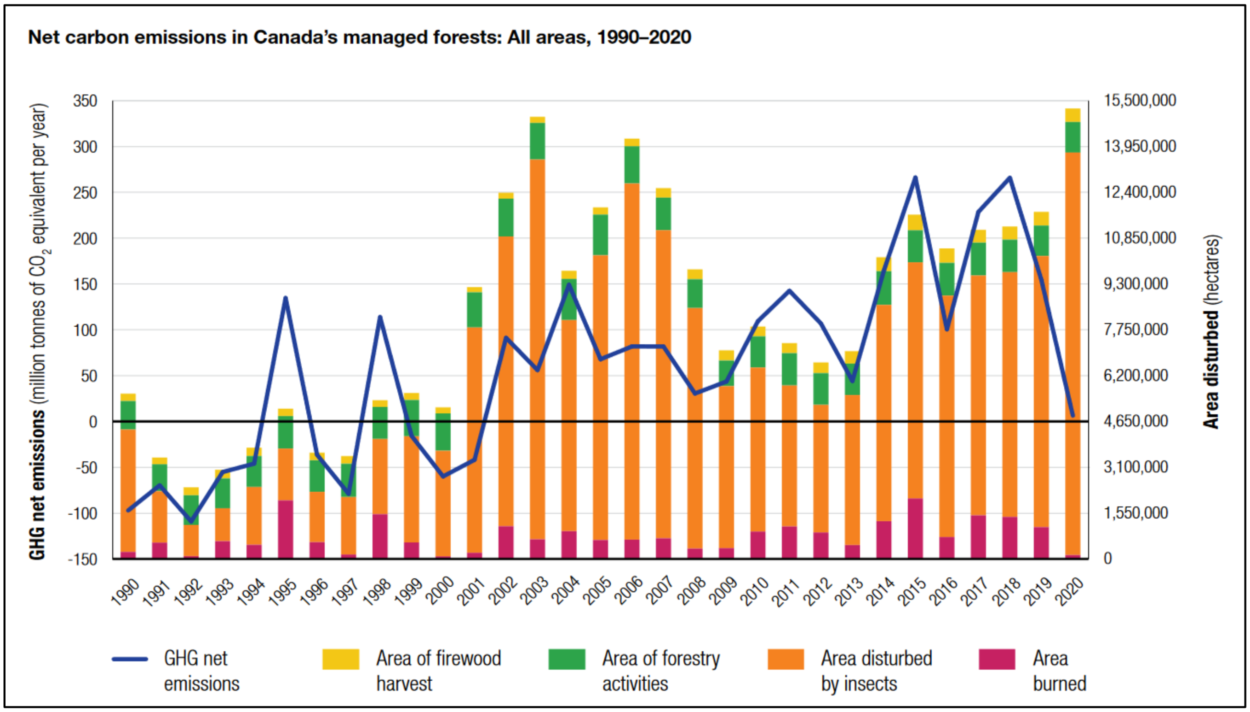
**Table 20: GHG emissions and removal in 2021 from LULUCF sector in Canada**

| Sectoral category | Net GHG Flux (Mt $CO_2$e) |
|---|---:|
| Forest land | -130 |
| Cropland | -18 |
| Grassland | 0.0 |
| Wetlands | 3.3 |
| Settlements | 2.0 |
| Harvested Wood Products | 130 |
| LULUCF total | -17 |

Source: (Environment and Climate Change Canada 2023a)

The GHG emissions in managed forests are also published in the report "*The State of Canada's forests*" (NRCan 2022). Figure 4 shows the net GHG emissions in Canada's managed forests from 1990 until 2020. Canadian managed forests have been a source of GHGs since 2002 and the area affected by wildfire in 2020 was relatively small compared to the previous recent years, which resulted in GHG emissions of **3.5 Mt** $CO_2$e in 2020.

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




Source: (NRCan 2022)

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

**Table 21: GHG emissions inventory of the Canadian forests**

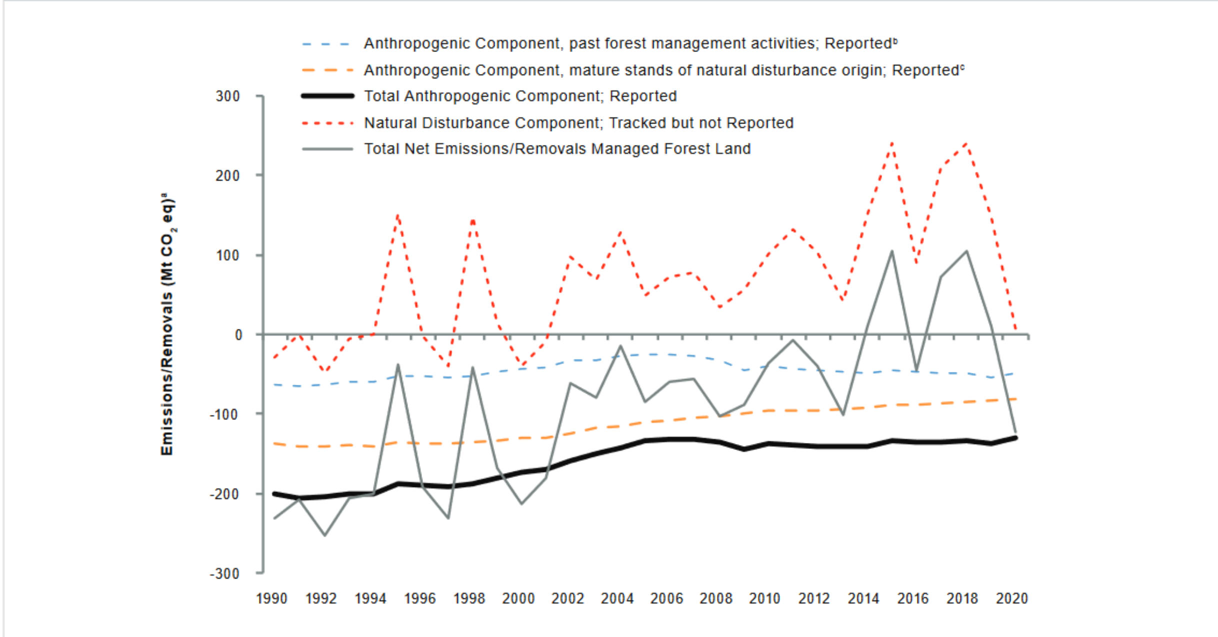
| **Canadian forest contributions to the GHG inventory in 2020** | | **GHG inventory** ($CO_2e$/year, Mt) |
|---|---|---|
| Managed forests *(225 Mha)* | Total net emissions or removal to the atmosphere, all causes (a + b) | 3.5 |
| | *(a) Net emissions or removal due to natural disturbances (not a reporting category in the NIR)* | *8.8* |
| | *(b) Net emissions or removal due to human forest management activities and from harvested wood products* | *-5.3* |
| Forest lands affected by land-use change | Emissions due to afforestation | 0.2 |
| | Emissions due to deforestation | 11.5 |

Source: (NRCan 2022).
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 of Canada's forests, emissions due to natural disturbances and removal due to the regrowth of these forest stands (*referred to as the natural disturbance component*) are separated from the other stands in managed forests that are commercially mature (*referred to as the anthropogenic component*). Anthropogenic component represents the stands for which the growth trajectory was modified by human intervention (associated with forest management activities), and which 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 are 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 removed from the reported categories, and the previously removed stands that reached maturity on that year, are added back to the reported category.

Even though all emissions and removal are tracked and presented in the NIR (Figure 5), the GHGs reporting is based on the anthropogenic component only. GHGs 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."***

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




Notes:

a. Not including indirect $CO_2$ or emissions from HWP.

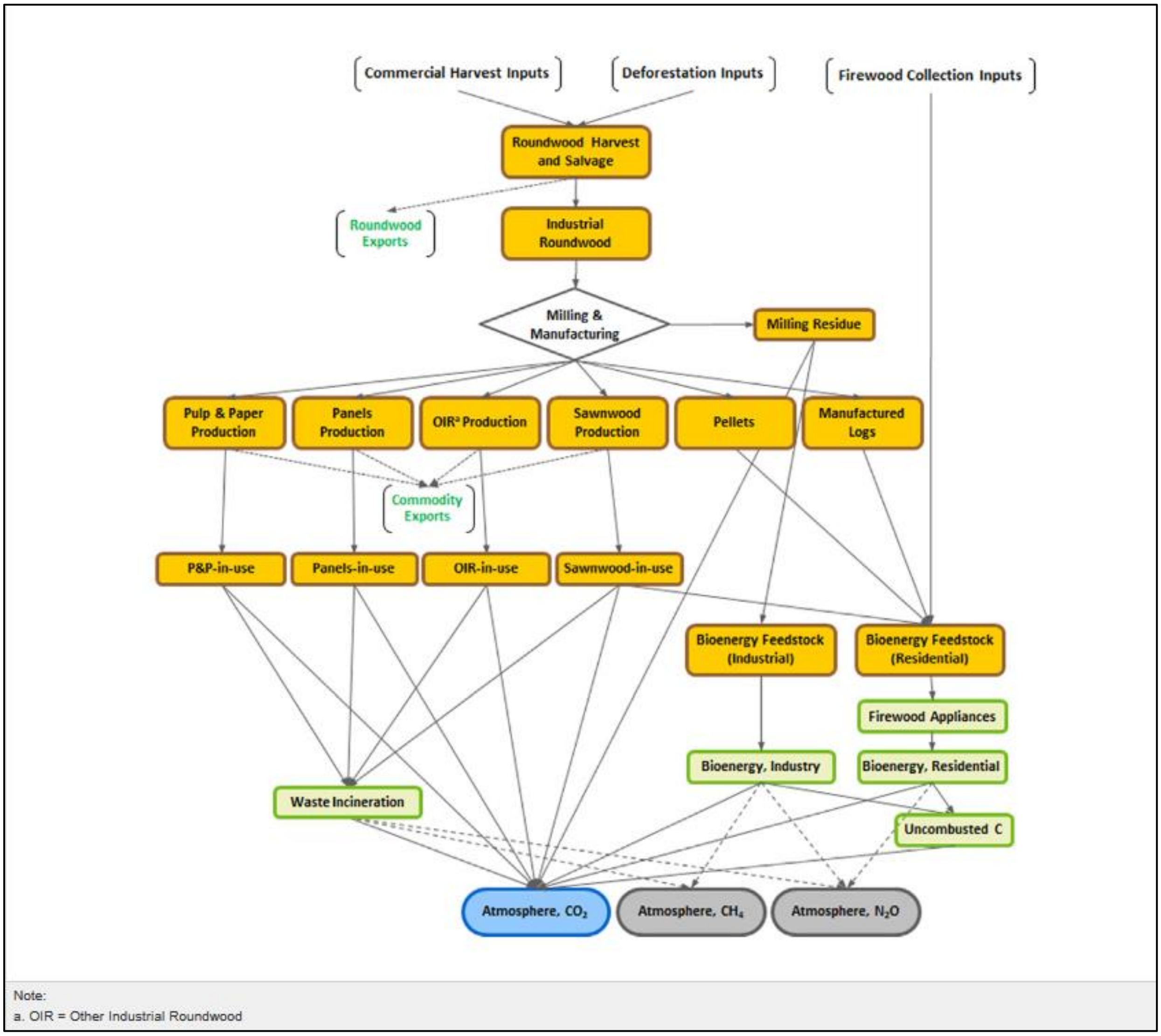
b. Clear-cut and partial harvest, commercial and pre-commercial thinning, and salvage logging.

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

Source: (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).**

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 by the LULUCF sector of the NIR. However, 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.




Source: (Environment and Climate Change Canada 2022e)

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

## 4.2. Agricultural Sector

The agricultural sector contributed to the total GHGs emissions in Canada by **54 Mt** in 2021 (excluding energy emissions) (Environment and Climate Change Canada 2023a). The major contributions to these emissions are due to enteric fermentation (24 Mt) followed by the impact of applying nitrogen fertilizers to annual and perennial cropland agricultural soils (13 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. These emissions were at their minimum (2.2 Mt) in 2002, a drought year, and their maximum in 2020 (4.5 Mt). In 2021, emissions declined to 3.4 Mt due to severe drought conditions mainly in the prairies (Environment and Climate Change Canada 2022e).

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

*In Canada's Energy Future 2023, the assumptions for the agricultural sector's emissions in Global and Canada Net-Zero scenarios were 51 Mt in 2030 and 41 Mt by 2050 (Canada Energy Regulator 2023).*

## 4.3. Waste Sector

The waste sector contributed to the total GHGs emissions in Canada by **21 Mt** in 2021 (Environment and Climate Change Canada 2023a). The waste sector in Canada includes emissions from the treatment and disposal of wastes (solid waste disposal, composting, biological treatment, incineration, open burning of waste, wastewater treatment and discharge).

The major contribution to emissions from the waste sector is due to the disposal of solid waste in landfills (**17 Mt** $CO_2e$). Of the **30 Mt** $CO_2e$ of $CH_4$ generated by MSW landfills in 2021, **11 Mt** were captured and flared or used for energy. Waste diversion practices and landfill gas capture have been increasing over time and offsetting the increase of emissions due to population growth.

It is important to note that emissions in the waste sector are due to anaerobic decomposition of disposed organic waste in landfills. However, since the $CO_2$ produced is biogenic, it is not reported as part of the total emissions of the sector.

*In Canada's Energy Future 2023, the assumptions for the waste sector's emissions in Global and Canada Net-Zero scenarios were 13 Mt in 2030 and 11 Mt by 2050 (Canada Energy Regulator 2023).*

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

Many regulations and programs in Canada were announced in the previous years with the objective of reducing carbon pollution from fossil fuels. Many programs were also put in place 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, and it applies to all provinces and territories that do not have carbon pricing systems that are at least at the level of the federal benchmark. Under *the Greenhouse Gas Pollution Pricing Act (GGPPA)*, two components of the federal carbon pollution pricing systems were established: 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 carbon pollution price will be $65 per tonne of $CO_2$e in 2023 and will increase $15 each calendar year until 2030 to reach $170 per tonne of $CO_2$e (Government of Canada 2022a).

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

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

Note that emissions related to land use and non-energy-related agricultural emissions are never covered by the carbon pricing systems in all jurisdictions 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 that they produce and sell for use in Canada by establishing CI requirements. The CI of a fuel depends on the feedstocks (extraction), refining process, distribution and the use of the fuel (2020).

The CI reduction requirement started at 3.5 g $CO_2$e/MJ in 2023 and will increase by 1.5 g $CO_2$e/MJ each year to reach 14 g $CO_2$e/MJ in 2030.

*The government of Canada has a Fuel Life Cycle Assessment (LCA) model that is used 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 the website of the government of Canada, 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* *next formal publication of the model is expected 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)<br>12% (2025)<br>14% (2028)<br>15% (2030) | 3% (2023)<br>5% (2025)<br>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)<br>11% (2025)<br>13% (2028)<br>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: (2020) (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 2023)

## 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. There are two types of carbon markets in general: 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 reducing further the CI of the fuels 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 that would 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 presently includes only two systems: "Landfill methane recovery and destruction" and "reducing GHG emissions from refrigeration systems" (Environment and Climate Change Canada 2023b).*

*ECCC is developing offset protocols to be included in the federal Offset Credit System for the following project types: Improved Forest Management, 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 under consideration by ECCC.*

Other than the federal regulatory carbon markets that are used to comply with the GHG emissions requirements, there are many provincial offsetting markets as well that already gave credits for forest carbon sequestration. For example, offset projects that are managed through the BC Carbon Registry include protecting forest areas and reducing harvest levels across the project area. BC is developing a new version for the Forest Carbon Offset Protocol (FCOP) for which the public consultation on the last draft closed in April 2023. This protocol includes 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 presently stock large amounts of carbon. When using biomass for bioenergy, carbon is released to the atmosphere and will only be sequestered after several years of regrowth of the vegetation, if no disturbances occur during that period. The sequestered carbon in biomass currently has no value, unless offset credits have been given to enhance the carbon stock compared to a baseline scenario or for avoided emissions. As mentioned in the 2020 expert assessment report of 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 4.*

*[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] 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 (billion $) | Biogenic carbon stock value @ $170/t $CO_2$ in 2030 (billion $) |
|---|---|---|---|---|---|---|
| | Wet basis | Dry basis | | | | |
| **Cereal crops** | 64.5 Mt | 56.1 Mt | 25 to 28 | 53 to 95 | 3 to 6 | 9 to 16 |
| **Oilseed crops** | 25.3 Mt | 22.8 Mt | 10 to 11 | 22 to 39 | 1 to 2.5 | 3 to 7 |
| **Total harvested roundwood** | 143 million m$^3$ | 42.9 to 100.1 million m$^3$ | 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 |

*What other mechanism could be used to value the total carbon stock in Canadian biomass?*

## 5.5. 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 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, use and management of forest resources. Not accepting applications currently (Government of Canada 2023b).
- **Net Zero Accelerator (NZA) Initiative:** Part of the Strategic Innovation Fund, it could accept projects using biomass for energy if they show a potential of GHG reductions (Government of Canada 2023d).
- **Low Carbon Economy Fund:** In the Low Carbon Economy Challenge, eligible projects could include those using biomass for energy if they could reduce the GHG emissions in 2030 and over the lifetime of the project (Government of Canada 2023c).
- **Sustainable Canadian Agricultural Partnership (CAP):** This is a *$3.5-billion, 5-year* agreement between the FPT governments that aims to strengthen the competitiveness, innovation and resiliency of the agriculture, agri-food and agri-based products sector. Azure Sustainable Corp's SAF plant received funding from the Sustainable CAP program for their proposed project that is being 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:** Within the purposes of this strategy is to increase the role of bioenergy 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 (Government of Ontario 2022).
- **British Columbia's Residual Fibre Utilization Policy:** This policy focuses on improving the use of lower-quality timber in areas of the Ministry of Forests where there is demand for residual fibre and encourages increased business-to-business relationships between the primary harvesters and secondary users (Ministry of Forests 2020).

*How much GHG reduction can we expect from the projects that are currently funded by these initiatives for the biomass sectors in Canada?*

*How much more biomass these programs would/could harvest?*

*Will these programs create competition for the biomass feedstocks?*

*Is there any expected GHG reduction or set target for GHG reduction associated with each of these programs?*

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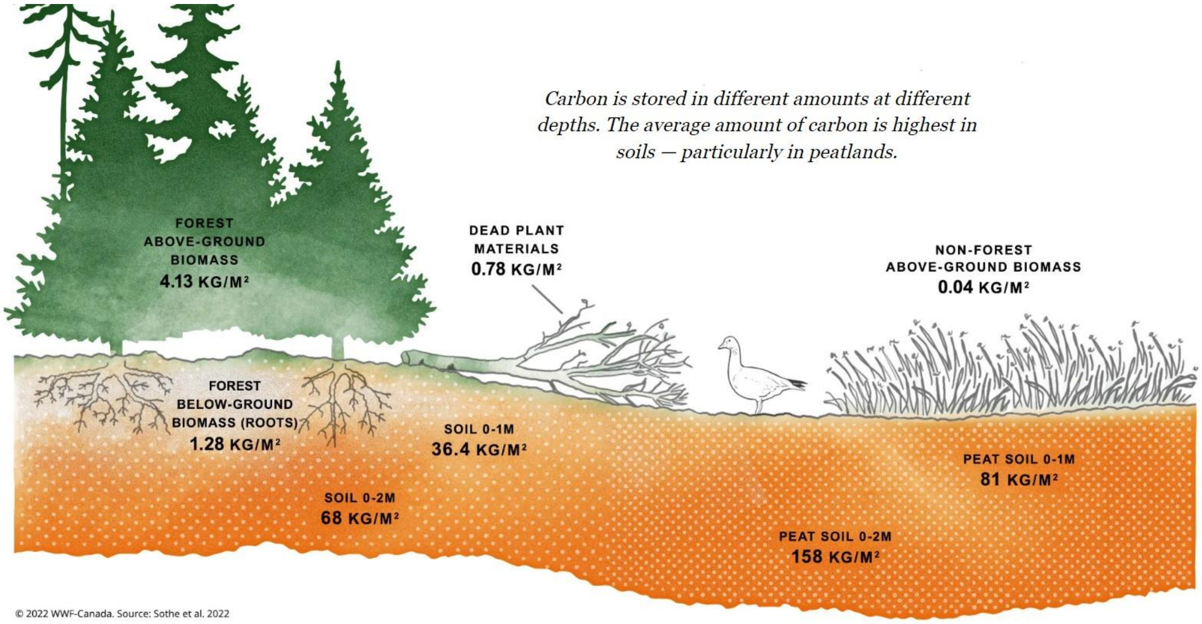
# 7. Appendices

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




Source: (WWF 2022)

| ***Biogenic carbon stock in Canada*** | ***Mean ± SD*** *(kg/m²)* | ***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 | 21 MJ/L | (Larsen, Johansen, and Schramm 2009; McGill, Aakko-Saksa, and Nylund 2008; REN21 n.d.) |
| Biodiesel | 34 MJ/L | (McGill et al. 2008) |
| Methane | 36 MJ/$m^3$ | (Hallbar Consulting Inc and Research Institutes of Sweden 2020) |
| Fresh wood (35–58% MC) | 3,000 MJ/$m^3$ | (IRENA 2019) |
| Dry wood [a] | 8,500 MJ/$m^3$<br>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<br>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/$m^3$<br>18.69 MJ/kg (dry basis) | (Forest Research n.d.; WSP Canada Inc 2021) |
| Wood pellets (8–10% MC) | 17 MJ/kg | (Drax n.d.-c; Forest Research n.d.; IRENA 2019) |
| 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) |

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 between 30 and 50 %.

## Appendix 3: Conversion factors used for estimating the energy content of animal manure

| Animal groups | Energy content (GJ/dry tonne) |
|---|---|
| Beef cow | 6.67 |
| Calf | 6.67 |
| Dairy cow | 6.67 |
| Beef heifer-bred | 6.67 |
| Poultry: broiler | 7.81 |
| Hog (heavier than 60 kg) | 8.36 |
| Steer | 6.67 |
| Dairy heifer | 6.67 |
| Bull | 6.67 |
| Beef heifer slaughter | 6.67 |
| Horse | 9.9 |
| Turkey | 7.81 |
| Other animals [a] | 6.67 |

Source: (WSP Canada Inc 2021)

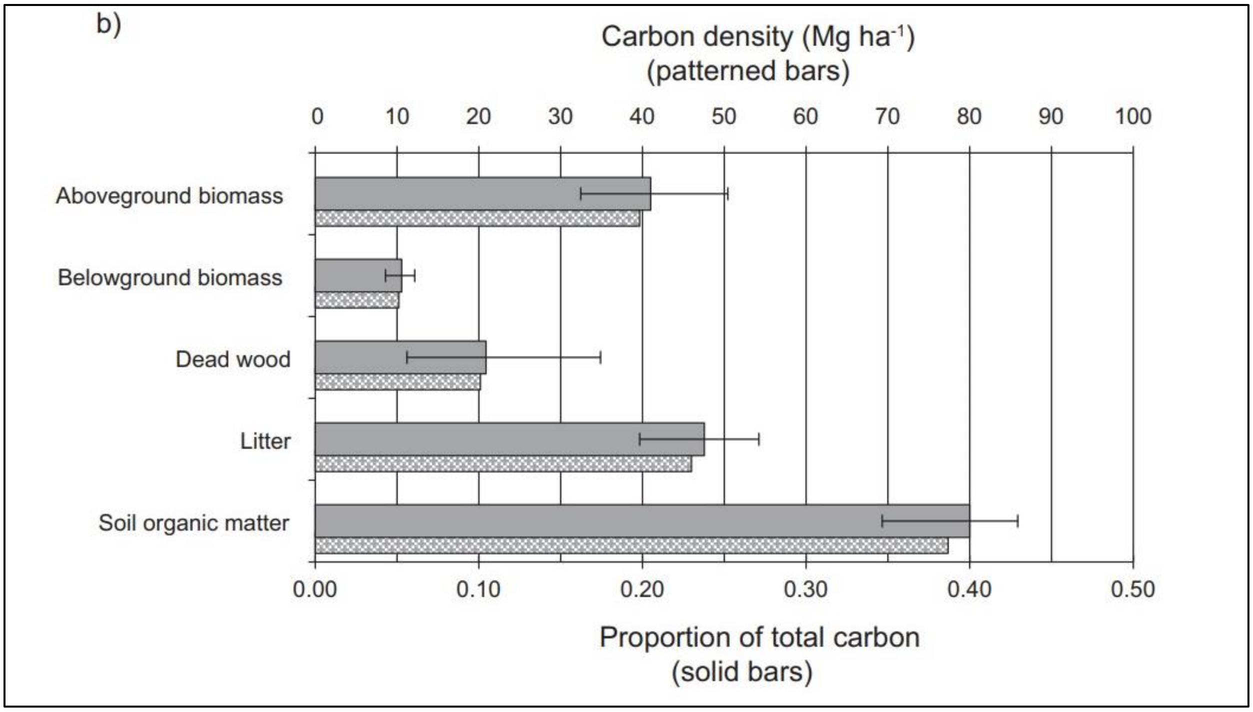
Note: [a] For the other animals, the lowest conversion factor of the other animal groups was used as an assumption to avoid overestimating the theoretical potential.

## Appendix 4: 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 |

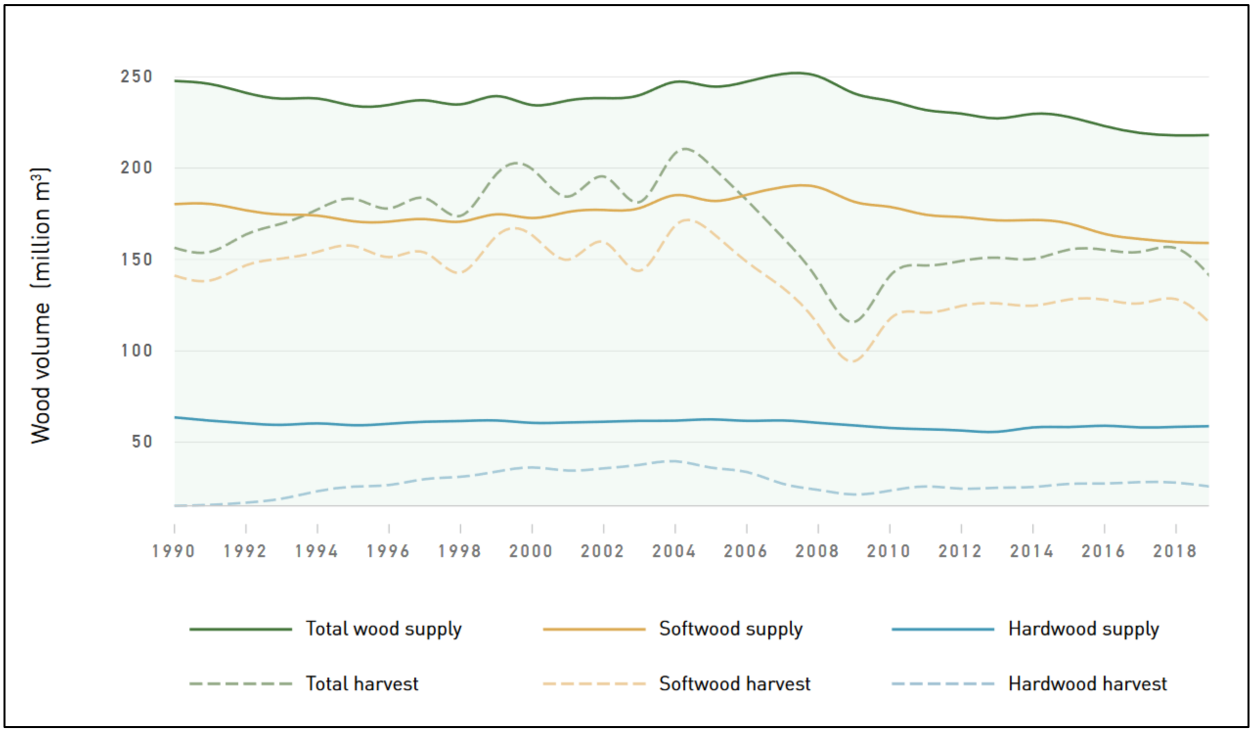
Source: (Adetona and Layzell 2019)

## Appendix 5: Carbon density and proportion of total carbon in biomass in Canadian forest lands



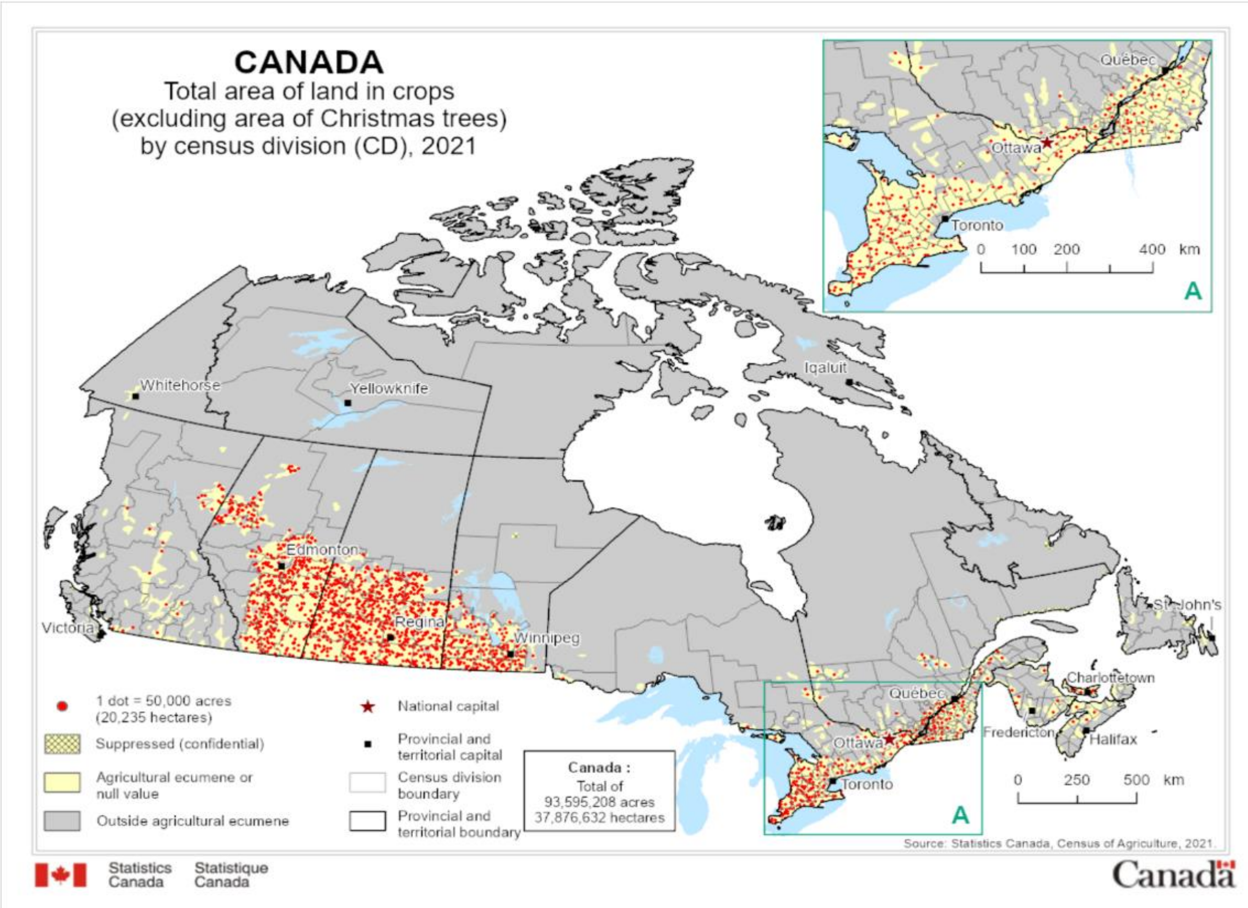

Source: (Kurz et al. 2013)

# Appendix 6: 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)

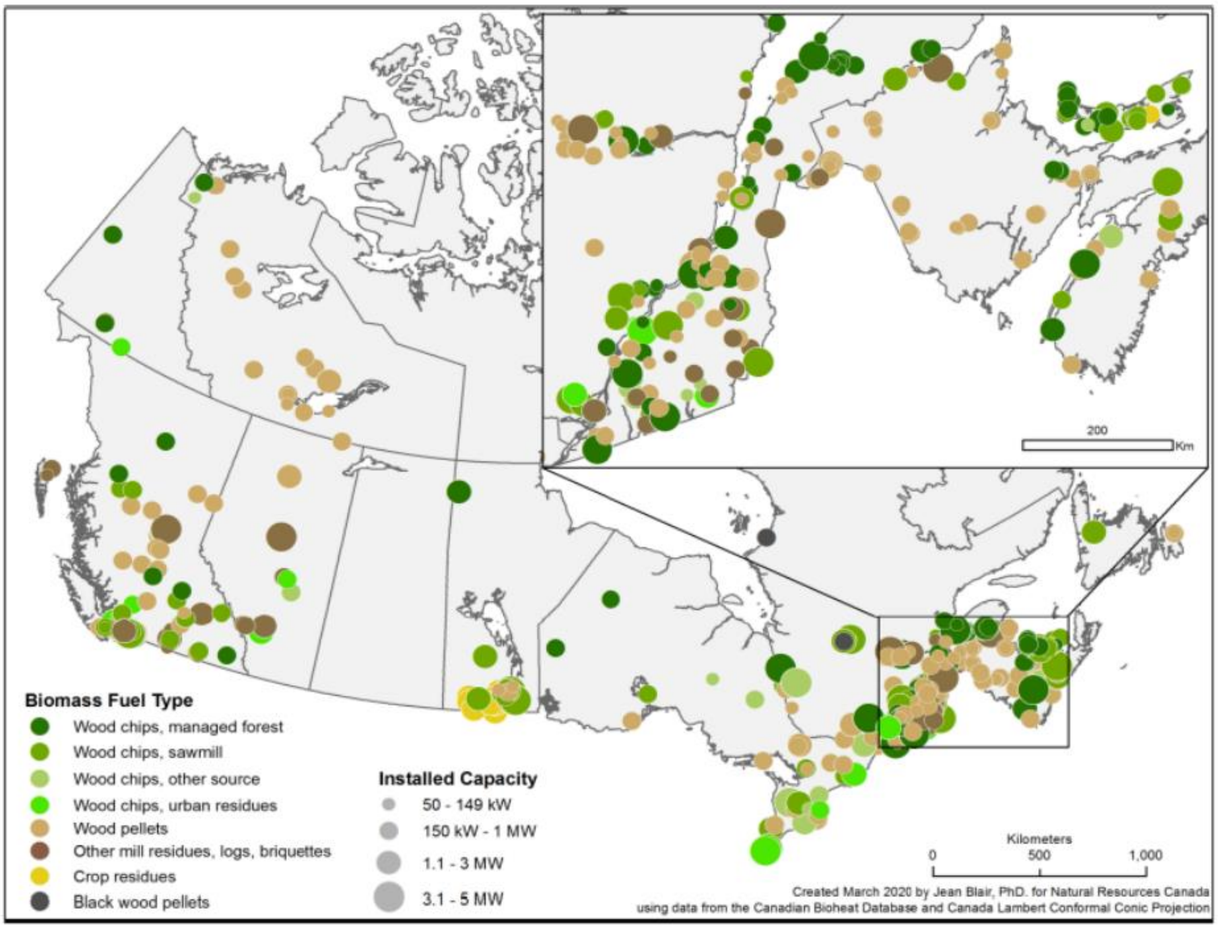
## Appendix 7: Figure showing the total area of land in crops by census division in 2021




Source: (Statistics Canada 2021)

## Appendix 8: Locations of Bioheat installations in Canada by biomass type fuel and installed capacity

Bioheat systems are installed around Canada for use of solid biomass. Multiple types of biomass feedstocks are used in bioheat systems (e.g., wood chips, wood pellets, other mill residues, crop residues), however, wood pellets and wood chips are the dominant feedstock of solid fuel bioheat installations in Canada (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 9: 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 10: Examples of requirements by certain governments to collect landfill gas to flare it or to 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)