Biomass and Carbon Neutrality

Putting in place an evaluation framework

A Biomass System Perspective Framework for a Net-Zero Future

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INSTITUT DE L'ÉNERGIE TROTTIER

The Transition Accelerator

L'Accélérateur de transition

Report

Writing and analysis

Roberta Dagher (lead author), Research Associate, Institut de l'énergie Trottier and the Transition Accelerator

Louis Beaumier, Executive Director, Institut de l'énergie Trottier

Normand Mousseau, Professor of Physics, Université de Montréal; Scientific Director, Institut de l'énergie Trottier; and Transition Pathway Principal, Transition Accelerator

Linguistic revision

Sabine Monnin

Laure-Anne Douxchamps, Research Associate, Institut de l'énergie Trottier

Decision support tool development

Design, Research and Implementation

Roberta Dagher, Research Associate, Institut de l'énergie Trottier and the Transition Accelerator

Louis Beaumier, Executive Director, Institut de l'énergie Trottier

Frédérik Lavictoire, Intern, Institut de l'énergie Trottier

Interface Development

kashika studio

External revision

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Stefan Pauer, Manager Technology and Economic Analysis, Clean Energy Canada

Edmund K. Mupondwa, Adjunct Professor at University of Saskatchewan and Project Leader/Research Scientist at the Saskatoon Research and Development Centre, Agriculture and Agri-Food Canada.

Nathan Curry, Bio Lead at the Transition Accelerator

Ian Thomson, Past President; **Fred Ghatala**, President and **Colleen Lamothe**, Vice President at Advanced Biofuels Canada.

Contributors

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Joseph Lefèvre, Research Associate, Institut de l'énergie Trottier

J. Harvey Consultant et Associés Inc.

ESMIA Consultants

About the Institut de l'énergie Trottier (IET)

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

As the initial 10-year mandate came to an end, the Trottier Family Foundation decided to renew its confidence in the IET and made a new donation. Given the scope of the IET's activities and its status as a key player, its mandate was extended. The team will thus be able to continue offering science-based advice and enriching societal dialogue in order to advance the way we produce, convert, distribute and use energy.

About the Transition Accelerator

The Transition Accelerator (the Accelerator) is designed 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 reach it. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground. The four-step approach of the Accelerator is to understand, codevelop, analyze and advance credible and compelling transition pathways capable of achieving societal and economic objectives, including driving the country towards net zero greenhouse gas emissions by 2050.

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Disclaimer

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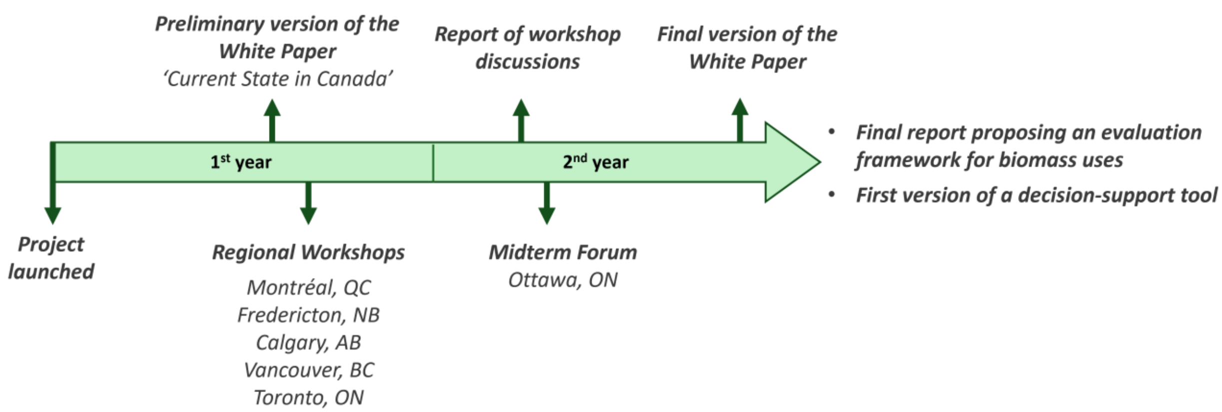
Why we are publishing this report and what you'll find inside

Biomass plays an important role in Canada's climate mitigation strategies. Its use, therefore, must be accurately assessed to ensure that projects will deliver the expected climate benefits and that we avoid situations where efforts to decarbonize different sectors could be counterproductive to climate change mitigation.

Given the development of multiple conversion technologies, competing demands from various economic sectors and a limited supply, which pathways would best contribute to net zero transition in Canada?

During this two-year project, we aimed to answer this question by researching current practices, holding discussions with stakeholders and experts, and co-developing an evaluation and comparison framework for biomass uses in the context of transition to net zero by 2050.



To reach this objective, we began by analyzing the current state of biomass use in Canada in order to identify uncertainties and gaps in current data. The preliminary White Paper was used as a starting point for discussions with experts and stakeholders about the challenges and elements that need to be considered within the framework. The first two phases of the project enabled us to produce this final report on the approach needed to evaluate biomass uses in the context of transition to net zero.

This report is accordingly separated into two main parts:

Part 1 presents the main characteristics of biomass and examines how scientific literature and national inventories currently track and analyze biogenic carbon. It then explores the methods currently employed in the literature to compare and evaluate biomass uses on a project and regional scale.

Part 2 describes the framework proposed to compare and evaluate biomass uses and sets out recommendations to ensure that biomass and bioenergy contribute to Canada's climate objectives.

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Part 1: Biomass in Canada's path to net zero

Although biomass use for bioenergy is often assumed to be carbon neutral, biomass resources and their end-uses are diverse and disparate in terms of their environmental impact. Biomass use can contribute to climate change mitigation under different circumstances that depend on many factors, including biomass type, biomass conversion efficiency and the non-bio products that we intend to substitute.

To develop an evaluation framework for biomass, we need to address these factors that make bioenergy unique among other types of renewable energy and that are crucial to understanding the impact of choices we make when developing new projects aimed at using these resources for bioenergy or non-energy purposes.

Part 1 thus explores the factors that impact the benefit of bioenergy in terms of climate change mitigation, the methods used to track biogenic CO_2, and those employed to evaluate biomass uses.

Box 1: Definitions

Biomass: Organic material consisting of, or recently derived from, living organisms. Biomass includes by-products and waste of biological origin from plants or animals.

Bioenergy: Energy derived from any form of biomass.

Biofuel: Any type of fuel derived from biomass.

Biofuels can be categorized depending on their physical form as gaseous biofuels (e.g., biogas), liquid biofuels (e.g., bioethanol) and solid biofuels (e.g., wood pellets).

Biofuels are also commonly categorized by generation. First generation consists of biofuels produced primarily from food crops such as cereal and oilseed crops. Second generation consists of biofuels produced mainly from lignocellulosic biomass such as agricultural and forest residues or from municipal solid waste. Third generation consists of biofuels derived from aquatic biomass such as algae with advanced processes still under development. Second and third generations are also commonly referred to as Advanced Biofuels (Allwood J.M. et al. 2014).

1. Biogenic carbon emissions and removals

Key messages from chapter 1

- While bioenergy can, in certain cases, provide mitigation benefits, it is not "carbon neutral." Mitigation benefits occur over a certain timescale. To evaluate whether bioenergy is providing mitigation benefits, the timescale considered must be defined. (**see section 1.2**)

- Three main factors can increase or reduce the timescale for bioenergy to provide mitigation benefits: type of biomass feedstock, biomass conversion efficiency, and type of displaced fossil fuel. (**see section 1.3**)

- CO_2 emissions from forest biomass combustion for bioenergy are included in Canada's national inventory report in the LULUCF category. The assumption of carbon neutrality in the inventory applies only to agricultural annual biomass. (**see section 1.4**)

- Managed Forests in Canada are a net carbon source even when excluding natural disturbances: carbon removals in forest lands are not high enough to offset carbon emissions that are reported in the LULUCF sector. (**see section 1.4.1**)

- In 2023, bioenergy contributed to 39% of the emissions from "Harvested Wood Products" in the LULUCF sector. (**see section 1.4.1**)

- The impact of biomass use on GHG emissions is distributed between the land use, energy and waste sectors. It is very difficult to distinguish the impact of different human activities on Canada's total GHG emissions which makes it increasingly important to improve the transparency of biomass use reporting (e.g., for bioenergy). (**see section 1.4.1**)

- Croplands have historically been a net carbon sink in Canada in almost all years declared in the national inventory. However, in 2022, they were a net source of emissions due to extreme drought. (**see section 1.4.2**)

- Crop residues contribute to carbon removals in croplands through carbon input to agricultural soils. This contribution has the highest impact on emissions declared in this sector. (**see section 1.4.2**)

- Climate change is a significant threat to carbon stocks in the forestry and agriculture sectors and is already contributing to the increase in intensity and occurrence of extreme weather events. (**see section 1.5**)

- Due to the extreme fire season in 2023, total emissions from natural disturbances in managed forests reached a total of 1100 Mt CO_2e, around 150% higher than the total GHG emissions in Canada. (**see section 1.5**)

- Forests play a huge role in the global atmospheric carbon budget. Potential large increases in emissions from Canada's forests and other terrestrial systems would have a significant impact on climate change mitigation efforts. (**see section 1.5**)

- As shown in IPCC reports and Canadian modelling exercises, very large quantities of negative emissions will be needed to reach net zero by 2050 to compensate for hard-to-abate residual emissions. (**see section 1.6**)

- Since negative emissions are needed to reach net-zero, it is crucial to understand the potential contribution of LULUCF sector and negative emissions technologies in Canada. (**see section 1.6**)

1.1. Biogenic carbon stocks

Carbon is stored in different amounts in forest and agricultural ecosystems, above or below ground in biomass, in dead organic matter and as organic carbon in mineral soils. Biogenic carbon is also stored in long-lived products made from biomass in use or in landfill sites until their complete decomposition (IPCC 2001; Kurz et al. 2013; WWF 2022).

Net carbon accumulation in biomass results from the balance between two main processes: the total amount of CO_2 assimilated by the ecosystem derived from the photosynthetic process (gross primary production) and the release of CO_2 into the atmosphere through losses due to plant respiration (IPCC 2000).

In old-growth forests, the change in carbon accumulation with forest ageing varies significantly according to forest type. Forests can be a carbon sink, carbon neutral or a carbon source, depending on their composition and age, management activities and natural disturbances impacting the rate of carbon sequestration and emission (Harel, Thiffault, and Paré 2021).

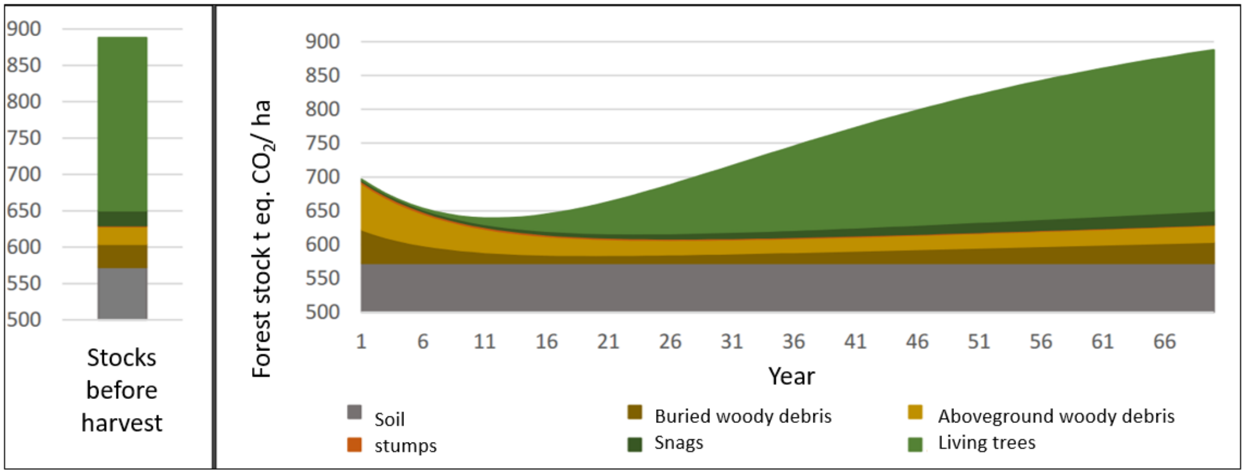
Harvesting operations alter the rate of carbon accumulation in forest stands since younger trees accumulate little biomass in the first 30 to 40 years. Harvesting also generates logging residues that decompose and emit carbon in the post-harvest years.

A recently harvested forest stand is a net source of emissions until the carbon accumulation in replacement biomass exceeds the emissions (Government of Canada 2024).

This especially applies to clear-cut harvesting, for which emissions from the decomposition of residues in the 10 to 30 years following the harvest are significantly higher than annual carbon sequestration. Other types of harvesting may limit the net emissions ascribed to harvesting (Moreau et al. 2023).

Conversely, continuous-cover forestry results in less variation between the removal of C by photosynthesis and the emission of C by residue decomposition, while stimulating the growth of the remaining trees in the forest stand, which leads to a better post-harvest carbon balance (Moreau et al. 2023).

Figure 1-1: Impact of clear-cut harvest on carbon stocks in a forest stand of balsam fir and white birch



Source: Beauregard et al. 2019

Notes: [1] The x-axis intersects the y-axis at 500 t CO_2 equivalent. [2] The figure is translated from the original French version.

1.2. Carbon neutrality assumption

Bioenergy is commonly considered to be carbon neutral because the carbon released during biomass combustion has previously been sequestered from the atmosphere and will be sequestered again as plants regrow (IEA Bioenergy 2024a).

However, it should be noted that since the term "carbon neutral" is used differently in various contexts, it can often be ambiguous and therefore unhelpful (IEA Bioenergy 2024a).

According to the IPCC approach, all biogenic CO_2 emissions from biomass combustion are reported as zero in the Energy sector. The objective of this approach is mainly to avoid double counting with the Agriculture, Forestry, and Other Land Uses (AFOLU) sectors (Camia et al. 2021; IPCC n.d.; Liu et al. 2017).

The IPCC guidelines do not automatically consider or assume biomass used for energy to be "carbon neutral," even in cases where biomass is thought to be produced sustainably (Camia et al. 2021; IPCC n.d.; Liu et al. 2017).

Even if CO_2 emissions from biomass combustion are reported as zero in the Energy sector, this should not be interpreted as a conclusion about the sustainability or carbon neutrality of bioenergy.

It is also important to distinguish between the approach used for agricultural biomass (annual production) and that used for forestry biomass (longer growth and decomposition cycles).

It is important to distinguish between bioenergy being carbon neutral and bioenergy having a mitigation benefit when replacing a fossil fuel:

- **Carbon neutral on a certain timescale = no net GHG emissions** (which means that C emitted during combustion is offset by C sequestered in forest)
- **Mitigation benefit = cumulative GHG emissions from bioenergy are lower than from fossil alternatives on a certain timescale** (due to subsequent C sequestration in forest in the case of bioenergy compared to fossil fuels)

The timescale necessary for net emissions from bioenergy to become lower than those from their fossil fuel alternative determines the net impact of bioenergy use on the atmosphere by 2050. Temporal trade-offs need to be evaluated based on the timeframe of the mitigation goal (Wang et al. 2022).

As noted in other studies, the assumption of bioenergy being "carbon neutral" and producing no net GHG emissions, should be avoided and bioenergy emissions must be estimated in a quantitative manner (Smyth, Kurz, et al. 2017).

The use of bioenergy can lead to increased or reduced emissions compared to business-as-usual (BAU), depending on the scale of deployment, the conversion technology, the fuel displaced, and how and where the biomass is produced (IPCC 2023).

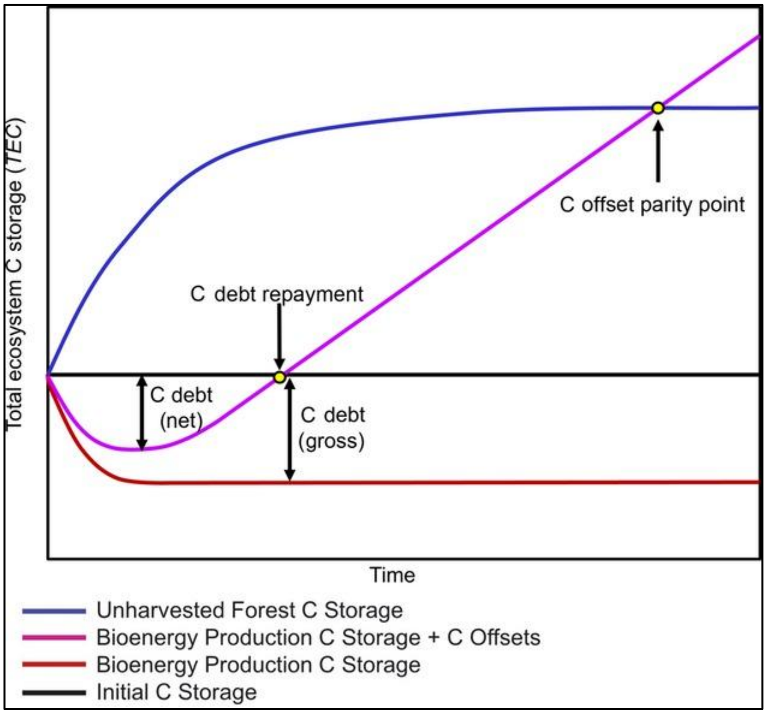
1.3. Timescale required to achieve mitigation benefits

Although biomass combustion is not carbon neutral, biomass resources are renewable and the carbon emitted during combustion could thus be sequestered again by replacement biomass.

The literature refers to the delay before atmospheric GHG benefits are achieved as "Carbon debt repayment time" or "Time to carbon parity" (Laganière et al. 2017; Ter-Mikaelian et al. 2015). However, it should be noted that these terms are not equivalent (Figure 1-2):

- **Carbon debt repayment time** (also called *Carbon payback time* or *Carbon payback period)*: The time required for the preharvest C level to be re-attained (absolute C balance).
- **Time to carbon parity** (also called *Carbon offset parity period* or *Break-even period)*: The time required for the C levels of a reference case (if harvesting did not occur) to be reached (relative C balance).

Figure 1-2: The concept of "Carbon debt repayment time" and "Time to carbon parity"



Source: Mitchell, Harmon, and O'Connell 2012

Note: "Carbon debt repayment time" and "Time to carbon parity" are noted as "C debt repayment" and "C offset parity point" respectively in the Figure.

Many studies have analyzed these metrics for bioenergy systems. The time required to obtain net GHG emissions mitigation benefits with bioenergy depends on the conversion efficiency of the biomass, the types of fossil fuels displaced, and the types of feedstocks used and their respective decomposition rates if they are not used for bioenergy.

Figure 1-3 shows the results of the carbon parity time calculated for biomass feedstocks used for heat or power to replace coal, oil or natural gas.

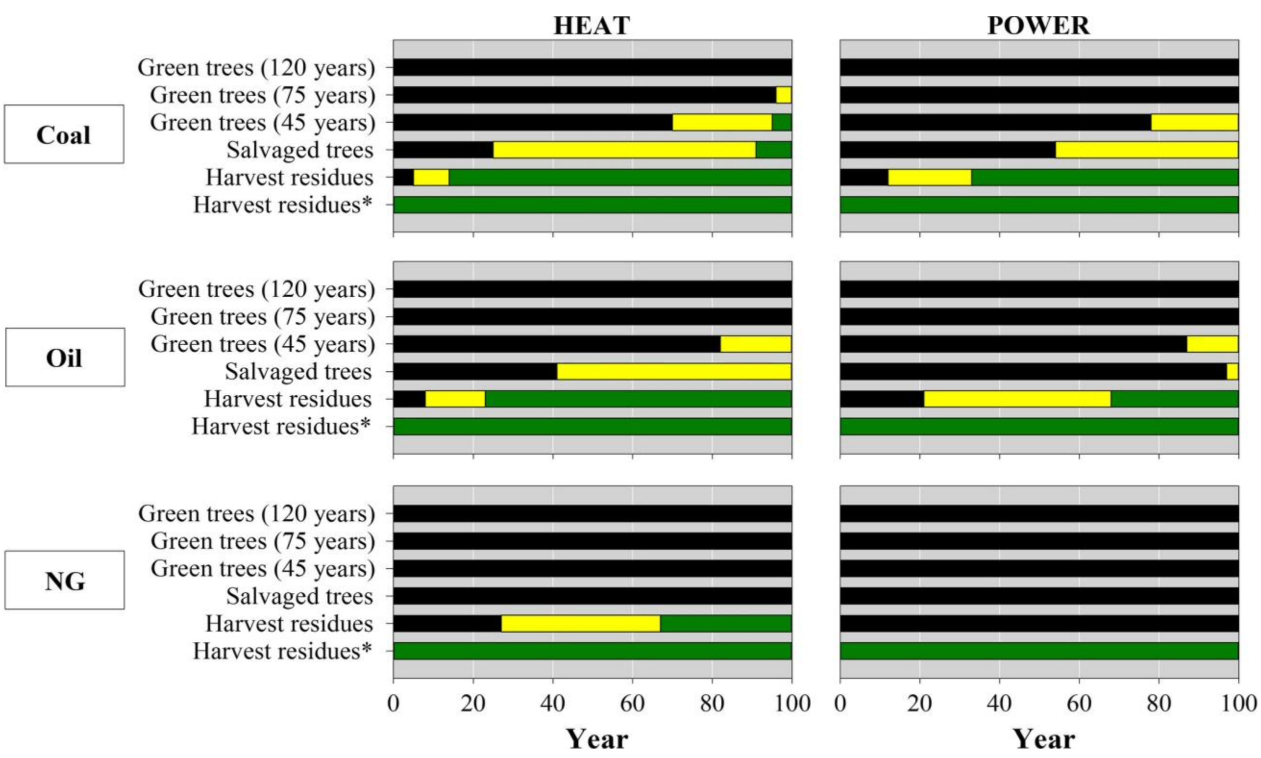
As this graph shows, the time required to reach parity depends on three main factors:

(1) **Type of biomass feedstock**: The use of harvest residues has the shortest carbon parity time compared to salvaged trees and green trees for the same energy usage and the same fossil fuel displaced. Although harvest residues do not sequester additional carbon, the carbon stored in the residues would be emitted gradually in BAU scenario. If BAU for harvest residues is slash burning, then the carbon parity time would be zero since the carbon would be emitted the same year either way. If the harvest residues are left in the forest to decompose gradually, then the carbon parity time would be between 5 and 67 years (Laganière et al. 2017; Smyth, Kurz, et al. 2017; Ter-Mikaelian et al. 2015).

(2) **Conversion efficiency of the bioenergy system:** If higher quantities of biomass feedstocks are needed for the same GJ of fossil energy displaced, then higher emissions from bioenergy would increase the carbon parity time. For example, Laganière et al. (2017) found that improving efficiency by 9% reduced the carbon parity time from 54 to 12 years for salvaged trees used to replace coal in power production. No GHG benefit was noted for green trees in the 100-year timeframe with all efficiencies investigated, which were between 26% and 35%.

(3) **Type of fossil fuel substituted:** As Figure 1-3 shows, the higher the emission factor of the fossil fuel displaced, the shorter the carbon parity time of bioenergy. For example, when harvest residues are used to substitute coal for heating, the time required to reach parity is less than 15 years. However, when harvest residues are used to substitute natural gas for heating, the time required can be up to 67 years.

Figure 1-3: Carbon parity time calculated for different biomass feedstocks in case of substitution of coal, oil or natural gas (NG) for use as heat or power



Source: Laganière et al. 2017

Notes: [1]Black color indicates the length of the carbon debt. Yellow indicates a phase during which it is uncertain whether there is a carbon benefit. Green indicates the phase during which there is a carbon benefit.
[2]The conversion efficiency factors used for heat and electricity are respectively: 75% and 26% for biomass, 80% and 33% for coal, 82% and 35% for oil and 85% and 45% for natural gas. [3] Harvest residues indicated with an asterisk refer to burning residues by the roadside in BAU compared to harvest residues (without asterisk) in which residues are left to decompose in the forest.

1.4. Biogenic carbon tracking in Canada

The IPCC does not provide a framework to assess the emissions from bioenergy as an industry sector. However, it requires complete coverage of all IPCC sectors, including AFOLU and Energy, which together, include the emissions (CO_2 and other GHG) from biomass used for energy purposes at the national level.

Removals and emissions from biomass are reported differently for forestry and agricultural biomass in national inventories (IPCC n.d.).

Biogenic CO_2 emissions from forest and agricultural biomass:

- **CO_2 emissions from combustion are not reported for agricultural biomass** since the carbon released during the combustion process is assumed to be reabsorbed by the vegetation during the next growing season. The net emissions are therefore almost zero over the course of a year. This method applies for annual biomass production, such as the production of corn, wheat, sugar-cane, and so on.
- The situation is more complex for forestry biomass due to longer cycles of growth and carbon sequestration. **CO_2 emissions from biomass combustion are captured within the CO_2 emissions in the AFOLU sector** through the estimated changes in carbon stocks from biomass harvest, even if emissions physically take place in the energy or other sectors.

Biogenic non-CO_2 emissions from forest and agricultural biomass:

- CH_4 and N_2O emissions are reported in the **energy sector** if biomass is combusted for energy use, since these emissions cannot be estimated using AFOLU carbon stock change methodologies.
- CH_4 and N_2O emissions from the biogenic part of waste burned without energy recovery are reported in the **waste sector**.

This approach is intended to provide a complete picture of the bioenergy emissions and to avoid double counting of emissions within the AFOLU sectors.

1.4.1. Managed forests

Managed forests are forest lands where human interventions and practices have been applied to perform production, ecological or social functions (IPCC 2006).

Countries report on carbon emissions and removals from managed lands through the United Nations Framework Convention on Climate Change (UNFCCC) national inventory report (NIR) category of Land Use, Land Use Change and Forestry (LULUCF) (see Table 1-1). It is worth noting that countries use very different estimating approaches for the LULUCF sector (Smith et al. 2023).

Managed lands are used by countries as a proxy for anthropogenic emissions and removals on the basis that the preponderance of anthropogenic effects occurs on managed lands. As for emissions and removals on managed lands, they can represent a combination of both anthropogenic and natural effects (IPCC 2019).

In Canada, emissions and removals from managed forests due to the anthropogenic component are reported in the NIR. As for the natural disturbance component, emissions are tracked and presented in the NIR but are not reported (Table 1-1).

Table 1-1: GHG emissions and removals from LULUCF sector in Canada's NIR of 2025

Sectoral category	**Net GHG Flux**[1] (Mt CO_2e)							
	1990	**2005**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Forest land *(anthropogenic component)*	73	140	60	40	40	34	22	24
Harvested Wood Products	-38	-57	-24	-18	-10	-12	-4	-5.1
Cropland	5.5	-20	-20	-15	-13	-16	25	-22
Grassland[2]	0	0	0	0	0	0	0	0
Wetlands	5.1	2.7	2.5	2.7	2.9	2.8	2.6	2.6
Settlements	4.8	4.7	5.4	5.3	5.3	5.5	5.2	5
LULUCF total *(reported)*	50	66	24	15	25	15	51	4
Natural disturbances in managed forests *(tracked but not reported)*	-120	12	250	160	2.7	290	87	1 100

Source: Government of Canada 2025

Notes:
[1]Positive values indicates GHG emissions and negative values indicates removals of CO_2 by biomass.
[2]Grassland emissions are in the range of 0.7 to 1.3 kt CO_2e.

All emissions of biogenic carbon due to biomass harvested from Canadian forests are tracked and reported in Canada, irrespective of whether they are exported or not. The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) model is used to monitor and report on the forest carbon balance of Canada's managed forests. It tracks the amount of carbon transferred annually to the Harvested Wood Products (HWP) pool.

The approach used in Canada to report on GHG fluxes in the HWP category is the simple decay approach described in the 2019 Refinement of the 2006 IPCC guidelines (Government of Canada 2025). This approach tracks the fate of carbon in all woody biomass harvested in Canada and subsequently consumed either in Canada or abroad including short- and long-lived wood products and wood combusted for bioenergy.

The Canadian Forest Service uses the National Forest Carbon Monitoring, Accounting and Reporting System for Harvested Wood Products (NFCMARS-HWP) model to produce the annual HWP carbon component of Canada's national GHG inventory report. It is used to estimate and report on the fate of carbon harvested in Canada's forests (Canada 2022)**.**

The annual mass of carbon in harvested wood is calculated by the CBM-CFS3 model and is used as input in the NFCMARS-HWP model. Quantities of wood used for residential firewood and industrial wood waste used for bioenergy are provided by the Energy sector and added to the model. Emissions from wood biomass combustion obtained from the Energy sector are grouped as residential firewood and industrial wood wastes. The third category of biomass emission from combustion, which applies to ethanol and biodiesel, is assumed not to be produced from wood.

As stated in the NIR, all wood harvested and transferred from the forest to the HWP pool is included in the HWP model, although some products (such as pellets) are not explicitly identified as separate outputs due to lack of information and are added to all the residual waste identified as "milling waste." All wood used for bioenergy (e.g., wood chips and pellets) is quantified and assumed to be oxidized in the year of harvest (Government of Canada 2020).

After harvest, the carbon stock stored in wood products and emitted in other sectors is tracked and reported in the HWP category. Emissions from wood products in HWP are calculated based on product-in-use half-life parameters depending on type and geographic location. Emissions from the decomposition of the logging residues left in the forest are reported in the Forest Land category.

Harvest activities and HWP use and disposal impact net emissions of the forest sector on both the short and the long term, making it more complicated to track the impact of specific activities. Annual carbon flux from use and disposal of HWP are reported in Canada's NIR for the sub-categories: solid wood, pulp and paper, unused mill residues, industrial bioenergy and residential bioenergy.

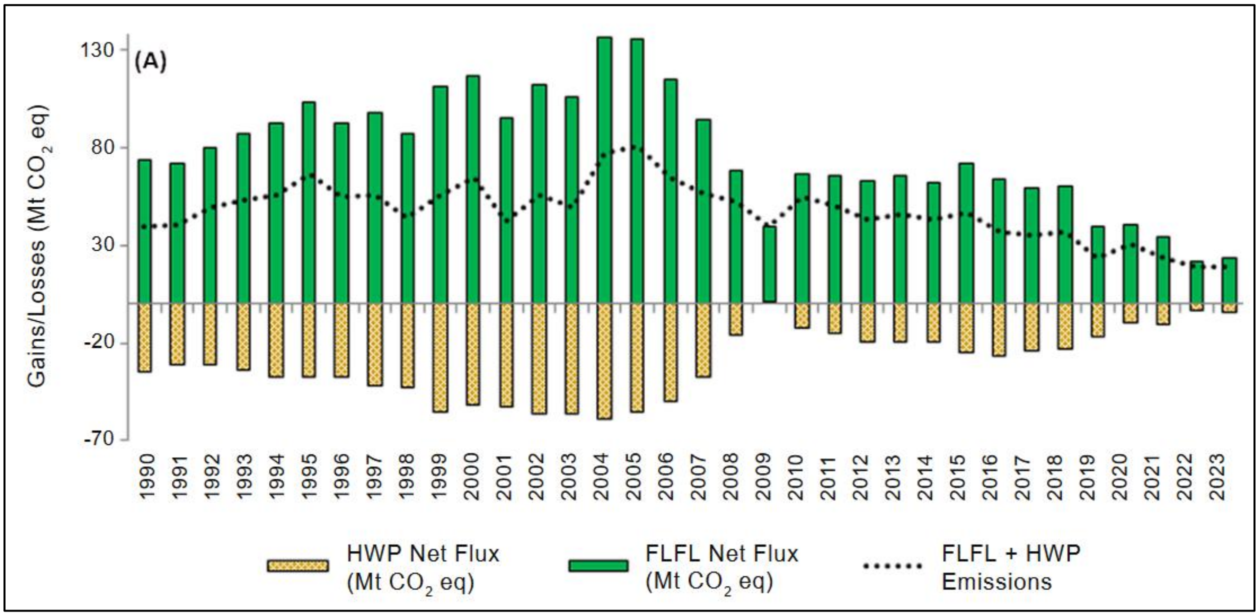
If carbon removals in forests remained higher than its carbon emissions, including carbon emissions from combustion or decomposition of wood products in a given year, forests would be a carbon sink. However, in all the time series reported in the 2025 NIR, forests were classified as a carbon source.

The sum of removals, emissions and carbon transfers reported in the Forest Land and in the HWP categories represent the net annual flux of carbon of the managed forests (Figure 1-4).

Approximately 33% of emissions in the HWP category in 2023 result from long-lived wood products *(e.g. sawn wood used in construction that reaches the end of its useful life*), 25% from short-lived products *(e.g. pulp and paper)* and 39% from bioenergy (Government of Canada 2025).

It is worth noting that in Canada, bioenergy is mostly used in the forest industry. Pulp and paper sector is the largest user of bioenergy, particularly from the use of wood waste and pulping liquor for the production of electricity and steam (IEA Bioenergy 2024b; NRCan 2024b).

Figure 1-4: Emissions of managed forests combining Forest Land Remaining Forest Land (FLFL) and Harvested Wood Products (HWP) in Canada's NIR of 2025



Source: Government of Canada 2025

1.4.1.1. Revisions in Canada's 2024 NIR

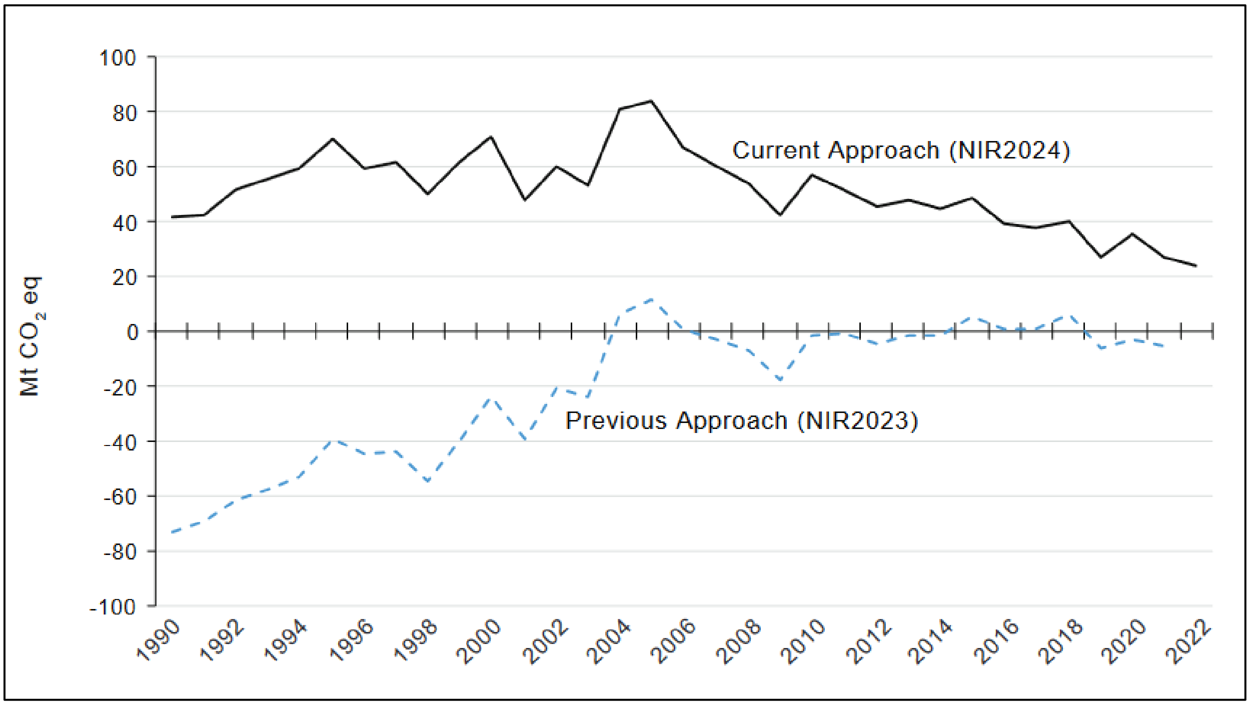
Recalculations were made in Canada's national inventory report of 2024 for the LULUCF sector, which had a significant impact on estimated emissions, mainly due to a review of the historical harvest areas.

The area of managed forests previously included as "anthropogenic component" were reduced by 34 million hectares (Mha). This correction shifted the removals of carbon in this area from the "anthropogenic" to the "natural disturbance" component, thus reducing the amount of carbon removals attributed to the anthropogenic component.

A change to estimated dead organic matter (DOM) stock in the managed forest also increased emissions from decomposition. Figure 1-5 shows the impact of the new approach on the emissions of Managed Forests (Forest Land + HWP).

These corrections shifted the LULUCF sector from a net carbon sink to a net carbon source through the entire inventory time series.

Figure 1-5: Emissions of Managed Forests combining Forest Land and Harvested Wood Products (HWP) in Canada's NIR of 2024 compared to the previous approach



Source: Government of Canada 2024

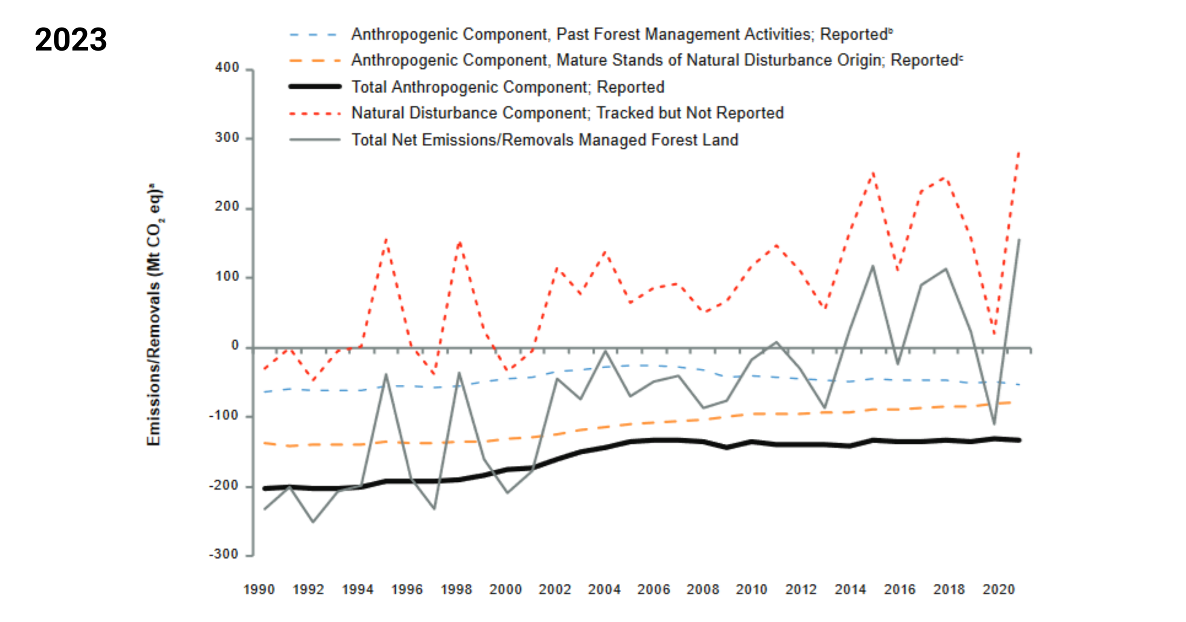
As previously mentioned, emissions and removals on managed lands can represent a combination of both anthropogenic and natural effects (IPCC 2019).

The estimated removals of carbon reported in the Forest land category in the anthropogenic component include net fluxes from forest stands that are of harvest origin or have recovered from natural disturbances.

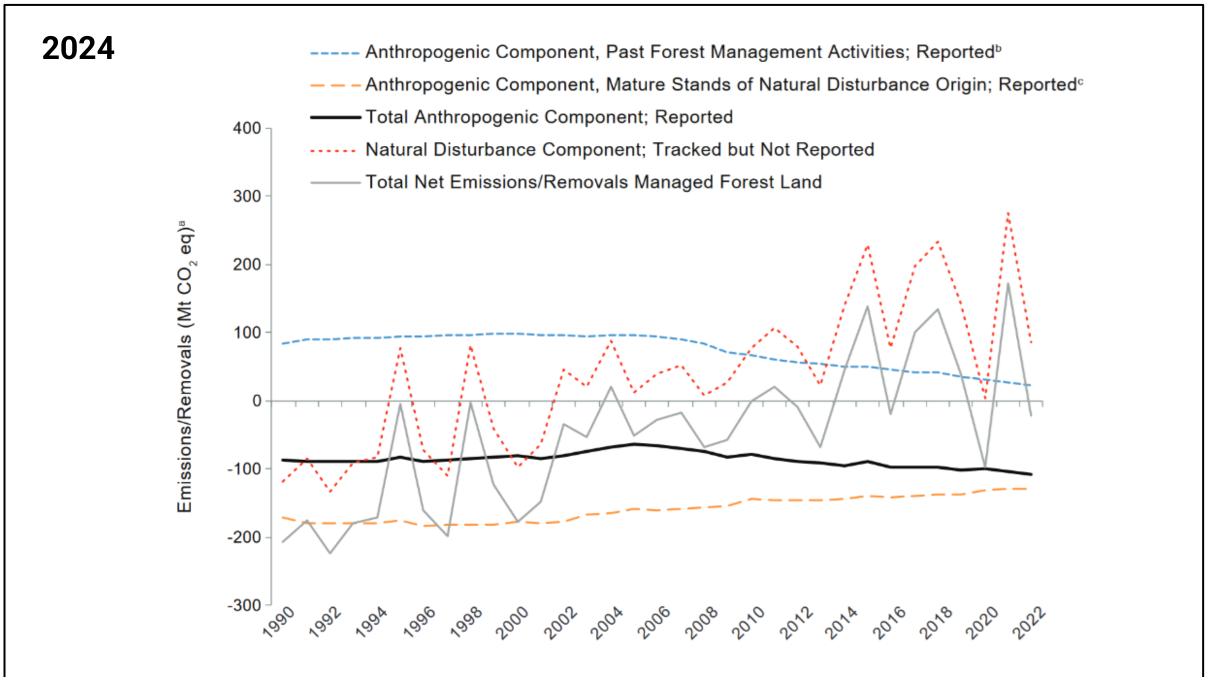
Emissions and removals reported in the Forest Land category for stands that have been directly affected by past forest management activities, as part of the anthropogenic component, shifted from net removals to net emissions in the 2024 publication (blue dashed lines on Figure 1-6).

The forest carbon removal in Canada's inventory mainly comes from stands that were affected by natural disturbance and grew back to their pre-disturbance biomass or reached the age of commercial maturity and are part of the anthropogenic component (orange dashed lines on Figure 1-6).

Figure 1-6: Emissions reported in Forest Land category in Canada's 2023 and 2024 NIR



Notes:
a. Not including indirect CO_2 or emissions from HWP.
b. Clear-cut and partial harvests, commercial and pre-commercial thinning, and salvage logging.
c. Stands that have reached minimum operable age (either commercial maturity or pre-disturbance biomass threshold) and are eligible to be scheduled for harvest.



Notes:
a. Not including indirect CO_2 or emissions from HWP.
b. Clear-cut and partial harvests, commercial and pre-commercial thinning, and salvage logging.
c. Stands that have reached minimum operable age (either commercial maturity or pre-disturbance biomass threshold) and are eligible to be scheduled for harvest.

Sources: Government of Canada 2023; Government of Canada 2024

1.4.1.2. Revisions in Canada's 2025 NIR

Major revisions to Canada's reporting approach for the LULUCF sector were also made in the 2025 NIR. The objective of these revisions were to improve the comparability of Canada's HWP reporting with other countries, to better capture the immediate impact of harvest on forest carbon stocks and the important role of Harvested Wood Products (HWP) as a significant global carbon store (Government of Canada 2025).

These changes have modified significantly the reporting approach among land and HWP categories, however, they have no net impact to reported emissions and removals in the LULUCF sector.

Reporting in the Forest Land category now includes the fluxes of carbon of wood products out of the forest ecosystem (as carbon loss) which is then transferred to the HWP pool (as carbon gain). Forest Land category previously included only CO_2 removals from the atmosphere and the emissions from decomposition of biomass in the forest ecosystem.

As for the HWP category, reporting in this category now represents the difference between annual carbon inputs to the HWP pool (as carbon gain) and the annual emissions originating from the disposal or from combustion of wood products. This category previously reported only the annual gross emissions from the disposal or from combustion of HWP.

The modifications in reporting applied to the HWP category (subtraction of -137 Mt for 2022) are fully offset by modifications in Forest Land (addition of +132 Mt for 2022) and in Forest Conversion in Cropland, Settlement and Wetland (addition of +5Mt for 2022). The changes flipped the Forest Land category from a net sink to a net source, while they simultaneously flipped the HWP category from a gross emission source to being reported as a net gain of carbon storage. Reporting HWP as a net gain of carbon is a result of annual inputs of carbon from new harvested wood products in the pool being greater than carbon outputs from the pool.

Despite the significant changes done in the reporting categories, the net emissions of the forest sector did not change in the 2025 NIR. Only, minor recalculations were made due to some methodological changes.

Therefore, managed forests in Canada remain a net source of emissions throughout the time series of the NIR.

As mentioned in the 2025 NIR:

> Emissions and removals reported from the forest sector, without the natural disturbance component but also considering fluxes of carbon to the Harvested Wood Products category, demonstrate that the Canadian Forest sector acts as a net source of carbon transferred to the atmosphere and to the global waste stream as a result of short- and long-term impacts of human management (Government of Canada 2025, section 6.3 in NIR).

Box 2: "Accounting contribution" methodology used in Canada for the Land Use, Land Use Change and Forestry (LULUCF) sector in national targets accounting

In the methodology used to account for emissions from the LULUCF sector when tracking Canada's progress towards its national targets, an "accounting contribution" value is calculated for the LULUCF sector and then added to Canada's total net GHG emissions.

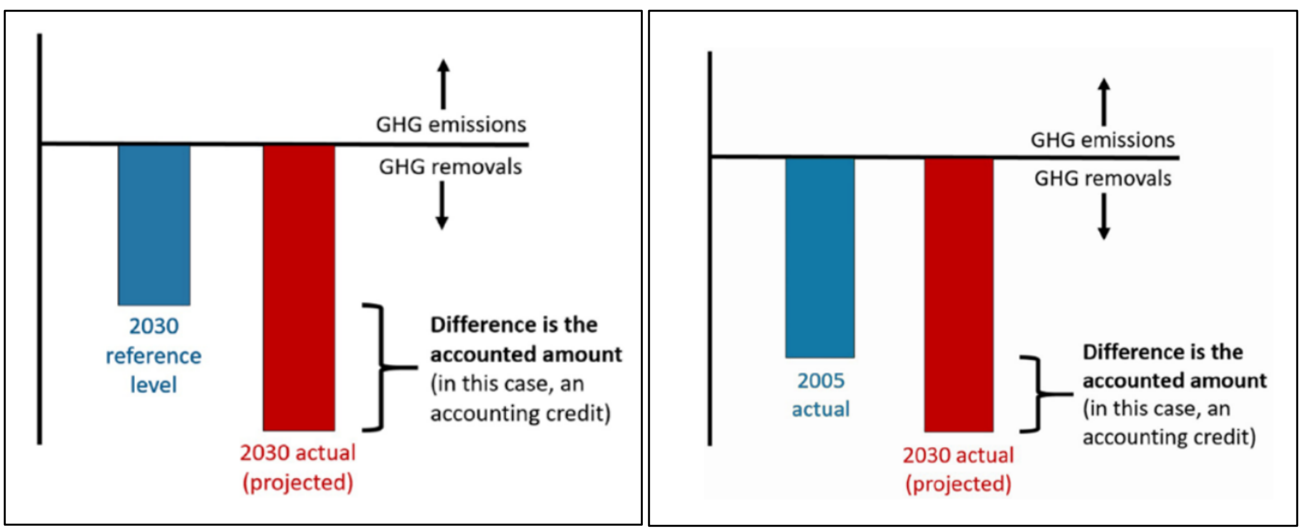
It is important to note that this "accounting contribution" of LULUCF is not equivalent to the total emissions of the LULUCF sector reported in the national inventory report.

To estimate the accounting contribution, Canada uses "reference level" accounting methodology for managed forests (forest lands and the associated HWP). As for the rest of the LULUCF categories, a simple "net-net" approach comparing emissions of the reporting year to a base year (2005) is used (Figure 1-7).

In the "reference level" accounting method, emissions reductions from managed forests are calculated as the difference between forest emissions in the reporting year and the estimated emissions for that same year that would occur if past management practices continued business-as-usual (a pre-defined value for that year based on modelling of a reference scenario in which historical harvest activities are held constant) (ECCC 2023).

Therefore, in 2022, the accounting contribution from LULUCF was +12 Mt CO_2e while the net emissions in LULUCF sector reported in the national inventory were +51 Mt CO_2e.

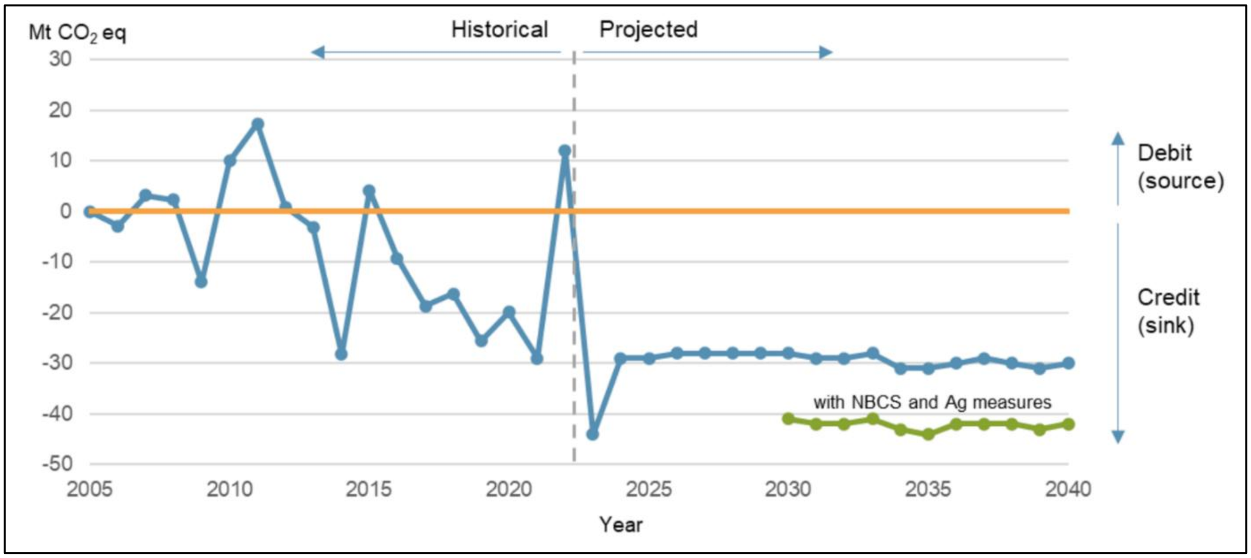
Figure 1-7: Schematic representations of the "Reference Level" accounting method (left) and "net-net" accounting method (right)



Source: NRCan 2022

The accounting contribution from the LULUCF sector in Canada is typically added as carbon removals (credit); however, it became a source of emissions (debit) in 2022 (Figure 1-8). That year's contribution was particularly high due to the increased emissions in croplands following extreme drought in 2021.

Figure 1-8: LULUCF accounting contribution in Canada's First Biennial Transparency report



Source: Government of Canada 2024b

In 2022, total GHG emissions of Canada (excluding LULUCF) were 708 Mt CO_2e. By adding the LULUCF accounting contribution (+12 Mt for 2022), Canada's GHG emissions were 720 Mt CO_2e.

The "accounting contribution" from LULUCF is expected to remain a credit of around -30 Mt CO_2e to Canada's GHG emissions until 2040.

As for the net emissions of the LULUCF sector, Canada's most recent projections (published in February 2025) show a decrease in emissions to reach negative emissions starting from 2023.

Table 1-2: Historical and projected LULUCF net GHG flux and accounting contribution

LULUCF sector	Historical GHG flux (Mt CO2e)			Projected GHG flux (Mt CO2e)				
	2021	**2022**	**2023**	**2023**	**2025**	**2030**	**2035**	**2040**
Net GHG flux	**+14** [a, b, c]	**+51** [a, b, c]	**+4.2** [a]	**-12** [c]	**-4** [b, c]	**-18** [b, c]	**-25** [b, c]	**-23** [b, c]
Accounting contribution	**-29** [b, c]	**+12** [b, c]	NA	**-44** [c]	**-29** [b, c]	**-28** [b, c]	**-31** [b, c]	**-30** [b, c]

Sources: Government of Canada 2024b; Government of Canada 2025; ECCC, 2025

Notes: [a] Published in Canada's national inventory report of 2025
[b] Published in Canada's first Biennial Transparency Report on 30 December 2024
[c] Datasets from Canada's current projections published in February 2025 on the website of ECCC
[d] Some values differ by 1 or 2 Mt CO_2e from one reference to another. For clarity of information presented in the table, only one value is presented.

1.4.2. Croplands

Emissions and removals from croplands in Canada are reported in the LULUCF sector. These emissions include CO_2 emissions and removals from mineral soils, from the cultivation of organic soils and from loss of woody biomass in agricultural lands.

As mentioned previously, CO_2 emissions from the combustion of annual crops are considered neutral and are not reported in the NIR. CO_2 emissions and removals in the Croplands category are impacted by the input of organic carbon in mineral soils and therefore by changes in crop productivity and the rate of soil organic carbon (SOC) decomposition.

Some of the woody biomass harvested in agricultural lands are used for residential bioenergy. The emissions associated to the loss of woody biomass are reported as emissions in croplands and transferred to the HWP pool. In 2023, these emissions accounted for 0.4 Mt CO2e of the firewood emissions of HWP.

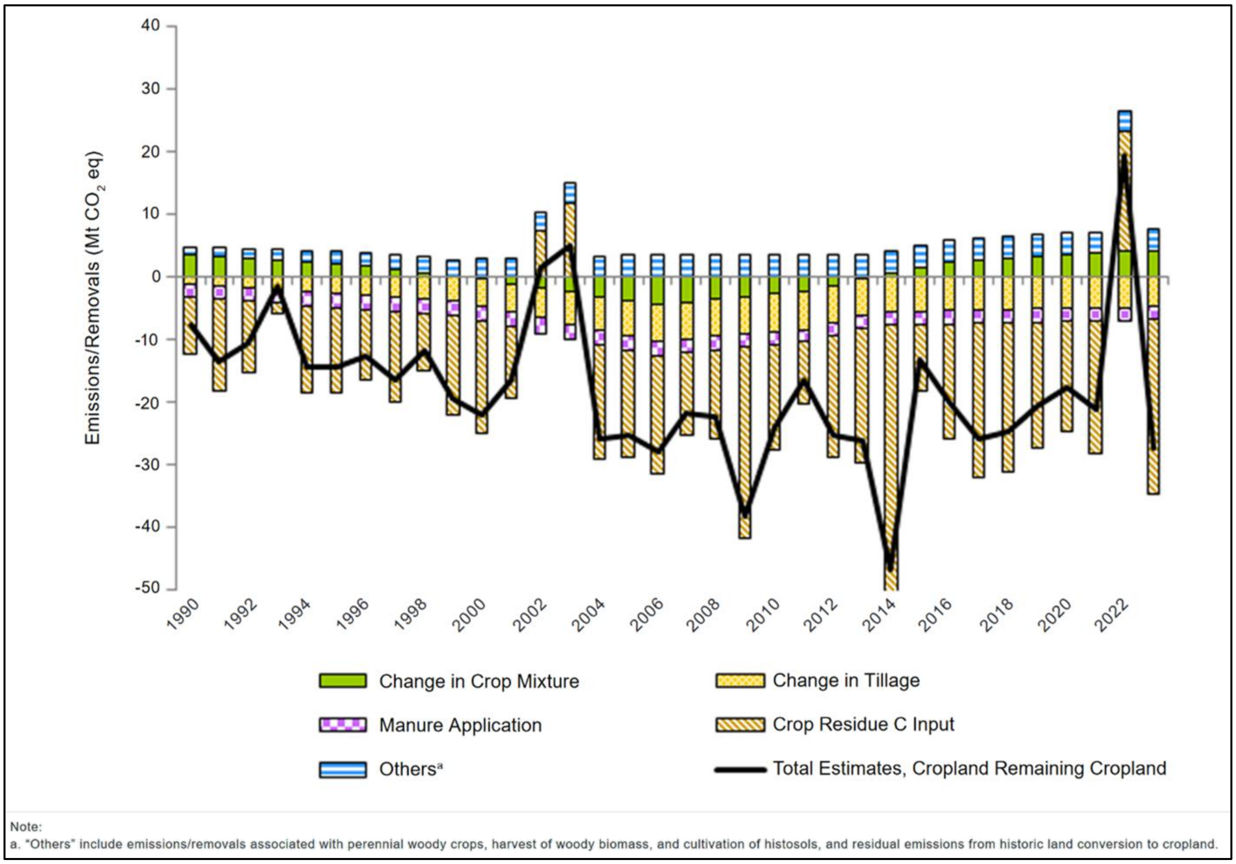
Crop residues contribute to the majority of CO_2 removals in this category due to organic carbon retained by soils. A small amount of carbon removal in this category was due to manure application on agricultural soils (Figure 1-9). Changes in croplands management (conversion from perennial crops to annual crops, conversion of forest land to cropland, etc.) therefore impact the magnitude of emissions and removals in this sector. Several factors impact carbon input to soils such as changes in crop productivity, use of summer fallow and changes in soil management practices such as the adoption of conservation tillage [1].

In Canada's NIR, croplands have been a net carbon sink in almost all the time series. However, exceptionally in 2022, they were a net source of emissions of 25 Mt, which was associated with the 2021 drought in Western Canada (Government of Canada 2025).

Weather variations and drought events have a huge impact on crop yields and carbon inputs to soils and, accordingly, on emissions from croplands.

[1] Conservation tillage consists of tillage retaining most of the crop residue on the surface, compared to conventional tillage which consists of tillage incorporating most of the crop residue into the soil (Li et al. 2012).

Figure 1-9: Emissions reported in Canada's 2025 NIR for Croplands remaining Croplands



Source: Government of Canada 2025

1.5. Climate change impact on biogenic carbon stocks

Climate change is already affecting biogenic carbon stocks in Canada and the impacts of extreme weather conditions are expected to increase in a warmer climate.

In agricultural ecosystems, climate change made droughts more frequent and severe. With increasing climate warming, the risks are significant for the country's agriculture sector. For example in 2021, a severe drought in Saskatchewan, which was considered the worst in nearly two decades, impacted crop production (reduction of 47%) (Canadian Climate Institute 2024a; Statistics Canada 2022).

In forest ecosystems, climate change is affecting the likelihood of the occurrence and intensity of wildfires, which led to an extreme fire season in 2023 (Barnes et al. 2023).

GHG emissions due to 2023's natural disturbances in Canada's managed forests presented in Canada's NIR of 2025 were a total of 1100 Mt CO_2e, around 150% higher than the total GHG emissions in Canada (Table 1-1).

As previously mentioned, total emissions from wildfires and from other natural disturbances in managed forests are not reported in Canada’s NIR, however, they are tracked and presented in the inventory.

Climate change also poses a risk to Canadian forests because of more frequent droughts, a general decline in forest productivity in most regions, a further spread of insect and disease outbreaks, and a change in growing conditions of trees, which will impact the forest composition by trees migrating to new locations. It is worth noting that even though trees can migrate, projections show that climate change is expected to grow 10 to 100 times faster than their ability to do so (NRCan 2024b).

Climate change also affects the potential of net carbon sequestration in wood and forest productivity due to the effect of environmental drivers such as temperature and precipitation on carbon assimilation and wood formation (Silvestro et al. 2024).

In Canadian forests, key drivers that would affect carbon balance include changes in forest dynamics and decomposition rates; future disturbances; and future economic, social and climate conditions that would lead to new areas of project developments and land-use change (Kurz et al. 2013).

Forests play a huge role in the global atmospheric carbon budget. Potential large increases in emissions from boreal forests and other terrestrial systems would impact global climate change mitigation efforts. It is thus important to reduce the uncertainties of the current and future carbon balance of Canada’s forests and to address the gaps in monitoring, observation and quantification of carbon dynamics (Kurz et al. 2013).

Many studies in the literature emphasize the substantial threat of climate change to carbon stocks and future carbon balances in Canada’s forests. Increases in temperatures and disturbance rates could result in higher emissions, which is unlikely to be offset by increased productivity and carbon uptake (van Bellen, Garneau, and Bergeron 2010; Kurz et al. 2013; MacCarthy et al. 2024; NRCan 2024a).

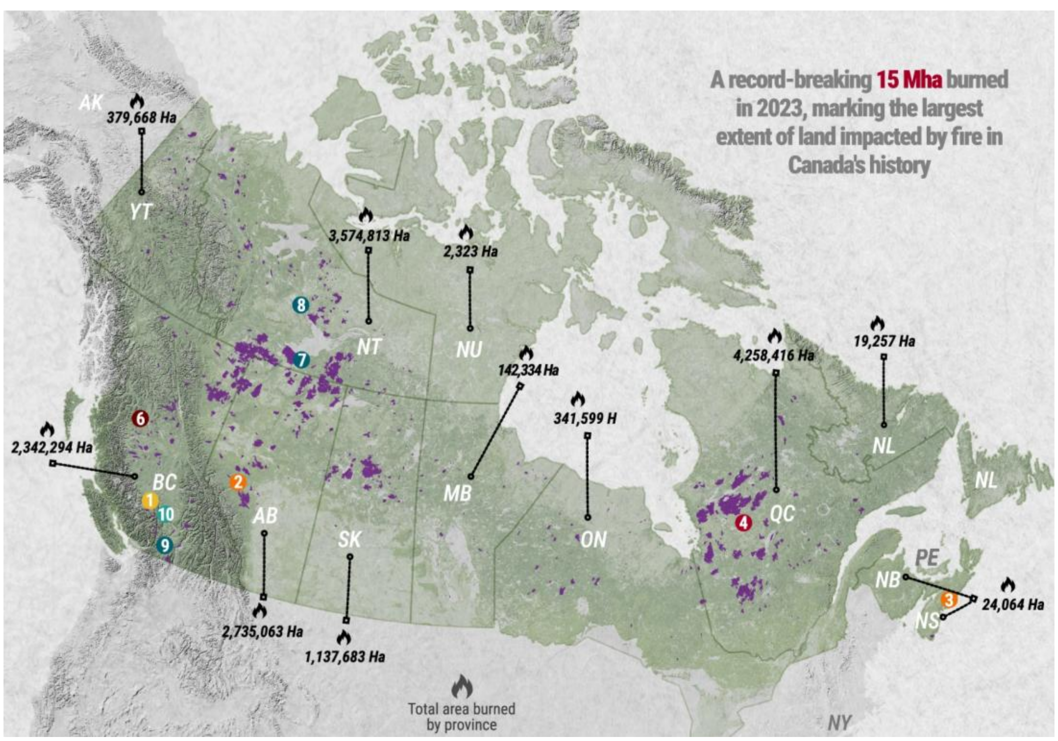
Box 3: Canada's fire season in 2023

Canada's 2023 fire season was extreme compared to all other fire seasons in its recent history. From May to July, wildfires burned 15 million hectares in 2023, compared to a nationwide annual average of 2.5 million hectares. The previous record was set in 1989 when 6.7 million hectares burned over the entire year. The number of megafires in 2023 was also extreme at 29, compared to a record 17 in 1989. Of the 10 biggest wildfires in Canada since 1950, four occurred in 2023 (Barnes et al. 2023; Kirchmeier-Young et al. 2024). Canadian wildfires in 2023 had a significant impact on global tree cover loss and carbon emissions, accounting for up to 27% of worldwide tree cover loss that year (MacCarthy et al. 2024).

Even though wildfires occur naturally every year in Canada, climate change contributes to an increase in their intensity and likelihood (as is the case for other extreme weather events). Human-induced climate change leads to changes in fire weather, which is associated with an increase in temperature and a decrease in humidity.

Researchers showed that climate change significantly increased the likelihood of the long fire season and the large area burned in most regions of Canada in 2023 (Kirchmeier-Young et al. 2024). A study on the 2023 fire season in Eastern Canada showed that peak fire weather like that experienced in 2023 is at least twice as likely to occur today compared to under preindustrial climate. The intensity of fires has increased by some 20% due to human-induced climate change. For example, in Quebec, climate change led to fires being 50% more intense at the end of July 2023 relative to the pre-industrial climate (Barnes et al. 2023).

Figure 1-10: Areas burned by wildfires in Canada's fire season of 2023



Source: Jain et al. 2024. Full size figure is presented in Appendix 1.

1.6. Importance of negative emissions in net-zero pathways

Results from modeled pathways in the IPCC sixth assessment report show that most pathways limiting warming to 2°C or less rely on carbon dioxide removals (CDR) in energy supply or from LULUCF to reach the net-zero target and that pathways requiring higher use of bioenergy with carbon capture and storage (BECCS) and direct air capture (DAC) had significantly higher residual emissions from other sectors. As mentioned in the report, even with substantial direct emissions reductions in all sectors and regions, a certain amount of CDR would still be needed to compensate for residual hard-to-abate GHG emissions (IPCC WG III 2022).

As mentioned by the IPCC:

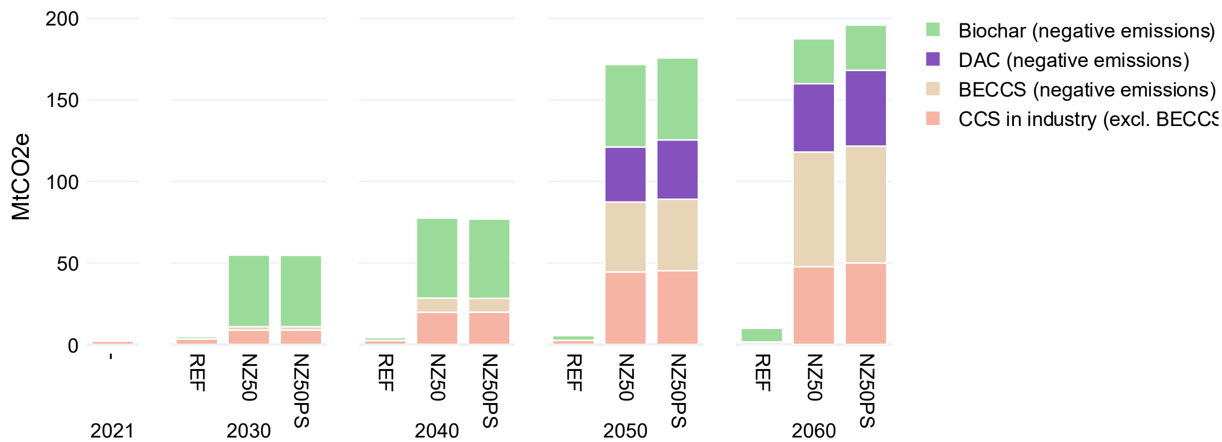
> **The deployment of carbon dioxide removal (CDR) to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or GHG emissions are to be achieved. The scale and timing of deployment will depend on the trajectories of gross emission reductions in different sectors. Upscaling the deployment of CDR depends on developing effective approaches to address feasibility and sustainability constraints especially at large scales (high confidence). (IPCC WG III 2022, Section C.11 of the Summary for Policymakers Report).**

Studies modelling pathways to net zero in Canada, also showed that negative emissions were required to offset remaining emissions in hard-to-decarbonize sectors by 2050.

The most recent edition *Canadian Energy Outlook,* led by the Institut de l'énergie Trottier, integrated energy system modelling by ESMIA Consultant that includes detailed information about the biomass-based technologies assessed in collaboration with Natural Resources Canada.

Modelling results show that, with the included technologies, achieving and remaining at net zero by 2050 requires a significant quantity of emissions capture and storage (Figure 1-11). Its net zero by 2050 scenario (NZ50) shows that 128 Mt CO_2e of negative emissions are required, including 43 Mt from BECCS, 34 Mt from DAC and 51 Mt from biochar, in addition to 44 Mt CO_2e captured by CCS in industry (Langlois-Bertrand 2024).

Figure 1-11: Emissions capture and storage across scenarios in the Institut de l'énergie Trottier *Canadian Energy Outlook* study



Source: Langlois-Bertrand 2024

In Canada's Energy Future 2023 report published by Canada Energy Regulator, negative emissions from BECCS and DAC were also needed to reach net zero by 2050 in both scenarios studied, in addition to negative emissions assumed from LULUCF. Canada's Energy Future 2023 assumed that the LULUCF sector could provide 50 Mt of negative emissions by 2050 (Canada Energy Regulator 2023).

Negative emissions technologies include all measures or technologies that result in a net removal of GHGs from the atmosphere and their storage in either living or dead organic material or in geological stores. The methods to achieve negative emissions are primarily based on biomass sectors, with non-technological solutions (e.g., reforestation, afforestation) or technologies that allow for the capture and storage of CO_2 emissions such as bioenergy combined with carbon capture and storage (BECCS) or pyrolysis of biomass to produce biochar that can be applied to agricultural soils. The only other methods to achieve negative emissions that are not based on biomass management and use are based on direct air carbon capture and storage (DAC) technology or ocean alkalinisation (IPCC WG III 2022).

In the planning of mitigation strategies, certain risks and uncertainties tied to negative emissions technologies, such as the need for clean electricity to operate DAC systems, which can compromise decarbonization through direct electrification in other sectors, need to be taken into consideration (Langlois-Bertrand 2024). As for land-based mitigation measures, it is important to note that although the impact of climate change on land-based sectors is currently uncertain, it could be substantial (IPCC WG III 2022).

Since negative emissions are needed to reach net-zero, it is crucial to understand the potential contribution of negative emissions technologies in Canada and carefully plan their deployment depending on the mitigation strategies adopted in other sectors.

2. Current evaluation methods for biomass

Researchers, project developers, policymakers and international standards committees have developed various methods to evaluate biomass uses for bioenergy or biomaterials, depending on the scope of the study and the objective of the evaluation. Biomass use can be assessed in relation to its impact on many environmental, economic and societal factors.

The main objective of this chapter is to explore methods currently deployed to assess biomass use in a context of Canada's transition to net zero. We thus focused on methods that included in the evaluation the impact of using biomass for energy or non-energy purposes on GHG emissions or that assessed biomass's role in climate mitigation strategies.

Evaluation methods are categorized as follows:

- Sustainability criteria and standards;
- Climate mitigation benefit assessment: Project scale vs regional scale;
- Decision making support tools: Resource focused vs End-use focused.

Key messages from chapter 2

- Sustainability standards and frameworks ensure a comprehensive approach to evaluating the sustainability of biomass supply chains. However, these methods do not provide a system-level overview of inter-sectoral impacts and trade-offs of biomass use on a national basis. **(see section 0)**
- To evaluate climate change mitigation potential of biomass use on a project scale, life-cycle assessment (LCA) is commonly conducted for biofuels and for biomaterials. **(see section 2.2.1)**
- To evaluate climate change mitigation potential of forest biomass on a regional scale, methodologies that are commonly used by researchers combine emissions and removals from forest ecosystems, from harvested wood products, and from avoided emissions that are due to product substitution. **(see section 2.2.2)**
- Most of the publicly available decision-support tools for biomass, that were identified during this project, can be grouped into two main approaches: End-use/demand focused approaches and Land-use/resource focused approaches. **(see section 2.3)**

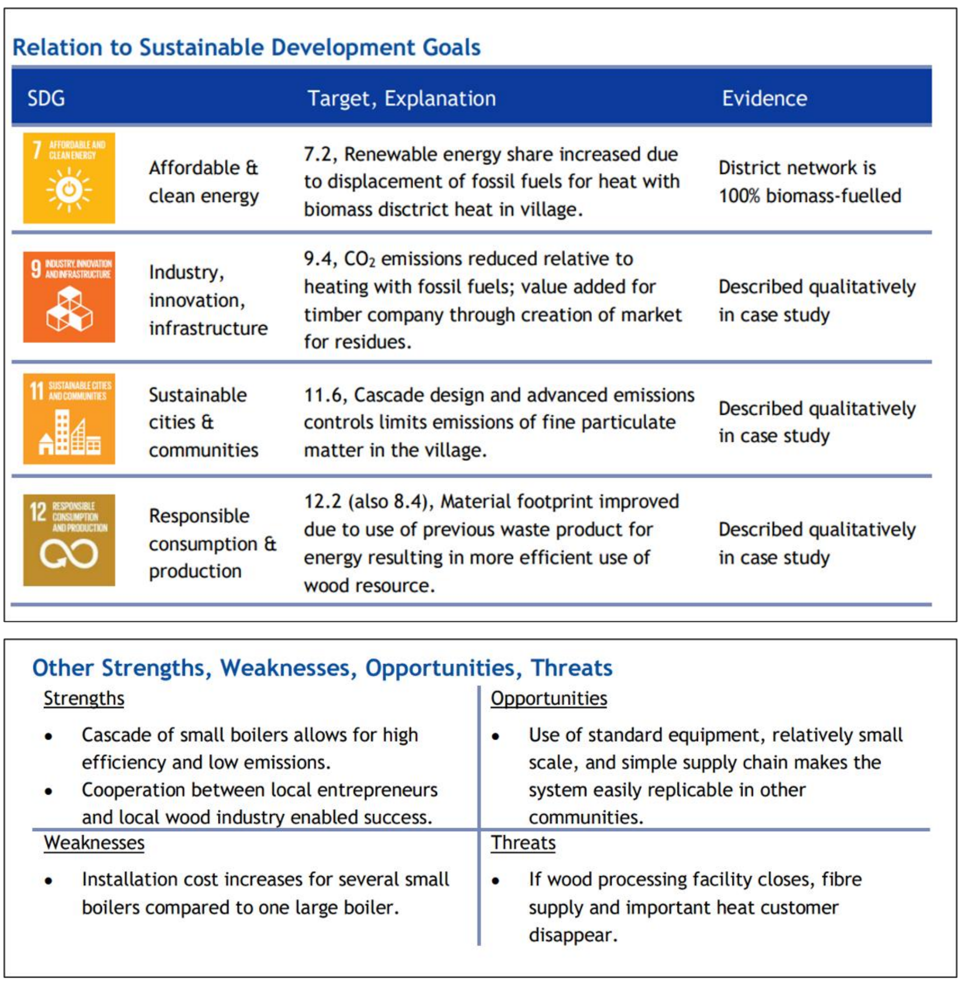
2.1. Sustainability criteria and standards

2.1.1. Description

To ensure a comprehensive approach to evaluating the sustainability of biomass supply chains, bioenergy frameworks and standards, such as the ISO Standard on Sustainability Criteria for Bioenergy (ISO 2015) and the Global Bioenergy Partnership Sustainability Indicators (GBEP), were developed.

Established by FAO and other international organizations (Global Bioenergy Partnership 2011), the GBEP provided a framework to assess the relationship between the production and use of modern bioenergy and sustainable development. The indicators were developed to report on the environmental, social and economic aspects of sustainable development. As part of an IEA Bioenergy initiative, experts identified 37 case studies of biomass supply chains worldwide considered to represent best practices and identified their contributions to the UN's Sustainable Development Goals (SDG) (Figure 2-1).

Figure 2-1: Example of an analysis performed for a case study of a wood chip boiler cascade in Switzerland



Relation to Sustainable Development Goals

SDG		Target, Explanation	Evidence
7 AFFORDABLE AND CLEAN ENERGY	Affordable & clean energy	7.2, Renewable energy share increased due to displacement of fossil fuels for heat with biomass disctrict heat in village.	District network is 100% biomass-fuelled
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Industry, innovation, infrastructure	9.4, CO_2 emissions reduced relative to heating with fossil fuels; value added for timber company through creation of market for residues.	Described qualitatively in case study
11 SUSTAINABLE CITIES AND COMMUNITIES	Sustainable cities & communities	11.6, Cascade design and advanced emissions controls limits emissions of fine particulate matter in the village.	Described qualitatively in case study
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Responsible consumption & production	12.2 (also 8.4), Material footprint improved due to use of previous waste product for energy resulting in more efficient use of wood resource.	Described qualitatively in case study

Other Strengths, Weaknesses, Opportunities, Threats

Strengths

- Cascade of small boilers allows for high efficiency and low emissions.
- Cooperation between local entrepreneurs and local wood industry enabled success.

Opportunities

- Use of standard equipment, relatively small scale, and simple supply chain makes the system easily replicable in other communities.

Weaknesses

- Installation cost increases for several small boilers compared to one large boiler.

Threats

- If wood processing facility closes, fibre supply and important heat customer disappear.

Source: IEA Bioenergy 2021a

2.1.2. Limitations in the context of net zero transition

Sustainability standards and frameworks can be used to monitor the sustainability of bioenergy projects as defined by specific standards or to determine their contribution to UN SDGs.

However, these methods do not provide a system-level overview of inter-sectoral impacts and trade-offs on a national basis. This type of framework also does not address the potential competition for biomass use when evaluating the role of biomass in the decarbonization of different economic sectors.

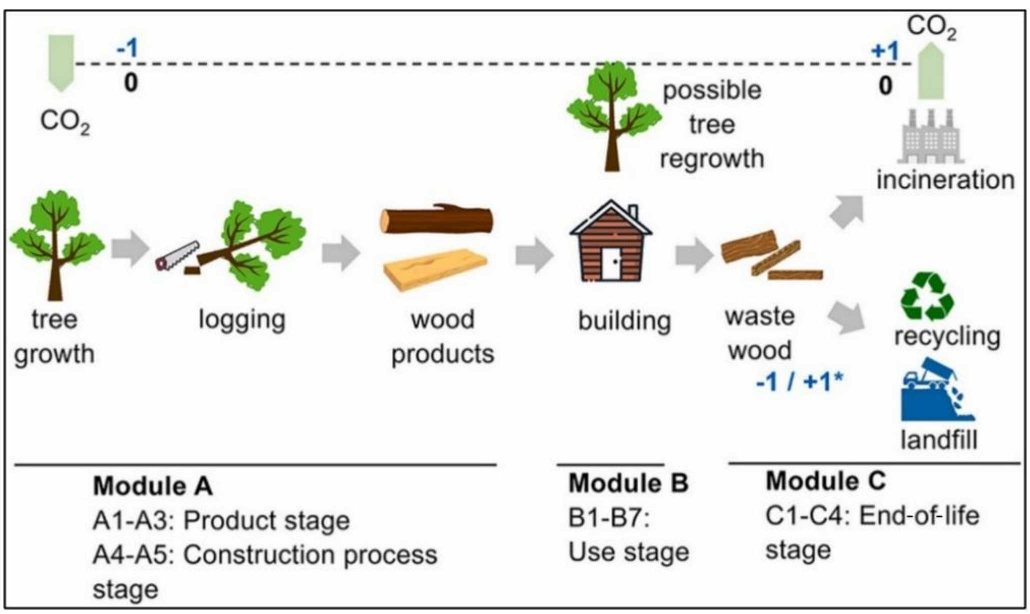
2.2. Climate mitigation benefit assessment

2.2.1. Project scale

To evaluate the benefits of a biomass project on GHG emissions, life-cycle assessment (LCA) is conducted to determine these emissions at all stages of the life cycle of a resulting bioproduct. Bioproducts can be biochemicals, biomaterials or biofuels.

In the case of biomass use for biomaterials such as wood use in buildings, LCA can be conducted for a certain product (e.g., a mass timber floor panel) or for an entire building, depending on the scope and objective of the evaluation (Figure 2-2).

Figure 2-2: Life cycle stages used for a wood building assessment



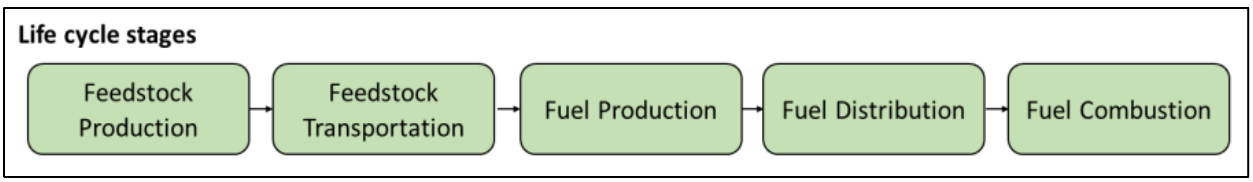
Source: Ouellet-Plamondon et al. 2023

Notes: The numbers indicated in blue represent the different methods used for accounting for biogenic carbon in LCA methods. The 0/0 method does not consider the fixation of biogenic carbon in products or its release in end-of-life stage. The -1/+1 method accounts for the sequestration of carbon in production and its release in end of life, irrespective of the method of disposal.
The -1/+1* method is a variation that assumes that landfills and recycling offer a partly permanent sequestration of biogenic carbon, and therefore accounts for fewer emissions in end of life compared to the -1/+1 method.

In the case of bioenergy projects, the carbon intensity (CI) of the biofuel produced is also determined through LCA methodology. The purpose of CI values is to quantify all emissions released during the life cycle of the fuel produced, from feedstock preparation and transport to combustion (Figure 2-3).

Different models for CI calculations have been developed in Canada and abroad. For example, the Government of Canada uses the Fuel LCA Model to determine the CI of fuels for its GHG policies and programs. By default, LCA models for CI calculations in Canada (e.g., Fuel LCA model) use generic or average values. However, since process-specific data can be used to obtain the CI of a facility-specific product, CI values are specific to each project.

Figure 2-3: Life cycle stages used for biofuels



Source: ECCC 2024a

By determining the life cycle GHG emissions (carbon intensity) of biofuels or biomaterials, it is then possible to estimate the relative GHG savings that would occur in using these bioproducts to substitute higher carbon intensive products and fossil fuels. Relative GHG savings describe the quantity of emissions that could potentially be avoided by using the bioproduct compared to the product currently used.

New announced projects mainly publish the estimated GHG emissions reductions, the CI of produced biofuel or the CI reduction percentage compared to the current fossil fuel used. Table 2-1 shows examples of new bioenergy projects in Canada and the environmental benefits that were published in their announcements or on their websites.

The approved CI of biomass projects under the Clean Fuel Regulations (CFR) were published in 2024 for organizations that agreed to be included in the publication. It should be pointed out that even among the published CI data, a lot of information regarding the name of the installation, the type of boundaries used, the value of the approved CI or the version of the model used was noted as confidential in the publication, thus constituting a barrier for tracking the CI of existing and new projects in Canada (ECCC 2024b).

Table 2-1: Example of environmental benefits published for bioenergy projects

Bioenergy projects in Canada	Environmental benefit as announced
Biomethanol project by Varennes Carbon Recycling (QC) *(project was suspended in 2025)*	Carbon intensity of biofuel not mentioned. Yearly GHG emissions reductions of 170 kt CO_2e with a yearly production of 125 million litres of biofuels.
RNG project from agricultural waste by Nature Energy (QC)	Carbon intensity of biofuel not mentioned. Yearly GHG emissions reductions of 60 kt CO_2e with a yearly production of 20 million cubic meters RNG.
RNG project by G4 Insights (BC) *(produced from wood)*	GHG emissions reductions of 712.8 kt CO_2 over the project's design life. It is assumed to be used in transport as compressed natural gas (CNG). Carbon intensity of produced RNG: 14.3 g CO_2/MJ, which is compared to a carbon intensity of 95.86 gCO_2/MJ of gasoline.

Sources: Énergir Développement Inc. 2025; Enerkem 2025; G4 Insights Inc. 2015

LCA studies have certain guiding principles and common structures, which are described in standards such as ISO 14040. However, depending on the study's goal and scope, the system boundary, assumptions and data used differ among models and studies.

2.2.1.1. Exclusion of biogenic CO_2

In LCA assessments of bioproducts, biogenic CO_2 is included is some studies and excluded in others. LCA models that are used for biofuel CI calculations in Canada do not account for biogenic CO_2 emitted by the combustion of biofuels in order to be consistent with the Government of Canada's policy on biogenic carbon and the guidelines of the national GHG inventories. It is assumed that biogenic CO_2 emissions are balanced by carbon uptake prior to harvest (ECCC 2024a).

The models include only biogenic CO_2 from land management for crop production (changes in soil organic carbon): changes in crop productivity, crop residue carbon inputs, tillage practices, and so on. However, indirect land use change and emissions due to changes in the proportion of perennial and annual crops are excluded (ECCC 2024a).

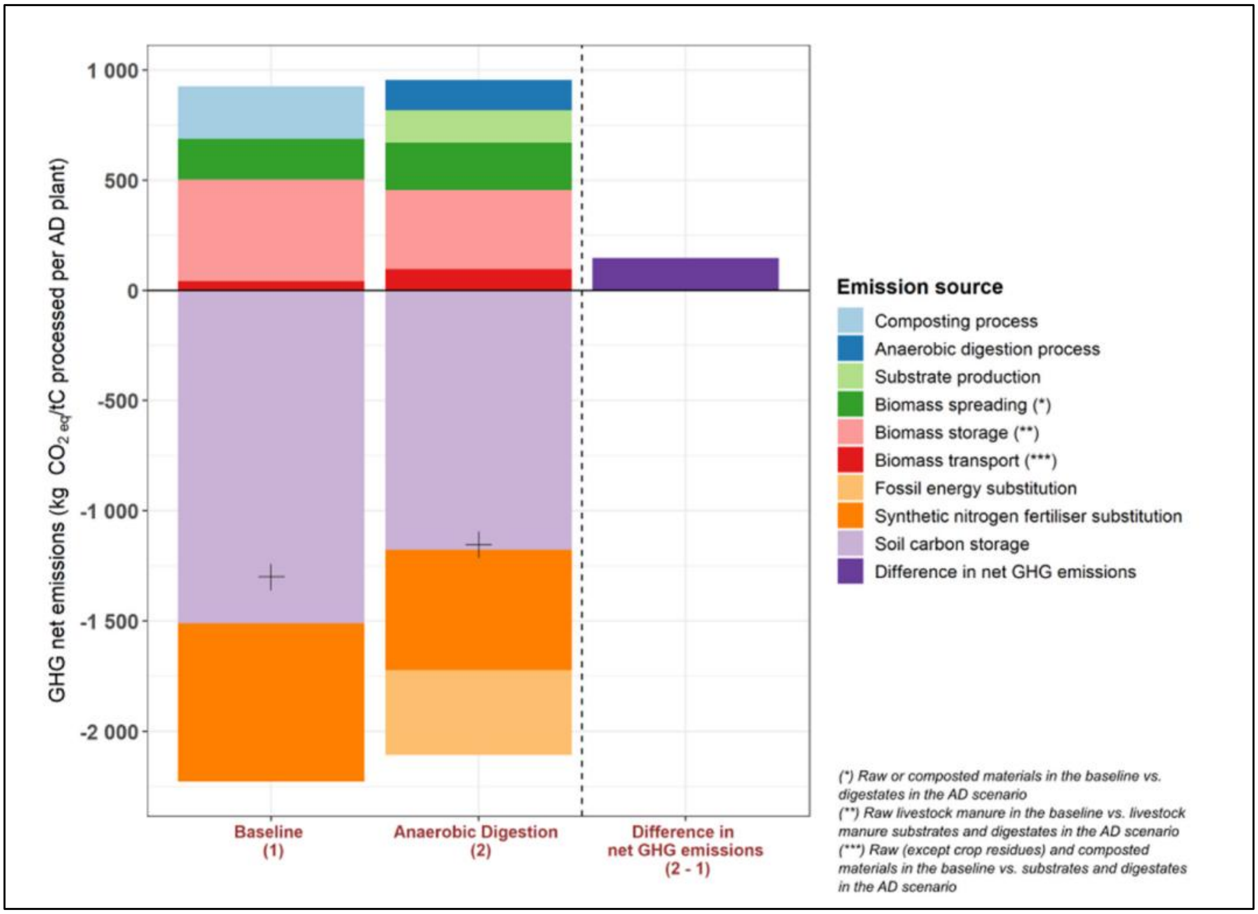
2.2.1.2. Variability among similar projects

In a study published in 2023, researchers applied the same methodology to assess the net GHG emissions from 30 similar facilities of biogas production by anaerobic digestion and used for cogeneration in France. They found significant variability between the results obtained for the different facilities. More specifically, they discovered that only one-third of the projects that were evaluated reduced GHG emissions compared to BAU (Figure 2-4) (Malet et al. 2023).

The impact of similar projects varied due to differences in management of the anaerobic digestion process (e.g., CH_4 emissions avoidance by covering digestates) and differences in BAU cases (e.g., efficiency of carbon storage in soils due to types of biomass used).

This study also shows the impact of the choice of system boundaries in LCA methodologies. For example, if synthetic nitrogen fertiliser substitution was not accounted for by considering it as an indirect impact and out of scope, then its exclusion from the system boundary would impact the final results.

Figure 2-4: Difference between emissions in the baseline and anaerobic digestion scenarios in LCA analysis



Source: Malet et al. 2023

2.2.1.3. Limitations in the context of net zero transition

Calculating net GHG emissions through LCA method is useful to determine the quantity of emissions that can be avoided by using a certain biofuel or bioproduct compared to an alternative product.

Using CI values in GHG reduction programs and policies also favours the production of bioproducts with lower fossil GHG emissions in the supply chain. However, there are limits to the CI values currently used in these programs and additional information is needed to estimate the impact of a new project. For example, CI value shows the emissions from 1 MJ of biofuel produced but does not address the quantity of biomass used to produce the biofuel.

In other words, the CI values are useful to calculate avoided emissions (substitution benefit) but do not account for the full impact on emissions of developing a new project that aims to use biomass resources. To determine whether local resources are used efficiently and to consider the emissions of biogenic CO_2 from biomass combustion, additional analyses are needed beyond CI calculations.

2.2.2. Regional scale

To evaluate the climate change mitigation potential of using biomass for bioenergy on a national or regional scale, many studies conducted for the forest sector used a "system approach" to quantify net emissions relative to a forward-looking baseline and by including biogenic CO_2 emissions.

More specifically, this approach combines the emissions and removals from three system components described below to determine whether biomass use has a climate mitigation benefit over a certain timescale.

(1) Forest ecosystems: includes all emissions and removals in the forest ecosystem (from tree growth, residues decay, slash burning, etc.).

(2) Harvested Wood Products: includes biogenic emissions from combustion or decay from all harvested wood that is sent to markets as wood products, bioenergy or residual biomass.

(3) Displaced emissions: includes avoided GHG emissions from the substitution of fossil fuels by bioenergy. Displaced emissions are obtained by multiplying the used biomass residues by a regional displacement factor.

Box 4: What is a displacement factor?

A displacement factor (DF), also known as a substitution factor (SF), is used to quantify the amount of fossil GHG emissions that would be avoided if a wood-based product is used as a substitute for another functionally equivalent non-wood based product (Leskinen et al. 2018).

$DF = (GHG_{\text{substituted product}} - GHG_{\text{wood product}}) / (WU_{\text{wood product}} - WU_{\text{substituted product}})$

With “GHG” representing emissions resulting from the production and use of the products, and “WU” representing the quantities of wood used in the products.

DF is a unitless ratio. GHG emissions are expressed as mass of C divided by the mass of C contained in the end-use product or the mass of the wood that was harvested to produce the wood product. A DF lower than 1 indicates that the mass of C avoided is lower than the mass of C used, which means, in this case, that using biomass to displace this fossil fuel will release more C than the C avoided.

Calculations of GHG emissions are made according to LCA rules (ISO 14040 and 14044). Some studies consider only one or two life cycle stages (e.g., production, use, end of life) and only fossil GHG emissions are usually considered in the calculations. Most studies do not include biogenic CO_2 exchanges (Leskinen et al. 2018).

Many studies have determined DF for wood products used in housing construction; however, very limited information is available for emerging wood-based products such as biochemicals (Leskinen et al. 2018).

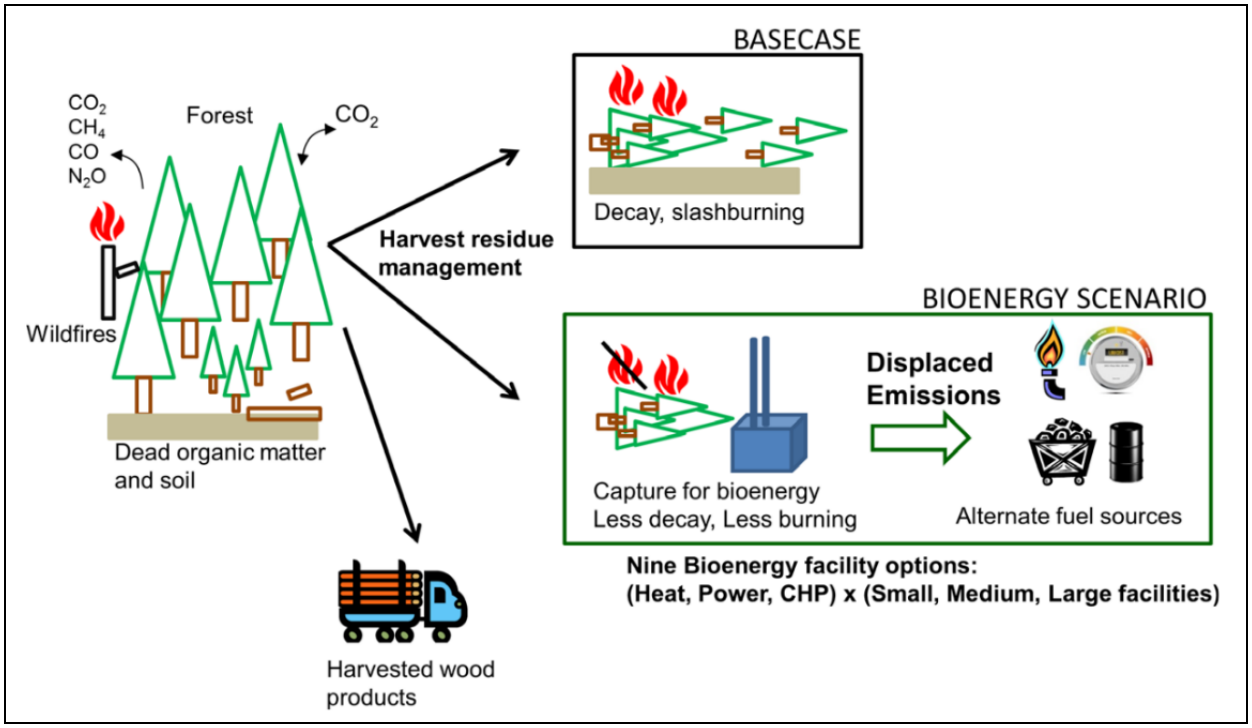
Product-level DF can be used for a market-level analysis to evaluate the amount of fossil emissions that would be avoided when wood-based products are used to substitute other non-wood products for a certain sector or region (substitution impact). Product-level DFs are aggregated by considering the corresponding end-uses of wood and weighing the product-level DF for each appropriate substitution case according to the market-level product consumption volumes (Hurmekoski et al. 2021).

It is worth noting that substitution impacts need to be interpreted against a baseline scenario or a forward-looking baseline. To estimate market-level DFs accurately, it is therefore important to define an appropriate reference scenario (Hurmekoski et al. 2021).

2.2.2.1. Example on a national scale

In a study published in 2017, NRCan researchers used the “system approach” to assess the mitigation potential of using logging residues locally for bioenergy on a nationwide scale over the 2017-2050 period. Results of the net GHG emissions were obtained by combining the three components of the system approach presented above (Figure 2-5) (Smyth, Kurz, et al. 2017).

Figure 2-5: Schematic representation of the systems approach used for analyzing climate change mitigation potential of bioenergy in Canada by diverting logging residues to bioenergy



Source: Smyth, Kurz, et al. 2017

To determine the displacement factor (DF) for bioenergy, researchers used a linear optimization model to calculate the maximum avoided emissions that could be attained based on the bioenergy options included in this study and the fossil fuels that can be substituted. Results of DF depend on the region's fuel mix and the quantity of logging residues locally available. For each FMU, a region-specific DF is obtained (Smyth, Kurz, et al. 2017; Smyth, Rampley, et al. 2017).

Results showed that the DF in Canada varies significantly across regions. This variability in avoided bioenergy emissions is due to differences in the region's BAU fuel mix, energy conversion efficiency, and local energy demand. In regions where bioenergy would exceed local demand and displace low-emission grid electricity, the DF obtained would be negative since no emissions are avoided (Smyth, Rampley, et al. 2017).

In other words, bioenergy displacement factors represent the highest avoided emissions that could be obtained with the types of bioenergy facilities included in this analysis and for the regions evaluated.

Table 2-2: Displacement factors determined for bioenergy at the national level in Canada

Bioenergy facilities used [4]	**Products substituted**	**Scenarios of supply for bioenergy** [3]	**Average DF** [1;2] *(tC avoided/ biogenic tC)*
The model displaced highest emissions-intensity fuels with different scale heat, electricity or CHP facilities	Coal, petcoke, fuel oil, diesel, natural gas, grid electricity	Constant supply of 64 oven-dry kt/year of logging residues across regions	0.47
		Constrained supply of logging residues based on local heat demand from fossil fuels	0.89

Source: Smyth, Rampley, et al. 2017

[1] DF determined by dividing the quantity of C contained in total maximum avoided emissions by the carbon contained in the harvest residues used.
[2] Emissions included from extraction, transportation of raw materials and manufacturing of products. Transportation of finished products was assumed to be equal for wood and substituted product.
[3] 634 FMU in Canada's managed forests were included in the study.
[4] Only local use of bioenergy is considered.

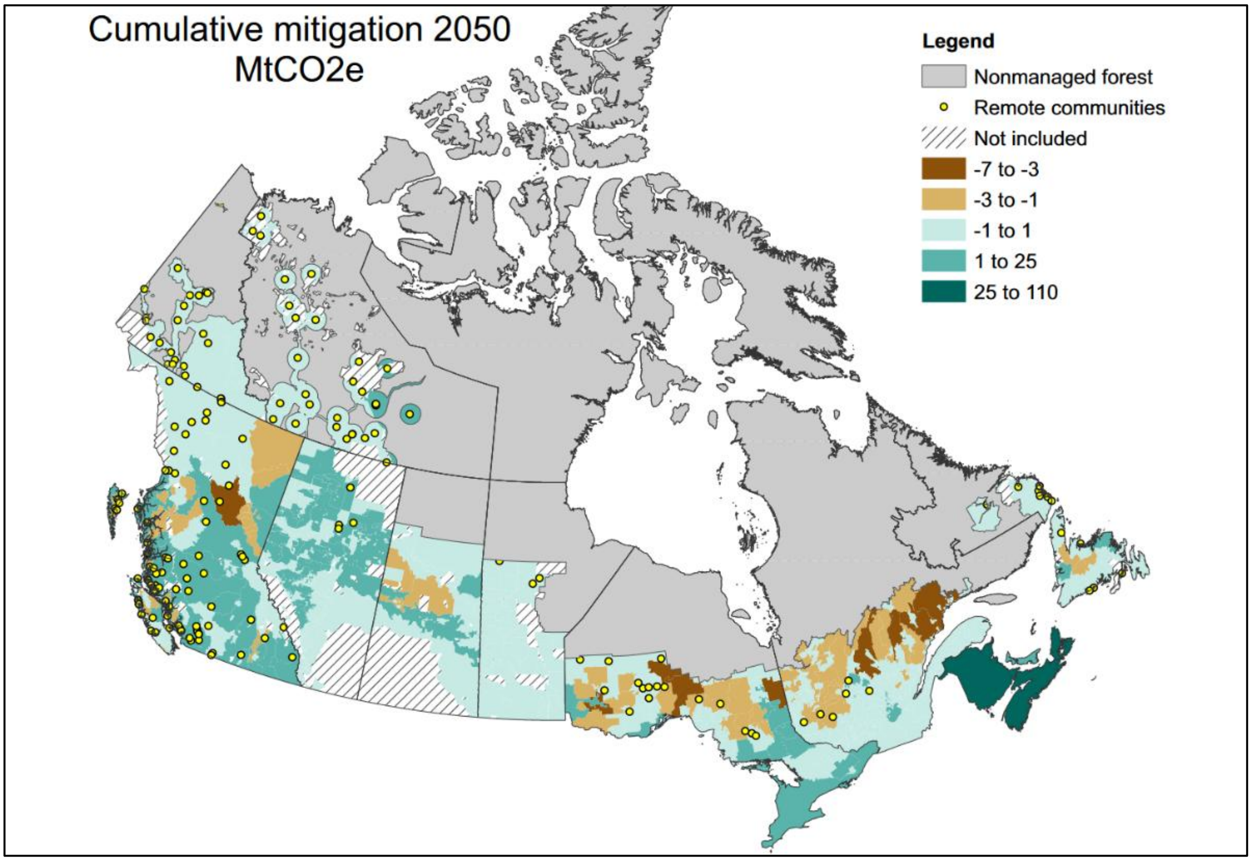
Figure 2-6 shows the total climate change mitigation potential in Canada by 2050 derived from using local logging residues for bioenergy. Results of this study indicated that not all regions showed a positive mitigation potential in 2050.

In some regions, using logging residues for bioenergy increased net GHG emissions from 2017 to 2050. Regions that had positive cumulative mitigation potential (reduced emissions compared to BAU) produced less bioenergy than local energy demand and displaced high-emissions fossil fuels.

Researchers concluded that decision making on the objectives and feasibility of forest-based bioenergy must take local or regional conditions into account.

Obtaining a positive or negative climate mitigation impact from bioenergy production was found to be location dependent across Canada, even when using the same types of biomass that are considered "residues" (Smyth, Kurz, et al. 2017).

Figure 2-6: Average cumulative climate change mitigation potential of using logging residues for bioenergy in Canada from 2017 to 2050



Source: Smyth, Kurz, et al. 2017

Notes: Positive values of cumulative mitigation indicate a net reduction in GHG emissions to the atmosphere. Negative values of cumulative mitigation indicate that the use of logging residues for bioenergy increased GHG emissions to the atmosphere in these regions.

2.2.2.2. Example on a provincial scale

In another study, researchers used the same approach to assess the climate change mitigation potential of the forest sector in the province of Quebec for the 2018-2050 period (Moreau et al. 2023). Although models of the Canadian Forest Service, CBM-CFS3 and CBM-HWP were also used in this study, changes were made to include parameters specific to Quebec.

Researchers found that the intensification of forest management led to an increase in emissions compared to BAU since the avoided emissions were not sufficient to offset the overall increase in emissions in the forest ecosystem due to harvesting and wood products decay.

Different studies found contrasting results on the increase or reduction of emissions due to the intensification of wood harvest. Researchers in this study argue that studies that found contrasting results showing higher mitigation benefit for the intensification strategies, had either higher assumptions for substitution benefits (DF) or different assumptions for CH_4 emissions in end-of-life. Results were very sensitive to the proportion of carbon that may be emitted as CH_4 at the end of life of products (Moreau et al. 2023).

A large share (99%) of wood products in Quebec is disposed in landfills. Of this, 40% of solid wood products are assumed to be not degradable and 60% are assumed to be degradable with a half-life of 11.7 years. Emissions from wood products in landfills are assumed to be 50% CO_2 and 50% CH_4 for all products. Of the CH_4 emissions in Quebec's landfills, 65.94% are assumed to be emitted to the atmosphere, 16.83% flared and 17% used for energy (Moreau et al. 2023). Therefore, 33% of carbon emissions from wood decay in Quebec are released to the atmosphere in CH_4 form and 67% in CO_2 form.

By reducing methane emissions from wood products, the displacement factor required to achieve mitigation benefits can be reduced from a range of 1.2-2.3 to a range of 0-0.9 tC/tC and therefore reach the mean DF threshold used in this study for the province of Quebec, which is 0.9 tC/tC (Moreau et al. 2023).

In current conditions used in this study for Quebec, the average 0.9 tC/tC DF from products substitution is insufficient to offset the remaining emissions that would occur from intensifying wood harvest.

Moreau et al. (2023) showed that strategies that aim to reduce overall forest harvesting levels (e.g., conservation) can provide a higher cumulative mitigation potential by 2050 than strategies with higher harvesting levels, without the need to change the substitution benefits (DF) or current management of CH_4 emissions from landfills.

2.2.2.3. Example on a local scale

The same method can also be used for an evaluation on a local scale. In a study published by USDA forest service in collaboration with NRCan, researchers assessed climate change mitigation options for two landscapes of the United States forest sector for the 2018-2050 period (Dugan et al. 2018). They found that none of their results support the assumption that "using wood for bioenergy is carbon neutral."

More specifically, Dugan et al. (2018) found that allocating more harvested wood for bioenergy does not result in a sufficient substitution benefit over a 32-years period, to compensate for the increase in emissions from the combustion of biomass or the reduction in ecosystem carbon stocks.

As the researchers noted, if the study timeframe were extended to more than 50 years, results would probably be different and could show a mitigation benefit since forests would have time to recover during this longer period. However, this longer timeframe is not compatible with current climate objectives aimed at achieving net-zero emissions by 2050, not to mention that the longer the timeframe, the greater the uncertainties (e.g., climate change impact on forests, reduction in fossil fuels in other sectors) (Dugan et al. 2018).

As mentioned by Dugan et al. 2018, the declaration of carbon neutrality for biomass burning is therefore a policy assumption that does not reflect the actual impacts and timing of bioenergy emissions on the atmosphere.

2.2.2.4. Limitations in the context of net zero transition

As mentioned in the study by Smyth et al. (2017), national-level substitution benefits need to be considered within a systems perspective on climate change mitigation to avoid the development of policies that deliver no net benefits to the atmosphere. Biogenic CO_2 sequestration in forest ecosystems and emissions from decay or from combustion need to be included to evaluate the climate mitigation benefit of biomass use on a local, regional or national level.

Studies that assessed biomass climate mitigation benefit on a regional or national level (described in section 2.2.2), used displacement factors that represent the highest avoided emissions to account for the substitution benefit of the new bioproducts sent to markets. These factors are based on the current energy mix and types of bioenergy facilities considered in the studies (primarily heat, electricity and cogeneration).

In a net zero future, many sectors need to decarbonize their production (e.g., cement, steel, transport), which would in turn impact the resulting “avoided emissions” by using bioproducts. When assessing the use of biomass in a context of transition to net zero, it is crucial to assess quantitatively the climate mitigation benefit of different biomass use scenarios by taking into account the potential decarbonization of other end-use sectors.

New potential technologies for biomass conversion with higher or lower conversion efficiencies and supply chain emissions also need to be assessed since different biomass conversion pathways can have a positive or a negative climate mitigation impact.

2.3. Decision support tools

Frameworks and decision-support tools for biomass were developed by researchers and stakeholders either in the context of evaluating the development of new projects, exploring the potential for decarbonization of economic sectors or for the planning of sustainable use of lands and biomass resources.

Most of the publicly available decision-support tools for biomass, that were identified during this project, can be grouped into two main approaches: End-use/demand focused approaches and Land-use/resource focused approaches.

This section presents examples of decision-support tools and explores the limitations of the existing approaches for biomass use evaluation in a context of transition to net zero.

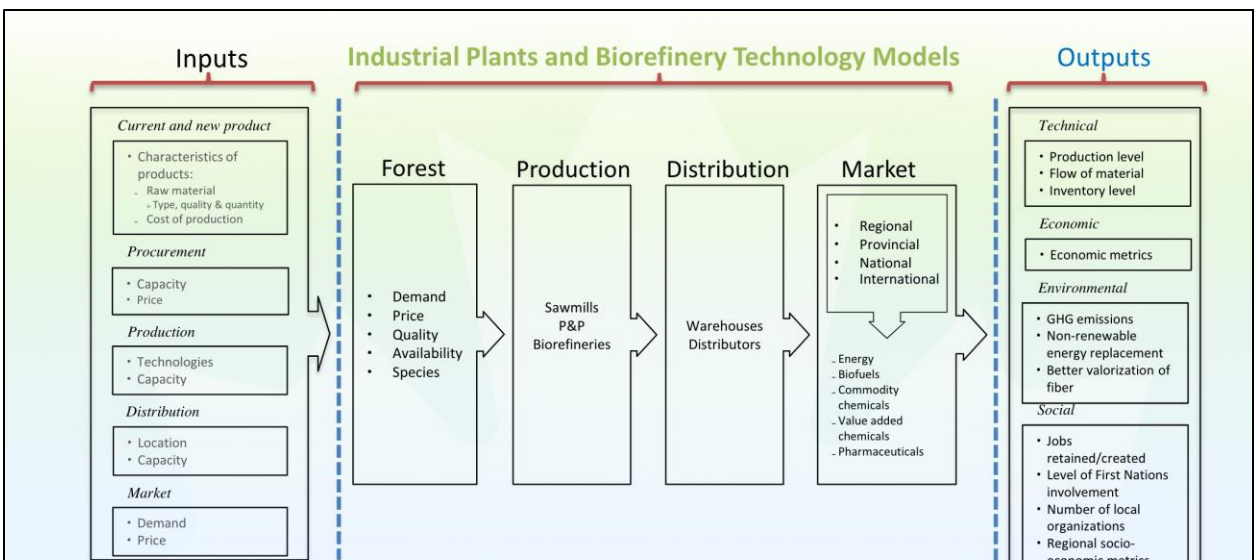
2.3.1. End-use/Demand focused

2.3.1.1. Description

Multi-criteria decision-making tools have been developed for the evaluation of different biomass projects. One example is the I-BIOREF Software Platform developed by CanmetENERGY, Natural Resources Canada (Figure 2-7) to assess the viability of integrating biorefinery to an existing mill or for a standalone biorefinery.

This type of tool includes technical, economic, environmental and social data for specific types of processes to assess the viability of a biorefinery project and help with the project design (Benali and Ajao 2018).

Figure 2-7: Approach used for I-BIOREF Software Platform developed by Natural Resources Canada in 2018

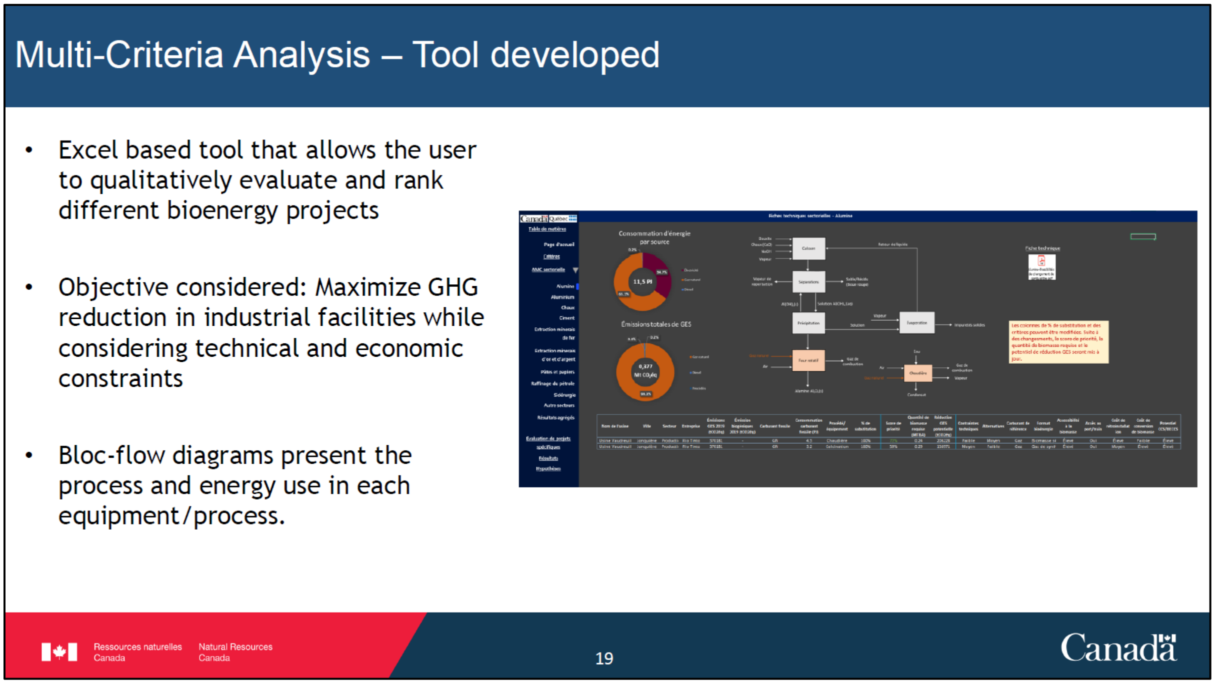


Source: Benali and Ajao 2018

Another example of a decision-making tool is the multi-criteria analysis tool developed also by CanmetENERGY which evaluates and ranks different bioenergy projects in the industrial sector to determine the order of merit of different biomass uses (Figure 2-8).

The main objective of the evaluation tool is to maximize GHG reduction in industrial facilities while considering technical and economic constraints. More details on this multi-criteria tool are included in the presentation available on the IET website [2].

Figure 2-8: Multi-criteria analysis tool for industrial use of biomass



Source: Presentation by CanmetENERGY in Varennes during the midterm forum in 2024

2.3.1.2. Limitations in the context of net zero transition

An end-use/demand focused approach that enables the evaluation of bioenergy projects with the objective of maximizing GHG reductions in a specific sector is useful for making an optimized decision for the corresponding end-use sector. This type of tools is helpful in prioritizing available options for end-use sectors, assuming the availability of a certain quantity of biomass.

However, this type of approach has limitations since it does not evaluate the impact of using these biomass feedstocks for bioenergy compared to alternative uses of biomass (e.g., no harvest or non-energetic use) and it does not account for the impact of using different biomass feedstocks on land use emissions.

[2] The presentation is available on the website of the Institut de l'énergie Trottier through the link, https://iet.polymtl.ca/en/biomass-and-carbon-neutrality/page/midterm-forum.

Therefore, the end-use focused approach needs to be coupled with additional assessments to be able to determine the best use of biomass while taking into account the potential benefits and trade-offs of the considered biomass harvest and use.

2.3.2. Land use/Resource focused

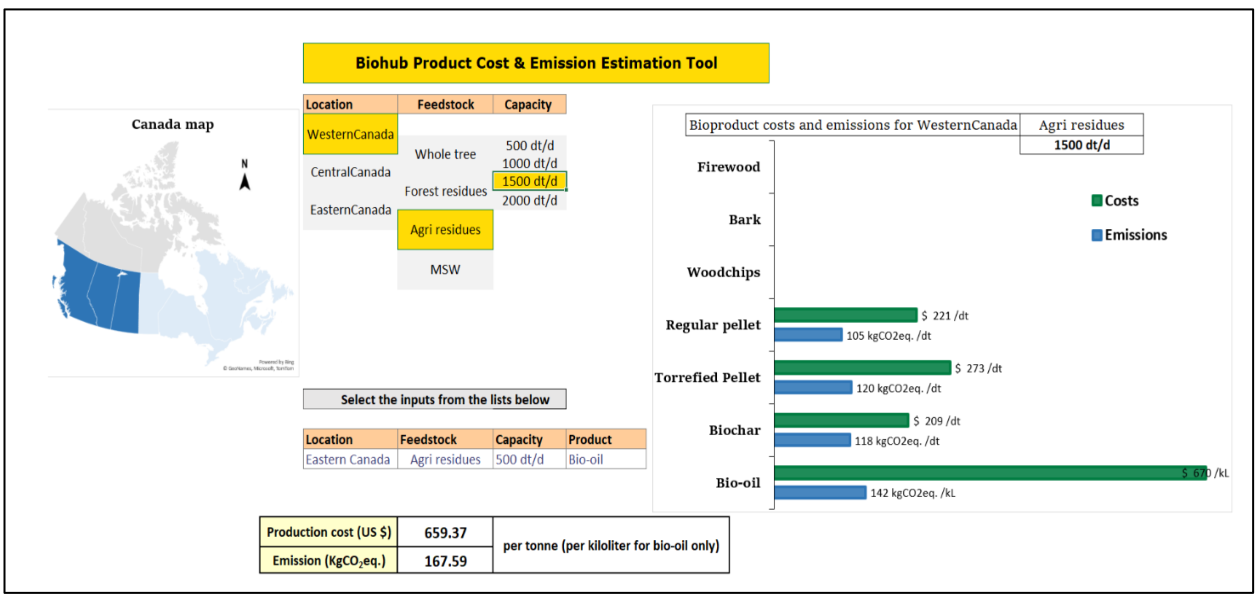
2.3.2.1. Description

The second category of available tools and frameworks for biomass evaluation is land use/resource focused approaches.

For example, frameworks were designed to ensure sustainable forest management in Canada (e.g., ensure sustainable harvest levels, avoid impact on water, soil, and biodiversity, among other indicators). The Canadian Council of Forest Ministers published a criteria and indicators (C&I) framework for reporting on forest management sustainability. This framework includes 6 criteria and 46 indicators, including biological diversity, ecosystem condition and productivity, and role in global ecological cycles to report on sustainability on the national level (Canadian Council of Forest Ministers 2003).

Decision-support tools were also developed for biomass supply chains. For example, a spreadsheet-based techno-economic analysis tool (CANBIO-HUB 2.0) was developed to assist in economic decision-making for bio-hubs development in Canada (IEA Bioenergy Task 43, 2025).

Figure 2-9: CANBIO-HUB 2.0 modelling tool for biohubs in Canada



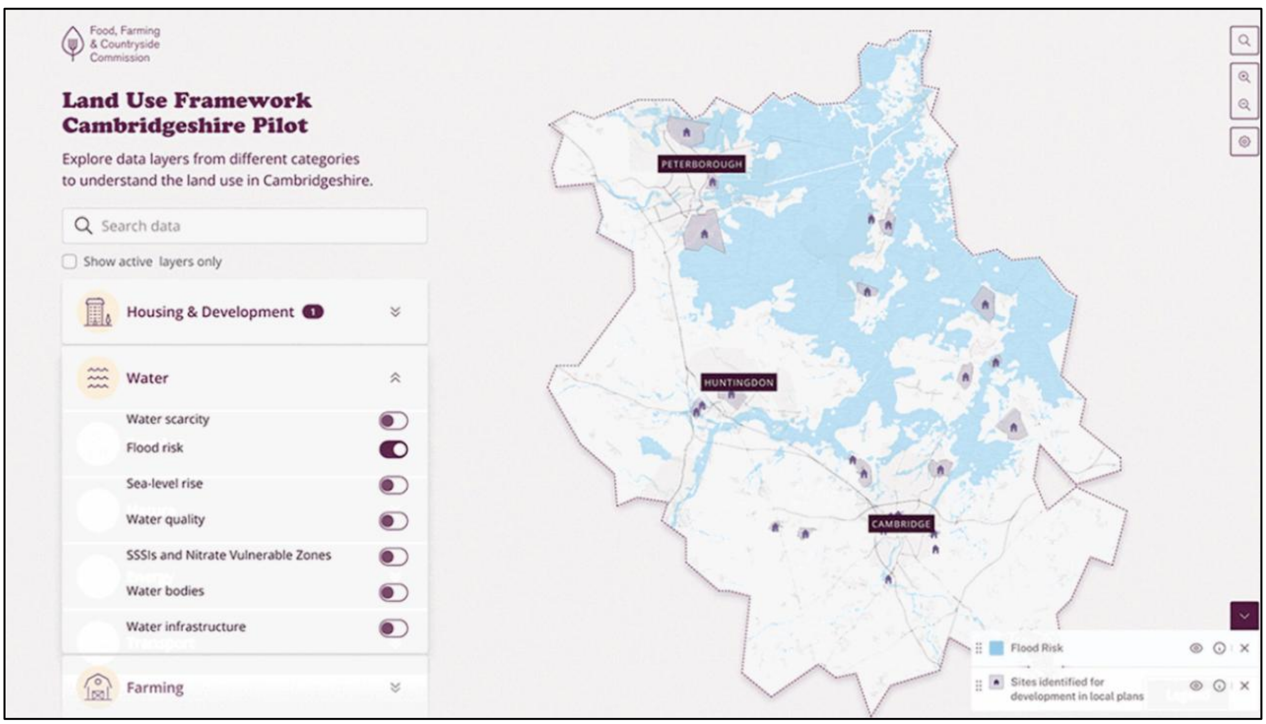
Source: IEA Bioenergy Task 43 2025

Biohubs are intermediate facilities that could be deployed to improve the cost-effectiveness of biomass supply chains by storing, handling and/or sorting feedstocks before reloading. In some cases, biohubs could include processing biomass into intermediates (e.g., pellets, bio-oil). This modelling tool provides product cost and emissions estimates for various bioproducts under certain input conditions for biohubs (location, feedstock and capacity of bioproduct production) (Figure 2-9).

To our knowledge, the framework developed by United Kingdom's Food, Farming and Countryside Commission (FFCC) is the closest existing example of a decision-support tool designed to aid in making better decisions on land use. In this case, decisions are made on how to use land, a finite resource, under increasing pressure (Food, Farming and Countryside Commission 2023).

This FFCC framework, called the Multifunctional Land Use Framework, is being developed through pilot programs in England. Its objective is to help manage complex land-use decisions and meet the different demands for land use, including food, housing, climate and biodiversity goals, the energy security and other (Figure 2-10).

Figure 2-10: The Multifunctional Land Use Framework developed for Cambridgeshire pilot



Source : Food, Farming and Countryside Commission 2023

2.3.2.2. Limitations in the context of net zero transition

Resource or land-use focused approaches, such as frameworks designed to ensure sustainable management of forests, are crucial to ensure the sustainability of current practices and track the impact on various indicators tied to soil, water and biodiversity for instance.

However, this type of framework has limitations in terms of the impact of using biomass feedstocks in the end-use sectors since it does not allow for a comparison with alternative options for decarbonization of these sectors and for the services required by the society (e.g., road transportation, space heating, industrial processes, etc.).

In other words, this approach is useful on the supply side but does not integrate the challenges and opportunities of the demand side in a context of transition to a net zero future.

The Multifunctional Land Use Framework is a good example of an integrative approach for decision-making support tool that connects both strategic and granular thinking with the objective of breaking down silos and supporting more holistic decision making for land use.

Part 2: Putting in place an evaluation framework

After extensive research on current evaluation methods and numerous discussions with stakeholders and experts through five regional workshops, a national forum and multiple other meetings, we see a clear need for a tailored approach to evaluate biomass uses in a context of transition to net zero.

Part 2 thus describes the proposed approach for project evaluation in Canada's transition to net zero and the structure of the new decision support tool.

3. Approach proposed for an evaluation framework

3.1. A tailored approach for biomass

As indicated in the first part of the report, biomass sectors differ from other renewable energy sectors, either in the methods they employ for emissions accounting and reporting or in the way that supply chain industries are structured.

Accordingly, evaluating biomass uses in a net-zero future requires a tailored approach due to three observations described below.

- Resource-focused and end-use focused evaluation approaches

Publicly available decision support tools are focused on forest and land use management or on project developments in various end-use sectors. Both approaches are essential to analyze the impact of harvesting biomass on the ecosystem and the benefit of using biomass in a given end-use sector.

However, no decision-support tool with a systemic view that integrates challenges and opportunities from both the supply and the demand perspective is currently available. Such a tool would enable decision makers to compare different biomass uses and make strategic decisions on how to best use biomass resources in a net-zero context.

- Multi-sectoral impact and interdependency of biomass industries

Biomass harvest and use are dependent on numerous industries that each use a portion of the harvested feedstocks for energy or non-energy purposes. Some industries rely on harvested wood, while others depend on residues or waste from sawmills, pulp and paper or disposed wood products.

Appendix 2 presents an example of these interconnections in the forest industry, showing the detailed flow of biomass from harvest to disposal in Quebec's forest sector.

Moreover, emissions from harvesting and using biomass stem from multiple sectors, ranging from forestry and agriculture to energy and waste. Thus, **the climate mitigation benefit of biomass depends on the decisions made at each step of this value chain, starting with ecosystem management and biomass harvesting, through to conversion processes and disposal** (as presented in detail in Section 2.2.2). Decisions made in silos without a system-level approach to quantifying emissions result in uncertainties about the full impact of the bio-industries on climate change mitigation.

- Project and system-level perspectives

The viability of a biomass project is primarily context dependant: there must be a sufficient quantity of resources over time and a market demand for its product. A project-level evaluation could consider, in addition to the project's viability, its impact on the existing value chain since it can complement or compete with other activities.

However, what a per project evaluation may not (and does not need to) capture are the collateral effects of this resource reallocation, not only on the local economy, but also on the systemic efficiency of the biomass use and its contribution to emissions reduction. Such effects can only be measured through a system-level perspective.

A system-level evaluation would allow for the consideration of a fate other than the proposed bioproduct for the biomass resource and alternative solutions for decarbonizing the end-use for which the bioproduct was intended. **Adopting such a biomass system perspective shifts the focus from fuel decarbonization to end-use decarbonization,** thereby broadening the possible contribution of biomass to the net-zero objective.

3.2. Concept of the proposed framework

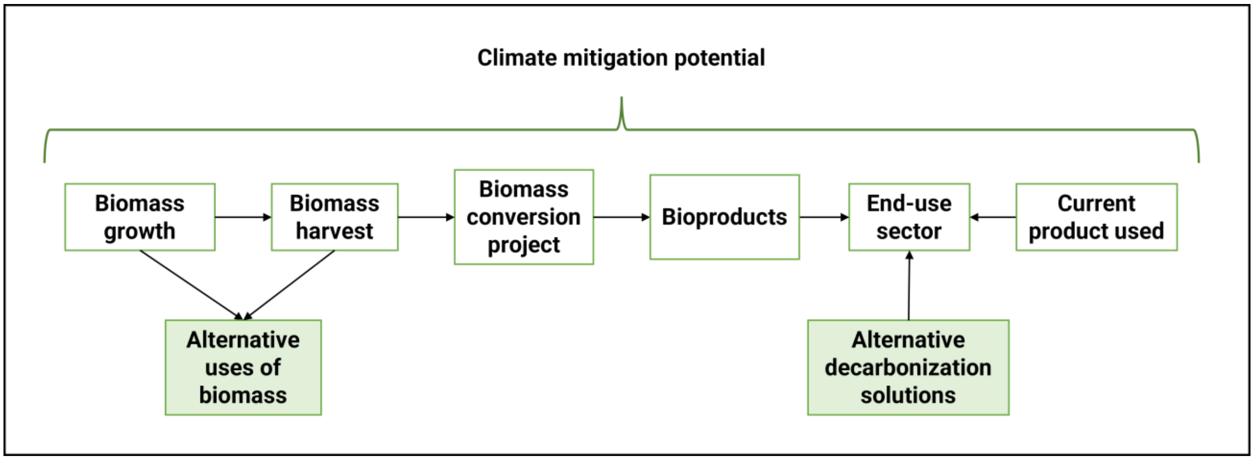
To take into consideration all the above-mentioned observations, the proposed approach for biomass evaluation is a strategic evaluation framework offering a systemic view of the biomass sectors.

In order to evaluate a project aimed at using biomass resources for energy or non-energy purposes in a context of transition to net zero, the following three questions need to be taken into consideration:

1. What are the **alternative uses** for the available resources and the trade-offs for the project?
2. What is the project's contribution to end-use sector decarbonization and how does it compare to **alternative solutions**?
3. What is the project's impact on **climate change mitigation**?

To answer these questions, indicators are needed from both the supply and the demand side in order to make an informed decision on the best way to allocate biomass resources to different projects in a net-zero future.

Figure 3-1: Schematic representation of a general value chain for a biomass project



3.2.1. Identifying and comparing alternatives

On the supply side, alternatives to the proposed project for biomass use need to be identified. These alternatives can be business as usual (e.g., leave residues in forest, dispose in landfills, use for non-energetic purposes, etc.) or involve an alternative conversion project. Viable alternatives should be selected based on the local context since biomass availability and conditions necessary for project development differ from region to region.

For example, some projects require relatively large quantities of biomass to be developed on a commercial scale. A renewable natural gas (RNG) project that aims to convert wood to RNG by gasification and methanation needs around 500,000 oven-dry tonnes (odt) of wood fibre per year (TorchLight Bioresources Inc. 2020), while a combined heat and power (CHP) plant requires relatively smaller amounts (small- and large-scale CHP plants need around 2,000 and 47,000 odt/year respectively) (Smyth, Rampley, et al. 2017).

The list of viable alternative projects in a given region will thus first depend on the availability of biomass for use.

On the end-use/demand side, alternative decarbonization solutions must be identified for the sector under consideration. To evaluate a new bioenergy project in a context of the transition to net zero, the benefits of the bioproduct must be compared not only to the fossil fuel it would displace, but also to the alternative choices that are compatible with a net-zero future.

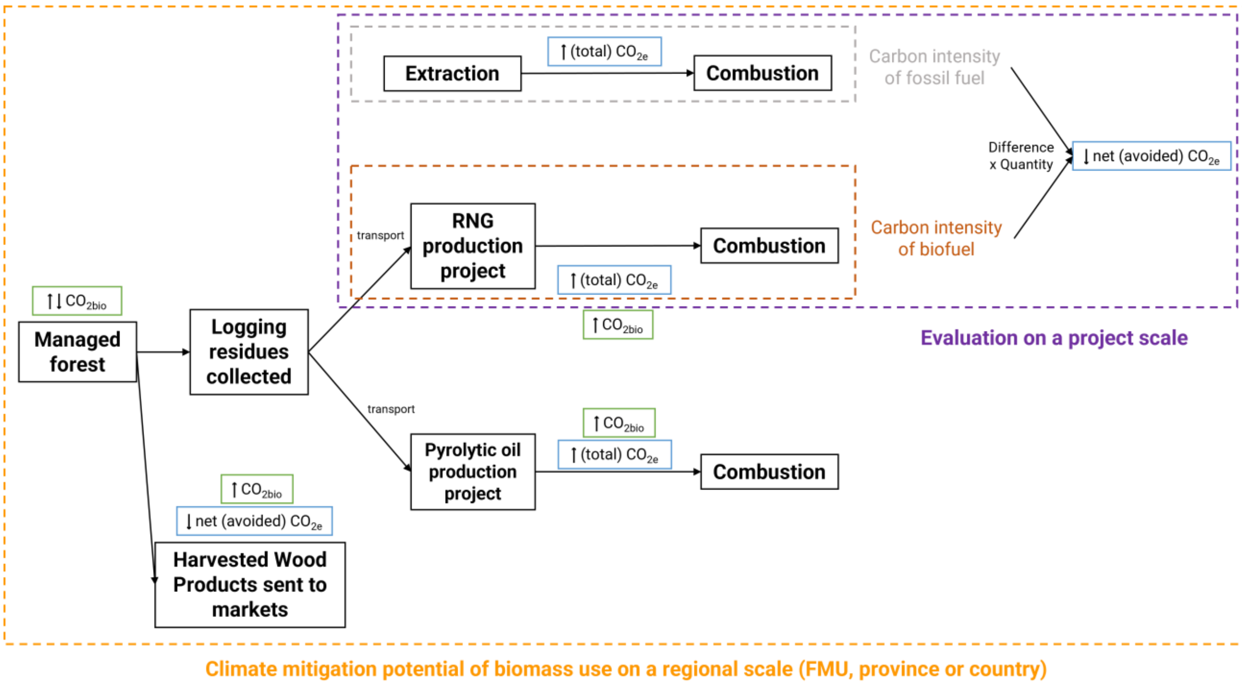
This project conducted a review of existing alternative technologies, either biobased or non-bio, for the different end-use sectors (e.g., transport, residential buildings, industrial heat), which is presented in Appendix 3.

After identifying relevant alternatives for biomass use and end-use sector decarbonization, the impact of these different choices must be compared, based on a variety of environmental, economic and social indicators.

3.2.2. Impact on climate change mitigation

Evaluating the impact of a new biomass conversion project on climate change mitigation cannot be straightforward because of the dynamics of biogenic carbon. The methodology researchers use to evaluate the impact of various biomass uses depends on the scale of the analysis (project vs regional) (Figure 3-2).

Figure 3-2: Example of boundaries considered in project-scale evaluation of climate mitigation potential of biomass use compared to a regional-scale evaluation



Notes: CO_2bio (in green) refers to biogenic CO_2 emissions. CO_2e (in blue) refers to all lifecycle GHG emissions, excluding only biogenic CO_2 emissions (biogenic CH_4 and N_2O are included).

A lifecycle approach is generally used to compare the GHG reduction potential of different biofuel projects (discussed in Section 2.2.1). This approach enables the determination of the carbon intensity (CI) of a bioproduct (brown dashed lines in Figure 3-2), which includes emissions from raw material extraction/collection to product end-use/combustion.

By determining the difference between the CI of a bioproduct and the CI of the substituted fossil-based product, total avoided emissions can be calculated based on the produced quantity of bioproduct in the new project. CI values do not include biogenic CO_2 emissions from biomass combustion or CO_2 removals from biomass growth.

It should be noted that using a carbon neutrality assumption in LCA analyses does not imply that biogenic carbon emissions are not accounted for in national inventories reported to the UNFCCC (see Section 1.4.1 for the detailed methodology used in Canada).

As mentioned in the IPCC guidelines for National GHG Inventories:

> Emissions of CO_2 from biomass fuels are estimated and reported in the AFOLU sector as part of the AFOLU methodology. While emissions from combustion of biofuels are reported as information items in the reporting tables, they are not included in the sectoral or national totals in order to avoid double counting. (IPCC, 2006, section 2.3.3.4).

Therefore, even if the impact of biofuel production and use on biogenic CO_2 emissions is not included in project-scale evaluations, the change in harvest levels and the types of biomass use in the future (e.g., if more forest biomass is used in long-lived products or for bioenergy) will still impact the emissions tracked and reported in the land use sectors.

To quantify the climate mitigation potential of the forest sector on a regional, provincial or national scale (e.g., per year or cumulative until 2050), researchers commonly use a system approach in accounting for emissions in a certain region (Section 2.2.2), which includes all biogenic emissions and removals in addition to the substitution benefit that is determined through LCA methodologies (purple dashed lines in Figure 3-2).

As demonstrated in studies presented in this report, many factors impact the overall carbon balance of biomass use (or net climate mitigation potential), including the types of biomass used and their origin, conversion efficiency of the selected technologies and type of substituted products.

Therefore, for comparison purposes, **various indicators can be used to identify projects that could potentially lead to a better carbon balance**; for example, by having a higher conversion efficiency, by substituting higher carbon intensive fossil fuels, or by storing biogenic carbon in products for a longer period (or permanent storage).

4. The Biomass System Perspective decision support tool

An evidence-based decision support tool was designed and developed during this project to support the evaluation of biomass uses in Canada's transition to net zero, based on the evaluation framework proposed and described in previous sections.

The Biomass System Perspective (BSP) decision support tool was designed by integrating biomass sectors that produce (supply side) or transform biomass feedstocks for energy and non-energy uses (end-use side).

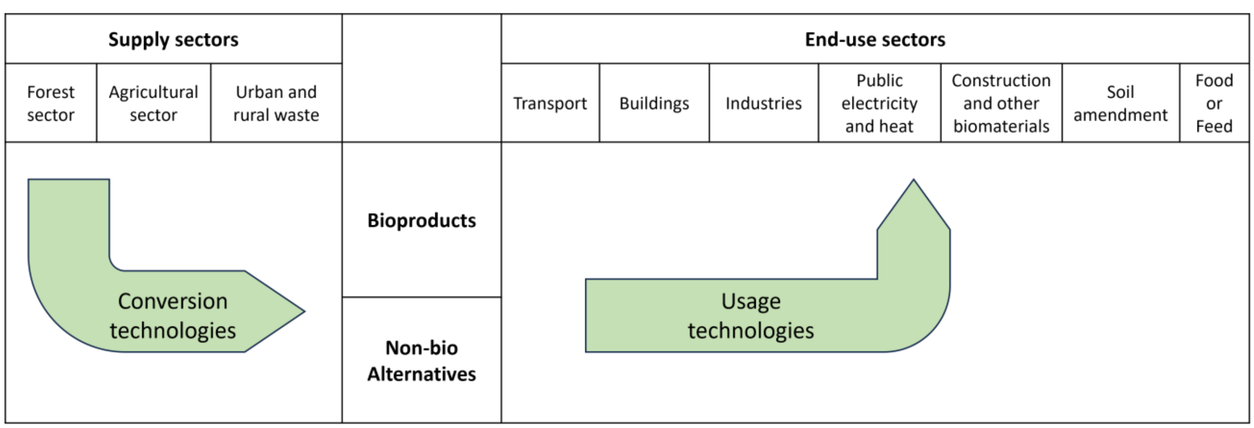
Figure 4-1 presents a schematic representation of the structure of the BSP decision-support tool.

This integrative structure enables the identification of potential competition or opportunities for biomass use, from the harvest of biomass feedstocks to the end-use of bioproducts in different economic sectors.

More specifically, the BSP tool can be used to:

(1) Identify possible uses of various biomass resources,
(2) Identify competing solutions for end-use decarbonization,
(3) Compare the alternative options based on different indicators (e.g., conversion efficiency, carbon intensity).

Figure 4-1: Schematic representation of the Biomass System Perspective decision support tool



During this project, regional workshops and a national forum were organized to bring together stakeholders and experts from academia, governments, Indigenous communities and industrial sectors to discuss elements that need to be considered when evaluating biomass uses. The workshops synthesis report sets out all the elements the participants proposed and discussed during the regional workshops[3]. The list of workshops participants is available in Appendix 4.

After consultations and a literature review, certain indicators were selected for the development of a Biomass System Perspective (BSP) decision support tool, based on their relevance for evaluating biomass uses in a context of transition to net zero and on data availability.

Table 4-1 presents the indicators that were selected for integration in the BSP tool.

[3] The workshops synthesis report is available on the website of the Institut de l'énergie Trottier through the link, https://iet.polymtl.ca/en/biomass-and-carbon-neutrality/results.

Table 4-1: Proposed indicators for integration in the Biomass System Perspective decision support tool

<table>
<tr><th></th><th>Indicators</th><th>Description and reason for selection</th><th>Data availability and how it can be integrated in the BSP tool</th></tr>
<tr><td rowspan="3">Supply sectors</td><td colspan="3">Biomass resources include different types of feedstocks that are collected directly after harvest or as wood processing residues or as waste after product end-use.

If a project aims to use lignocellulosic feedstock for example to produce biofuels, the impact on the ecoystem and emissions depends on which specific feedstock is used. Indicators are thus needed to compare the impact and potential risks of choosing one feedstock over another.</td></tr>
<tr><td>Availability of biomass resources (historical and forecasted quantities)</td><td>Estimations of feedstock availability on a national, provincial or local level in Canada are needed to identify potential alternatives that can be used for a certain project.

Feedstock availability might increase or decrease on the long term, depending on the region, due to climate change, changes in practices or market demand.

Therefore, in addition to historical data, forecasts of potential changes in availability must be considered.</td><td>Quantities of biomass resources can be found in different references in publications by Natural Resources Canada and Statistics Canada or in scientific articles (e.g., for logging residues).

As for the potential changes in biomass availability, data and specifications could be added to the tool based on literature review.

The challenges involved in tracking biomass quantities are mainly due to the diversity of the biomass feedstocks (from forestry, agricuture and waste sectors) and the nomenclature used in references.</td></tr>
<tr><td>Potential impact of biomass harvest</td><td>Harvesting biomass for use in a conversion project can impact positively or negatively, or have no impact on, the ecosystem (e.g., regeneration of replacement biomass).

For example, when considering the collection of logging residues, there is generally a concern that removal of residues from forests could result in the depletion of soil nutrients and soil organic matter and thus impact soil productivity. As for harvesting burnt logs after wildfires, it could potentially lead to more rapid regeneration of the forest stand (Lamers et al. 2013; Thiffault 2024).</td><td>This indicator can be integrated to the tool as a type of impact (e.g, positive, negative or no impact) with a corresponding description of scientific evidence and reference.

Previous studies analyzing risks of harvesting biomass on soil productivity concluded that risks are feedstock specific and vary in terms of scientific certainty (Lamers et al. 2013; Thiffault, Serra, and St Laurent Samuel 2015; Thiffault and St-Laurent Samuel 2012).</td></tr>
</table>

	Carbon parity time by resource type	Carbon parity time is a metric that represents the time required for the biogenic carbon levels of a reference case (if harvesting did not occur) to be reached. The value of carbon parity time (expressed in years) depends on three main factors: type of feedstock used, biomass conversion efficiency, and type of fossil fuel substituted (described in Section 1.3). It can be used here to **compare different types of feedstocks for the same combination of conversion technology and fossil fuel substituted**, to show the impact of using one type of feedstock compared to another.	This metric has been calculated in many studies for different types of forest biomass. NRCan has developed a publicly available Bioenergy GHG calculator [4]. Since the collection and use of a certain biomass feedstock can have an impact on biomass regeneration, researchers are exploring new carbon parity time values by taking into account the impact of collecting these logs on the regeneration of replacement biomass (e.g., faster regeneration leads to lower carbon parity time) (Thiffault 2024).
Technologies	**Technology readiness level**	To identify potential alternatives for biomass use or for end-use decarbonization on the short- or longer term, the technology readiness level (TRL) of available technologies must be known.	Information on the TRL of technologies can be found in different references such as the IEA ETP Clean Energy Technology Guide, and in reports and articles that explore the development status of emerging technologies. As for technologies for which the TRL cannot be found, information on commercial readiness can be added based on the existence of a commercial facility deployed in Canada or abroad.
	Efficiency of biomass conversion technologies	Conversion efficiencies can be used to compare the yield and losses resulting from converting biomass to bioproducts on a per technology basis. A higher conversion efficiency of biomass is important, not only to ensure that limited resources are used in the most efficient way possible, but also because conversion efficiency impacts the overall carbon balance of new biopathways.	Two efficiency indicators are proposed for integration in the tool: **Conversion efficiency**, representing the ratio of the main bioproduct produced to the inputs required in a conversion process. **Overall efficiency**, representing the ratio of all outputs (including co-products) to the inputs required in a conversion process. Conversion efficiencies of biomass conversion technologies can be found in public reports and scientific articles. These indicators can be added to the tool for each conversion technology (e.g., slow pyrolysis, gasification).

[4] The Bioenergy GHG calculator developed by Natural Resources Canada can be accessed through the link, https://apps-scf-cfs.rncan.gc.ca/calc/en/bioenergy-calculator.

	Efficiency of usage technologies	In addition to the efficiency of biomass conversion technologies, efficiency of end-use technologies must be considered to compare the total efficiency of biopathways to other biopathways or to non-bio alternatives in decarbonizing end-use sectors.	Efficiencies of end-use technologies can be found in public reports and scientific articles. This indicator can be added to the tool for each end-use technology (e.g., boiler, heat pump).
	Maximum substitution rate by usage technologies	Bioproducts can be used by blending (partial substitution) or by fully substituting fossil-based products. The maximum possible substitution rate depends on the technology of use, and current standards. For example, Hydroprocessed Esters and Fatty Acids (HEFA) biojet is certified by ASTM for a maximum blending level of 50% with jet fuel. Therefore, even if biomass feedstocks and projects were available to fully substitute jet fuel, certain technical and regulatory limits have to be taken into account.	The substitution rate can be added to the tool for each combination of a bioproduct and usage technologies by taking into account the allowed substitution under regulatory standards in Canada if the technology is already commercialized or based on its specificity if it is still under development. This indicator can be integrated as a percentage of maximum substitution possible for a fossil product by a bioproduct, in a certain usage technology (e.g., substituting diesel by biodiesel in internal combustion engine).
	Carbon intensity	Carbon intensity (CI) metric, expressed as gCO_2/MJ, is commonly used to compare the lifecycle emissions of biofuels (e.g., in government programs and standards). CI values are based on life cycle approach and are therefore facility-specific and differ from one project to another, depending on each project's conditions. As presented in Section 2.2.1, LCA models used to calculate CI include GHG emissions from feedstock production to fuel combustion do not include biogenic CO_2 from biomass combustion (which impact the emissions in land use sectors). Carbon Intensity metric is useful to compare different bioproducts based on the lifecycle GHG emissions and to estimate GHG emissions savings that can be obtained.	Average CI values on a national or provincial level can be added for a combination of a bioproduct and a feedstock (e.g., CI of ethanol from corn in Quebec). It is challenging to track the CI of specific projects due to lack of public information. Average values of CI for certain biofuels in Canada can be found in public publications (Government of British Columbia 2025; Navius Research Inc. 2023). In the case of conversion pathways for which average values for Canada cannot be found, values for an existing facility can be added instead. Note that information on the region considered and the model used needs to be included for each added CI value in the database to be able to compare CI values (different models can use different methodologies and assumptions).

End-use sectors	**Secondary energy consumption in end-use sectors**	The secondary energy demand of each end-use sector needs to be integrated to the tool in order to track the demand, and to be able to estimate the potential of different pathways to contribute to satisfying the end-use demand.	Final energy demand in the end-use sectors in Canada can be added on a national and provincial level. Information on energy demand is publicly available and was previously published in the Canadian Energy Outlook of the Institut de l'énergie Trottier.
	Useful energy conversion factor	The useful energy conversion factor can be used to estimate the useful energy demand in each end-use sector, considering that secondary energy demand (before combustion) is mainly published in inventories for end-use sectors (Statistics Canada 2024).	Useful energy conversion factors can be added for each end-use sector (by province and for Canada as a whole) to estimate the useful energy obtained from conversion of secondary energy use for different services (e.g., transportation, residential).
	GHG emissions in end-use sectors	GHG emissions can be tracked for each end-use sector to compare the demand for end-use decarbonization and estimate the potential of different conversion pathways to contribute to reducing emissions based on the availability of biomass resources.	GHG emissions in end-use sectors can be added on a national and provincial level. Information on GHG emissions is publicly available and is published in the National Inventory Report for Canada.

5. Recommendations

Through the work done in this project, many gaps and barriers were identified, which limit the evaluation and comparison of different biomass uses and the analyses of their potential contribution to decarbonization.

Section 5.1 sets out specific recommendations to address the gaps in evidence that can enhance the integration of quality-data in the Biomass System Perspective decision support tool.

Section 5.2 presents recommendations for actions beyond project analyses that are necessary to ensure that all biomass sectors in Canada contribute to the transition to net zero.

5.1. Evidence gaps

Recommendation 1: Improve data availability for biomass supply

Studies exploring decarbonization solutions or transition pathways for economic sectors in Canada often include biomass feedstocks as potential energy sources to meet demand. The accuracy of projections depends on the data and assumptions used in the analyses. However, information on biomass quantities is often hard to track, for several reasons:

- **Variability and lack of precision in terminology employed for reporting biomass supply:** the term "wood waste" can refer to sawmill residues, logging residues, or low-quality logs without market depending on the reference.

  For example, as defined by Statistics Canada in their annual survey used for data reporting of solid wood waste and spent pulping liquor for energy production in Canada, the category of "wood and wood waste" represent: "Wood and wood energy used as fuel, including round wood (cord wood), lignin, wood scraps from furniture and window frame manufacturing, wood chips, bark, sawdust, shavings, lumber rejects, forest residues, charcoal and pulp waste from the operation of pulp mills, sawmills and plywood mills". (Statistics Canada 2023; Statistics Canada 2024b)

- **Lack of data on "emerging feedstocks":** Sawmill residues, which are the main types of feedstocks currently used for bioenergy, are almost completely used by existing industries. Reports estimating the potential of biomass in decarbonization pathways refer to additional types of emerging feedstocks that can be used for bioenergy, such as logging residues, salvaged wood and wood from thinning operations.

  Available quantities for these types of emerging feedstocks are not explicitly reported by Statistics Canada. Estimations of potential quantities of some biomass types, such as salvaged wood, can be found in scientific studies which are based on wildfire data from previous years (Barrette et al., 2018). However, for upcoming years, it is not possible to estimate with high certainty the potential available quantities for bioenergy production.

Estimations of the available and accessible quantities of each type of feedstock, based on recent evidence, are essential for future analyses to accurately estimate the potential of biomass conversion pathways and reduce uncertainties about biomass potential for end-use sector decarbonization.

Recommendation 2: Impose transparency in carbon intensity reporting

Carbon Intensity (CI) is the main indicator used to compare the impact of existing and emerging biofuels on GHG emissions. This metric is also used in government programs, such as the Clean Fuel Regulations, to set targets, track compliance of biofuel industries, and establish a credit market. But it is currently challenging to track the CI of projects deployed in Canada and compare different projects because of the confidentiality of CI information.

CI value depends on many factors, including the feedstock used, the transport distance, the fossil fuels used, and process specifications. For similar biofuel pathways, CI can therefore vary greatly among projects and could change over time for a given project.

Approved CIs of projects under the Low Carbon Fuel Standard (LCFS) are regularly published in British Columbia. However, the publications do not specify which feedstocks were used to obtain the corresponding CI value.

As mentioned in Section 2.2.1, the CI of projects in Canada that were approved for the CFR are published only for the industries that agreed disclosing the information. Information on the name of the installation, the boundaries used, the value of the approved CI, and the version of the model used was described as confidential in the publication, thus constituting a barrier for tracking the CI of existing and new projects in Canada (ECCC 2024b). This issue was also mentioned by other researchers and stakeholders (Whitmore and Pineau 2025).

A higher transparency in CI reporting under federal and provincial programs is needed to more accurately track the impact of bioenergy and compare different biopathways for biomass use in Canada.

5.2. From analyses to action

In addition to project-specific evaluations, additional measures are needed nationally to establish a common basis ensuring that future project deployments do not result in counterproductive actions.

Recommendation 3: Put in place measures to ensure that the LULUCF sector reaches negative emissions

As presented in this report, biogenic CO_2 emissions resulting from biomass use are tracked and reported in the LULUCF sector. Even when excluding natural disturbances, this sector is a net carbon source through the entire time series of the national inventory (Government of Canada, 2025).

Croplands have historically been a net carbon sink in Canada in almost all years declared in the national inventory. High variability in emissions mainly occurs due to drought, which made 2022 an exception compared to previous years.

Emissions from managed forests have been consistently higher than removals, and there are currently no regulatory targets or incentives driving efforts to reach zero or negative emissions in that sector. Nevertheless, projections published by ECCC show that emissions from the LULUCF sector are expected to reach negative emissions starting in 2023 (Table 5-1).

It is important to note that the 'accounting contributions' from LULUCF that are included to reach Canada's national targets, are not equivalent to the total net emissions in the LULUCF sector (see Box 2).

Table 5-1: Historical and projected LULUCF accounting contribution and net GHG flux

LULUCF sector	Historical GHG flux (Mt CO2e)			Projected GHG flux (Mt CO2e)				
	2021	2022	2023	2023	2025	2030	2035	2040
Net GHG flux	**+14** [a, b, c]	**+51** [a, b, c]	**+4.2** [a]	**-12** [c]	**-4** [b, c]	**-18** [b, c]	**-25** [b, c]	**-23** [b, c]
Accounting contribution	**-29** [b, c]	**+12** [b, c]	NA	**-44** [c]	**-29** [b, c]	**-28** [b, c]	**-31** [b, c]	**-30** [b, c]

Source: Government of Canada 2024b; Government of Canada 2025; ECCC, 2025

Notes: [a] Published in Canada's national inventory report of 2025

[b] Published in Canada's first Biennial Transparency Report on 30 December 2024

[c] Datasets from Canada's current projections published in February 2025 on the website of ECCC

[d] Some values differ by 1 or 2 Mt CO2e from one reference to another. For clarity of information presented in the table, only one value is presented.

With foreseen increasing demand for biomass feedstocks, it is important to set clear objectives for emissions in the LULUCF sector ensuring that emissions from forest biomass harvest and use would evolve in the required direction: that is, a net carbon sink rather than a net carbon source.

A similar recommendation was also shared in an article published in December 2024 in which Professor Évelyne Thiffault proposed that the province of Quebec set an official target to reduce net emissions to zero in the land use sector. The same article also cited Dominique Blain, an expert and long-time contributor to the IPCC Task Force on National

GHG Inventories, who pointed out that land-use emissions do not always receive the attention they deserve (Riopel 2024).

Recommendation 4: Establish a Biomass Strategy compatible with Canada's Net-zero commitment

Canada currently has no strategy for biomass use that sets out a vision for biomass role in reaching net zero emissions in 2050. A national biomass strategy is needed to reduce uncertainties about the future role of biomass, the demand for bioproducts and to ensure coherence of Canada's actions and investments with its climate objectives. This is particularly relevant considering that modeling efforts (Langlois Bertrand 2024) suggest a major role of biomass for negative emissions raising questions as to the relevance of different biopathways.

More specifically, a Biomass Strategy for Canada needs to be established based on:

- Scenarios for biomass use that are compatible with a net zero future; and
- Projections of biomass availability across Canada in a changing climate;

As concluded through the research presented in this report, there is no one-size-fits-all solution for biomass uses. The impact of its use, from an ecological, social and economic standpoint, depends on the local context.

Scenarios for biomass use leading to climate mitigation benefits must be identified for different regions across the country. As indicated in Section 2.2.2, studies determining the climate mitigation potential of biomass in the forest sector on a national level showed that the result is location specific because of differences in current energy fuel mix, energy demand, and biomass availability. In some regions, biomass use resulted in a positive mitigation potential, while in others, it resulted in a negative impact on emissions (biomass use for energy increased the emissions compared to BAU).

To set out a national strategy for Canada, the analyses must be based on the system approach that includes:

- biogenic emissions and carbon removals from the ecosystem,
- biogenic emissions from wood product use and disposal,
- avoided emissions in the end-use sectors (substitution benefit).

An analysis based solely on GHG reduction in the end-use sectors does not represent the full impact of biomass use on emissions.

Although biomass emission and removal mechanisms are complex, sufficient scientific studies and methodologies have been developed in Canada and abroad that can be used to analyze biomass use pathways and their full impact on emissions.

Canada needs a national Biomass Strategy based on regional analyses of different scenarios for biomass use across the economy that are compatible with a net-zero future and that account for projections of biomass availability in a changing climate.

6. Conclusion

Biomass resources can play a strategic role in Canada's energy transition as the country's vast forest and agriculture lands and the diversity of conversion technologies make biomass part of potential decarbonization pathways for several end-use sectors, such as industries, buildings, road transport, marine, rail or aviation.

Even though using biomass as an energy source is not new, since crop-based biofuels or wood-based heat have been a part of the country's energy mix for many years, its role in the transition to net zero still raises many questions and concerns.

The numerous reasons underlying these concerns, include the complexity and variability of accounting and reporting practices, as compared with other types of renewable energy, which result in a lack of coverage of (or confidence in) the full impact of the bio-industries on climate change mitigation.

Moreover, even though potential bio-energy resources are considerable, they currently represent a relatively small fraction of Canada's total energy consumption (Dagher et al., 2024). It is therefore crucial to adequately evaluate bioenergy uses and to prioritize strategic use of biomass resources.

The research and consultations carried out during this project were designed with the aim of advancing the systemic understanding of the biomass sectors to better assess biomass contribution to Canada's climate objectives.

More specifically, the project's activities and publications allowed to:

- Document the current state of biomass use in Canada and identify gaps in knowledge and evidence relating to biomass resources, bioenergy and biomaterials.
- Bring together experts across Canada from industry, academia, governments, environmental organizations and Indigenous communities to discuss the challenges, risks and elements to consider when evaluating biomass uses.
- Explore and analyze the current methods used for tracking, reporting and evaluating biomass uses in national inventories and scientific studies.
- Propose an evaluation framework for biomass to compare and evaluate biomass uses in Canada.

Evaluating biomass uses during the transition to a net zero future requires a tailored approach to account for the specific features of biomass sectors and to consider the impacts, not only on the end-use demand, but also on the biomass supply sectors.

A new bio project can have an impact on the existing value chain as it can complement or compete with other activities. Furthermore, the climate mitigation benefit of biomass use depends on decisions made at each step of the value chain, from ecosystem management and biomass harvesting, to the conversion processes and disposal.

Therefore, adopting a biomass system perspective when evaluating potential new projects shifts the focus from a project-level evaluation to a systemic perspective by considering alternative options, either for resource use and conversion or for end-use decarbonization.

The proposed evaluation framework will enable decision makers to avoid making decisions in silo and to capture the collateral effects of the resource allocation on the systemic efficiency of biomass use, thus broadening the possible contribution of biomass to the net-zero objective.

During this project, a first version of the Biomass System Perspective (BSP) decision-support tool was developed based on the proposed approach for an evaluation framework, to support the evaluations of biomass uses in Canada. This tool is publicly available and can serve as a common basis for evidence-based project evaluations.

Thanks to its integrative structure, the BSP tool enables the identification of potential competition or opportunities for the use of biomass resources and alternative solutions for end-use decarbonization. Alternative options can be compared based on different indicators that are selected and integrated in the tool (e.g., conversion efficiency, carbon intensity).

Indicators that were not covered in the scope of this project, such as economic indicators tied to the cost of resources and the cost of fuel production, can be further integrated to the tool in future work.

This report presents specific recommendations to address gaps in evidence that could enhance the integration of quality-data in the BSP decision-support tool. More specifically, recommendations include the improvement of data availability of biomass supply and a higher transparency in carbon intensity reporting.

Finally, it is crucial to move beyond project analyses and prioritize measures ensuring that potential biopathways do not lead to counterproductive actions in the future.

With the increase in demand for biomass feedstocks from energy or non-energy sectors, there is a need for additional measures to ensure that land use sector emissions in Canada evolve in the required direction. A national biomass strategy is key to establishing a vision for the role of biomass sectors in Canada’s transition to net zero by 2050 and to ensuring coherence between project deployments and Canada’s climate objectives.

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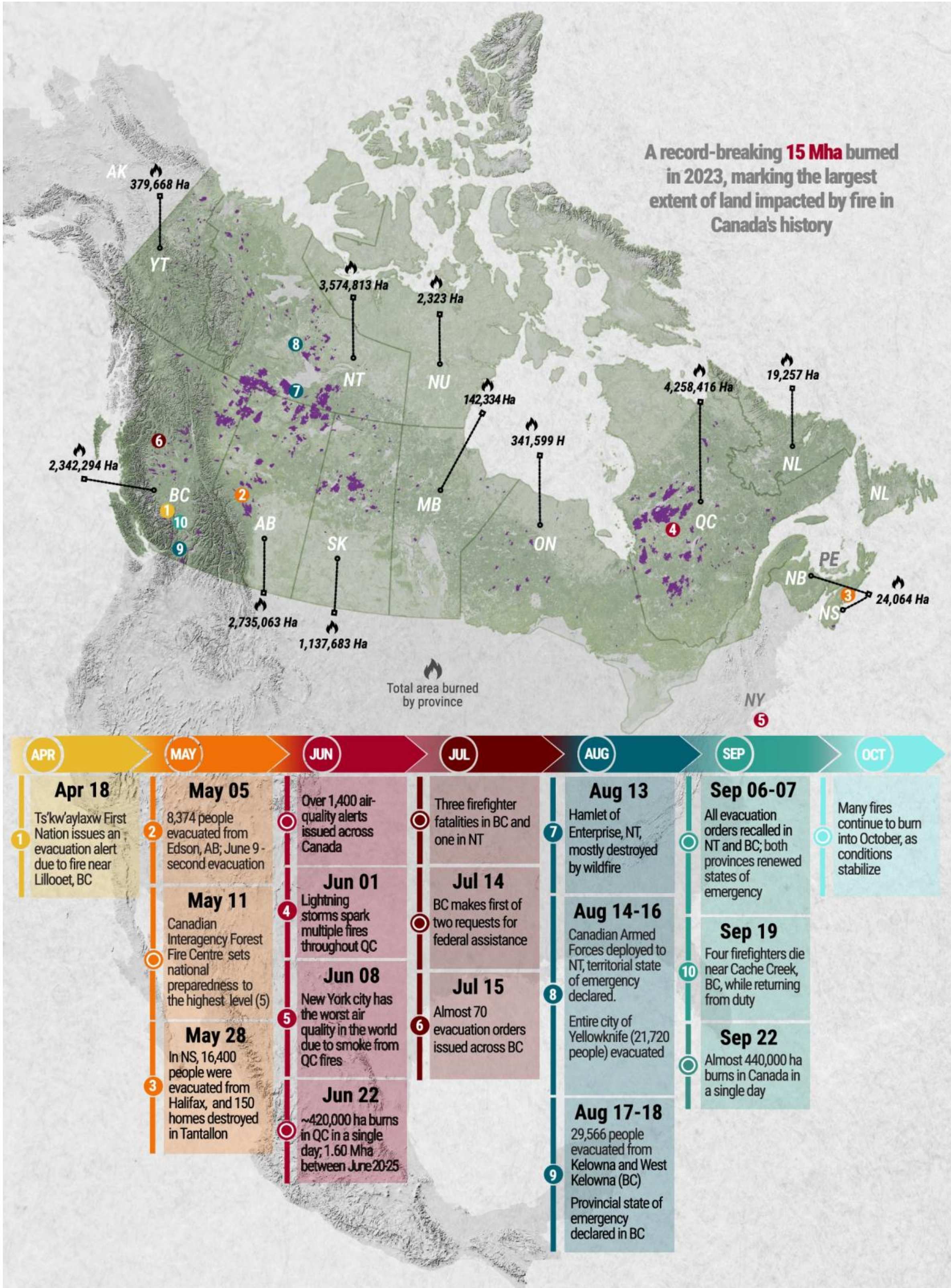
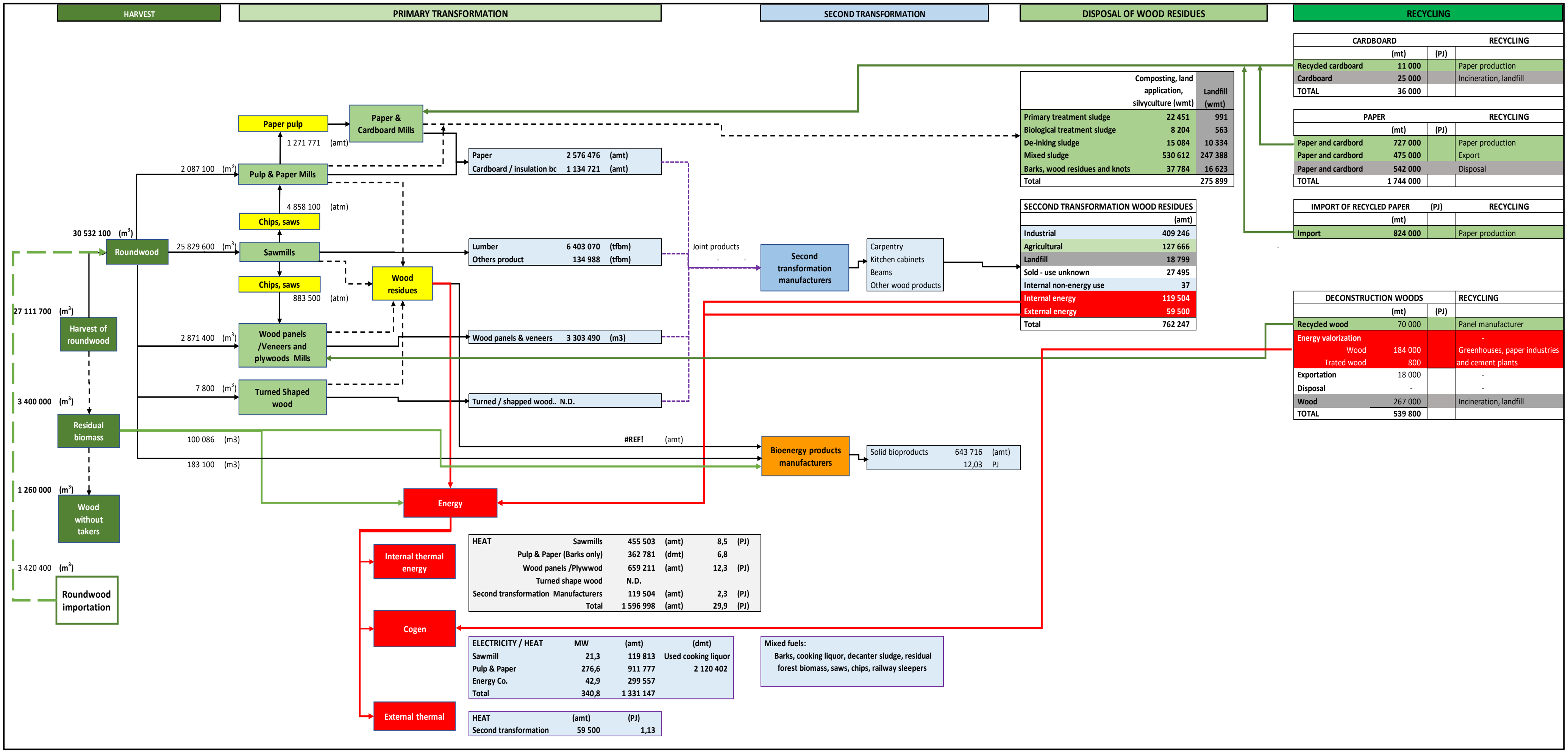
Appendix 1: Overview of the 2023 fire season in Canada



Source: Jain et al. 2024

Appendix 2: Schematic representation of biomass flow between industries, from harvest to disposal in Quebec's forest sector



Source: J. Harvey Consultant et Associés Inc.

Appendix 3: Bioproducts and non-bio technologies presented by end-use sector

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Light-Duty Road Transport	Bioethanol is already used in LDVs in Canada by blending it with gasoline. As of 2021, ethanol consumption amounted to 2,876 million L/yr in Canada. Another possibility for biomass use is integrating biocrude (HTL Oil) or bio-oil (pyrolysis oil) for co-processing fossil fuels in refineries to produce gasoline with lower carbon intensity. Upgrading bio-oil before insertion will be required to partially deoxygenate it. Prior steps depend on the insertion unit in the refinery. Because bio-oil from pyrolysis has a higher oxygen level, it is less suitable and complex for use in co-processing. Ensyn's bio-oil (called biocrude on its website) which is produced by a fast pyrolysis process, is used as a feedstock for co-processing to produce diesel and gasoline.	Electrification (BEVs and PHEVs) of LDVs is already commercial and being deployed in Canada at a higher scale. Federal targets for zero-emission vehicle (ZEV) sales in Canada for all new light-duty vehicles are set to 100% ZEV sales by 2035 and interim targets of at least 20% and 60% for 2026 and 2030 respectively have been established. BEVs are expected to take a significant portion of the market share for the LDV sector in Canada. Fuel cell light-duty passenger vehicles are commercially available today both globally and in limited numbers in Canada. Fuel cells are expected to be of more interest for the medium and heavy-duty transportation sector, which has high power demand and long duty cycles.	Dunsky 2022; Zen and the Art of Clean Energy Solutions 2020; Steeper Energy n.d.; Ensyn n.d.

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Medium- and Heavy-Duty Road Transport	Biofuels made up 3.5% of the diesel pool in Canada in 2021 (biodiesel constituted approximately 1.5% and renewable diesel fuel about 2%). A compressed natural gas (CNG) trucking fleet is already mature; however, RNG use is expected to be limited due to supply and competition from other sectors. Another possible biomass use in this sector is to integrate biocrude (HTL Oil) for co-processing fossil fuels in refineries to produce diesel with lower carbon intensity. Upgrading bio-oil before insertion will be required to partially deoxygenate it. Prior steps depend on the insertion unit in the refinery. Bio-oil from pyrolysis has a higher oxygen level, which makes it less suitable and complex for use in co-processing. Ensyn's bio-oil (called biocrude on its website) which is produced by a fast pyrolysis process is used as a feedstock for co-processing to produce diesel and gasoline.	Electrification is expected to be an alternative for buses, cargo vans and specific classes of medium-duty vehicles. On the longer term, electrification could be an alternative for regional haul and long-haul vehicles in certain use cases only. Heavy-duty trucks require devoted infrastructure or high-energy density battery chemistries to be competitive (such as solid-state batteries, which are still at the prototype level). Catenary technology is a mature technology in streetcars, light rail and trolley buses in North America. Catenary electric trucks have had successful pilot deployments in Europe and in California. Constraints for its deployment in Canada are mainly tied to its implementation (high capital costs of infrastructure and lack of trials in road vehicle applications). Electro-fuels include e-diesel, which can be blended with diesel fuel, and e-gas, which can be blended with CNG. Both are estimated to be commercial on longer term after 2030. FCVs can be an alternative especially for regional and long-haul vehicles after 2040. Challenges for fuel cell trucks include lack of fueling infrastructure, limited availability of vehicles and the price of green hydrogen.	Hongyu 2024; Grinsven et al. 2021; Whitmore 2023; IEA n.d.; Steeper Energy n.d.; Ensyn n.d.

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Off-road transportation	Off-road vehicles use both diesel and gasoline fuels. The alternatives from biomass would include bioethanol, biodiesel and renewable diesel. However, since this category is too diversified, assessment by type of vehicle and technology available is complex.	A wide range of technologies could be available for this sector.	Thornton, Ratcliff, and Kelly 2022; Steeper Energy n.d.; Ensyn n.d.
Aviation	HEFA biojet is currently the major commercially produced SAF (biojet) fuel. Biojet produced from the ATJ process is emerging; the first commercial production facility of LanzaJet opened in Soperton, Georgia in January 2024. The third type of biojet that is near commercialization is based on the Fischer-Tropsch process; the world's largest FT biojet production plant (in Louisiana, US) was announced in April 2024. Another possible biomass use is co-processing lipids and FT-liquids with petroleum jet. This option is approved for a maximum 5% of biobased intermediates. Upgraded biocrude (HTL Oil) and bio-oil (pyrolysis oils) co-processing or use for SAF production is still being pursued but is at lower TRLs and is not yet certified. Many technical challenges will need to be resolved for this pathway.	Electro-fuels (or PtL), the non-bio SAF alternative to biojet, are expected to play a role in this sector after 2030. A demonstration project is underway in Canada with SAF+ consortium (using CO_2 from industrial flue gas). In Europe, it was announced in May 2024 that the Swiss company, Metafuels, is planning, in conjunction with European Energy, to construct an e-SAF facility that will be able to produce 12,000 litres of eSAF daily. Liquid hydrogen and battery electric aircraft require further development of aircraft design and infrastructure. They are estimated to start playing a role in reducing the sector's emissions on the longer term. Since neither are feasible for long-haul flights, their role may be limited to regional and short-haul flights. Air Canada has purchased 30 electric regional aircraft to be delivered in 2028. For hydrogen technology, Airbus will conduct hydrogen demonstration flights by 2026.	World Economic Forum 2020; Allan, Goldman, and Tauvette 2023; IEA Bioenergy Task 39 2024; Brown 2024; US Department of Energy 2024; European Energy 2024; Csonka, Lewis, and Rumizen 2022

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Marine	Biomethanol can be used in ICE engines today (many commercial ships have been retrofitted with methanol engines). Less than 0.2 Mt of renewable methanol is produced globally per year, chiefly as bio-methanol. Before its recent closure, Enerkem produced biomethanol in Alberta by gasifying biomass. Another project that was intended to use Enerkem's technology to produce methanol was under construction until recent announcement of project's interruption (Recycling Carbon Varennes); however, it was also planned to incorporate in the process the addition of H_2 produced by electrolysis, which makes it a combination of biomethanol and e-methanol. Currently, biodiesel can be used up to a 20% blend without modifying a ship's engine. Trials have been carried out only with biodiesel blends up to 30%. From a technological standpoint, renewable diesel (HDRD) and FT-diesel can replace diesel as a blend or drop-in fuel. Compressed natural gas (or RNG, e-gas) can be viable for vessels traveling short distances but not for deep sea shipping. Liquified natural gas (or liquified RNG or e-gas) is estimated to be limited due to lack of refuelling infrastructure. Biomass pyrolysis or HTL is being investigated in pilot-scale demonstrations for use as marine fuels. To our knowledge, there is as yet no commercial use in the marine sector.	While e-diesel (PtL) can replace diesel from a technical standpoint, its production is not yet commercialized. E-methanol or power-to-liquid commercial facilities are in development. A commercial e-methanol production facility is in construction in Kassø, Denmark and another commercial scale e-methanol project (FlagshipONE project) is expected to be commissioned in 2025 in Sweden. Green hydrogen, which is best suited for small or medium-sized vessels, is still immature for use in the shipping sector. Fuel Cell technology is available but hydrogen used in an ICE is less mature with no established practical examples and is currently at testing levels. While ammonia is considered one of the fuels that can be used for shipping decarbonization, both FCs and ICE current technology levels for ammonia fuel applications are still in the development and research stages, with few real-world applications in the shipping industry. Battery electric ships are in early commercial operations but due to the low energy density of batteries, they are limited to short distances and domestic routes.	IRENA 2021; IRENA and Methanol Institute 2021; Vikjær-Andresen 2022; MITSUI & CO 2023; IEA n.d. Accessed on 18 July 2024; Steeper Energy n.d.; Tan et al. 2021; NREL 2021

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Rail	Biodiesel and renewable diesel can be used for blending or substitution of petroleum diesel. Another possible biomass use in this sector is integrating biocrude (HTL Oil) for co-processing fossil fuels in refineries to produce diesel with lower carbon intensity. Upgrading bio-oil before insertion will be required to partially deoxygenate it. Prior steps depend on the insertion unit in the refinery. Bio-oil from pyrolysis has a higher oxygen level, which makes it less suitable and more complex for use in co-processing. Ensyn's bio-oil (called biocrude on its website), which is produced by a fast pyrolysis process is used as a feedstock for co-processing to produce diesel and gasoline.	About 25% of the world's railways are electrified, mainly in Europe. However, for North America, alternative propulsion technologies (battery electric and hydrogen fuel cell) present an alternative solution to traditional (catenary) electrification since they do not require changing the existing railway lines. Evolving battery electric and fuel cell technologies are not expected to be deployed before 2030. They present major economic barriers because of the need for large-scale fleet replacement. Battery electric technologies have more potential than hydrogen fuel cell technologies, which present more challenges and uncertainties. Although trials for the world's first battery-electric freight train were carried out in California, challenges stemming from battery technology, charging infrastructure and availability of low-carbon intensity electricity remain. A National Research Council of Canada and Transport Canada R&D project was launched in 2022 to evaluate the option of using hydrogen for the rail sector, which is known as "Hydrail." E-diesel (also known as PtL or e-fuel) can technically replace petroleum diesel; however, the production technology is not yet commercial.	LaRochelle, McCauley, and May 2022; Mandegari, Ebadian, and Saddler 2023; Steeper Energy n.d.; Ensyn n.d.; National Research Council of Canada 2022

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	Non-bio alternatives	
Residential buildings	RNG can be used for building heat by blending it with natural gas. RNG production from first generation feedstocks is already commercialized and deployed in Canada. However, RNG production from lignocellulosic biomass is emerging and not yet commercialized. Without the commercialization of woody biomass-to-RNG technologies, the availability of RNG supply would limit its role in decarbonizing this sector, especially with the competing demand for RNG in the industrial sector. Hybrid heating systems, which combine the installation of an electric heat pump with a gas furnace, is also an option for this sector. In hybrid systems, heat pumps are mainly used for heating and cooling, but a gas furnace is available to be used during very cold days. In remote communities that are not connected to the gas or electricity distribution infrastructure, other types of fuels, such as biomass in biomass stoves (without conversion, as pellets, briquettes, etc.), can be used to substitute fossil fuels. While pyrolysis oil (bio-oil) has been tested in Europe for residential heating systems (20 kWth to 200 kWth), it still poses challenges since bio-oil properties differ from those of conventional heating oil.	Heat pumps (air or ground source) are the most promising technologies for building decarbonization due to their high efficiency. Electric base-boards and furnaces could be part of net-zero future but are of less interest for deployment than heat pumps, which are more efficient. E-methane (or e-gas) can also be blended with natural gas; however, its production is not yet commercialized. TES Canada has announced that part of the green hydrogen that will be produced in its facility in Quebec will be used to produce e-gas. Hydrogen boilers can be used for building heat if connected to a 100% green hydrogen network. However, this solution presents some safety concerns and challenges for deployment at scale. Hydrogen blending in low percentages with natural gas distribution infrastructure is being tested by natural gas utilities in pilot projects.	The Transition Accelerator n.d. Accessed on 11 June 2024; Canadian Climate Institute 2023; Canadian Climate Institute 2024b; Fortis BC 2024; TESCanada H2 Inc. n.d.; CORDIS-EU 2020

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
C&I buildings	Since commercial and institutional (C&I) buildings have higher heating loads than residential buildings, challenges and speed of decarbonization may differ from those of residential buildings (e.g., due to electricity peak demand). However, from a technological standpoint, alternative solutions for decarbonizing building heat are the same as those described in the Residential Buidlings section.		
Industrial heat, low to medium temperature	Industrial heating needs and challenges vary widely among industries. Technological solutions can be categorized according to their operating temperatures. Bioproducts that can be used for industrial heat include biocoal, biogas, syngas, bio-oil, bio-hydrogen and direct use of biomass.	Many direct electrification technologies are currently available for industrial heat, including heat pumps, electric resistance, induction, electric arcs and plasma torches, infrared heating, lasers and electron beams. However, not all these technologies can be used at scale. The most promising option, commercialized industrial heat pumps, are currently available for industrial process heat at temperatures up to some 150°C or a maximum of 165°C. Heat pump technology for ultra low heat applications (lower than 100°C) is mature and can be used for near-term decarbonization. Industrial heat pumps are particularly well suited for industries that mainly require heat temperatures of less than 200°C, such as the food and beverage, textile and wood products industries for example. On a global scale, the food and beverage and tobacco industrial sectors have the largest electrification share based on heat pumps so far. Heat pump uptake remains less common for industries that rely on both high- and low-temperature processes at the same facility, such as the chemical sector.	IEA BIOENERGY Task 40 2021; Rissman 2022; Deloitte 2023

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	Non-bio alternatives	
Industrial heat, High temperature	High temperatures (above 500°C) are primarily needed in industries like iron and steel, non-metallic minerals like cement and glass, chemicals and nonferrous metals. Bioproducts that can be used for industrial heat include RNG to replace natural gas, biocoal to replace coal and pyrolytic oil to replace heavy fuel oil (e.g., as currently used by Arcelor Mittal in its Port Cartier pellet mill).	Electricity is used only in certain specific applications for high temperature industrial heat (e.g., resistance heaters in the production of carbon fibre). However, for most large-scale processes such as steam crackers and cement kilns, electrification remains challenging and impossible with current technological developments. There are some solutions for higher temperatures that could eventually become broadly applicable, e.g., plasma generation, but they are thus far limited to smaller scales. Other alternatives for high-temperature industrial heat include green hydrogen. While hydrogen can be used for process heat, retrofitting existing gas-based heating systems to work with hydrogen presents many challenges (transport, storage, cost, combustion properties, etc.). Green hydrogen can be used for heat generation in the cement industry although not in all processes. For rotary kilns (operate at 1200°C to 1400°C), physical and chemical differences between hydrogen and natural gas combustion are critical to performance. However, heat generation for pre-calciners (operate at 600°C-700°C) is typically fuel agnostic as long as sufficient temperatures are achieved and green hydrogen can likely be used.	Deloitte, World Wildlife Fund, and Renewable Thermal Collaborative 2023; IEA 2019, 2023a; IEA BIOENERGY Task 40 2021

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<tr><th rowspan="2">End-use sectors</th><th colspan="2">Synthesis of commercial and emerging technologies that can be used in end-use sectors</th><th rowspan="2">References</th></tr>
<tr><th>Bioproducts</th><th>Non-bio alternatives</th></tr>
<tr><td>Iron and steel production</td><td>In conventional coal-based blast furnace (BF) processes, pulverized coal could be partially replaced by biocarbon as an alternate reductant. Biomass can reduce emissions from blast furnaces, but cannot fully replace a standard blast furnace's coal and coke needs.

The direct injection of biomass into blast furnaces is already applied commercially in Brazil, but to smaller scale furnaces. The conversion of biomass to biocarbon is less mature and can be suitable for standard blast furnaces. Another alternative is to fully replace the ironmaking process with a new process based on the direct reduction of iron ore to iron (DRI) without melting it by using a reducing gas. Typically, the reducing gas is a blend of hydrogen and carbon monoxide derived from natural gas. Alternatives for reducing gas include green hydrogen (H-DRI) and gasified biomass (syngas).

For steelmaking, both basic oxygen furnaces (BOF) and electric arc furnaces (EAF) are common today. To replace the fossil carbon sources that are used as carbon inputs in the EAF steelmaking process, biocarbon could potentially be used for the key inputs in EAF (charge carbon and injection carbon). Smelting reduction is also an innovative technology that is still in development.</td><td>Alternatives for the reducing gas include green hydrogen (H-DRI). Many pilot projects around the world are testing DRI-EAF with hydrogen use. This process could be deployed commercially before 2030. Other processes using electricity (electrolyser and electrowinning) are not yet commercialized and are not expected to be deployed before 2040-2050.</td><td>CRIBE 2025; Echterhof 2021; IEA n.d.; Mckinsey & Company 2020; Mission Possible Partnership 2022; Somers 2022</td></tr>
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End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Ammonia production	Ammonia is produced by using hydrogen. In 2022, about 60% of fossil-based hydrogen used globally in industries was used for ammonia production. Low-emission hydrogen is needed to decarbonize the production of ammonia. Using bio-hydrogen would be limited by biomass supply.	Electro-fuels include e-ammonia that can be produced by using green hydrogen from electrolysis. E-ammonia production does not require carbon, which makes it simpler than other e-fuels that need to find available CO_2 sources specially from biogenic sources close to renewable energy sources. Based on announced projects globally, IEA's report shows that the majority of green hydrogen production could be used to produce e-ammonia (followed by e-methanol and FT-Fuels then e-methane). One example of emerging projects is the Hydrogen Energy Metallurgical Demonstration in China, which is expected to produce 390 kt of ammonia using green hydrogen and aims to begin operation in 2025.	IEA 2023b, 2023a; Sheldrick 2023

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
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Petrochemical production	Petrochemicals are a category of organic chemicals mainly obtained by using natural gas liquids (NGL, chiefly ethane, propane and butane) and oil refinery streams such as naphtha and light gas oil. Limited feedstock alternatives are currently available in Canada. Ethylene, the petrochemical produced in largest quantities in the country, is used as an intermediate for various end products (packaging, plastics). Biobased ethylene can be produced using biomass feedstocks through the ethanol production route. Bioethanol can thus be used to produce bio-ethylene. Methanol is also a primary chemical that can be produced by using biomass feedstocks through gasification. Before its recent closure, Enerkem in Alberta was producing biomethanol by gasifying biomass. Methanol is used as a primary chemical for the production of many secondary chemicals and therefore many everyday products. Other than replacing conventional feedstocks with bio-feedstocks for the same process, bio-based feedstocks can also be used to produce new types of biomaterials to replace fossil-based materials and plastics such as biodegradable Polyhydroxyalkanoates (PHA) and Polyhydroxybutyrates (PHB).	Alternatives could include Power-to-X technologies to produce e-methanol or e-gas for use in different processes.	Government of Canada 2024; Mckinsey & Company 2023; Nesterenko et al. 2023; Sheldrick 2023; U.S. Department of Energy 2023

End-use sectors	Synthesis of commercial and emerging technologies that can be used in end-use sectors		References
	Bioproducts	**Non-bio alternatives**	
Electricity and Cogeneration	Wood chips, agricultural residues, pellets or biocoal by combustion can be used to generate electricity generation from biomass. Biogas produced from anaerobic digestion or syngas from biomass gasification can also be used for power generation. Conversion of biomass to electricity has low efficiencies; higher efficiencies are obtained by Combined Heat and Power (CHP) systems. The role of bioelectricity is marginal in Canada where most bioenergy is used for thermal energy purposes. The Atikokan Generating station in Ontario for example was converted from coal to 100% wood pellets in 2014. Biomass systems can play a role in remote community decarbonization to replace diesel-based electricity and heat buildings. For example, since 2017, Kwadacha FN has been operating Canada's first off-grid, utility standard, biomass gasification, combined heat and power (CHP) system using wood chips. Biogas produced by anaerobic digestion is also used in electricity generation in Canada (around 49% of all biogas produced in 2022). Some 50 biogas projects nationwide provided 196 MW of electricity generation capacity in 2022. However, interest is shifting to using biogas for RNG production.	The alternatives to bioelectricity are other renewable sources for power generation (including hydro, solar, wind) and nuclear, depending on the location and context.	Airex Energy 2016; IEA Bioenergy 2021b; Indrawan et al. 2020; OPG n.d.; Wolinetz 2022

Appendix 4: List of stakeholders and experts that participated to the workshops and/or provided comments on the white paper.

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

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

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