Forest Sector in Quebec

CIRCULARITY ASSESSMENT AND MARKET OPPORTUNITIES

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EXPERT EN LA MATIÈRE

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INFORMATION SHEET

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TABLE OF CONTENTS

APPENDICES

TABLES

FIGURES

INTRODUCTION

The Canadian Forest Service, part of Natural Resources Canada (NRCan) (hereafter "CFS"), is the national and international voice for Canada's forest sector. The CFS collaborates closely with Canada's provinces and territories to ensure the sustainability and health of forests. In the wake of a gradual transition to the circular economy globally, CFS is actively engaged in advancing the bioeconomy and the circular economy across Canada. In particular, the CFS supports the transition of the forest sector to higher value-added products and more efficient technologies, while moving the country toward greener practices. However, the lack of data on material flows across all sectors of the economy, including the forest sector, as well as on current initiatives makes it difficult to target the actions and measures needed for effective deployment of circular economy strategies in Canada.

The aim of this report is to take advantage of material flow data from Quebec forest sector to improve the assessment of its circularity. This will lead to the development of policies or initiatives such as the creation of biomass transfer and processing centres, or *biohubs*, across the country.

To this end, the assistance of the Centre de transfert technologique en écologie industrielle (CTTÉI), a technology transfer centre based in Quebec, was sought. With its expertise in industrial ecology and circular economy, the CTTÉI has a good knowledge of the flows and market opportunities of industrial by-products. In addition, it drives Synergie Québec, a community of practice that brings together more than twenty industrial and territorial symbiosis projects throughout Quebec. Supported by a variety of regional stakeholders, these projects promote the creation of synergies, particularly in the forest sector. Their feedback will help identify what hinders or drives the development of forest sector residues and emerging market opportunities.

1. OBJECTIVES AND MANDATE

The specific objectives of this evaluation were to:

1. Provide the rates of use of raw materials and industrial residues from Quebec forest sector (using data from the Ministère des Forêts, de la Faune et des Parcs);
2. Study the production and valorization rates of main forest products and by-products;
3. Evaluate the extent to which forest industries and products are represented in the regional industrial symbioses supported by the CTTÉI;
4. Identify the types of material flows most frequently supplied and used by forest industries in regional industrial symbioses;
5. Provide innovative and emerging case studies involving forest industries or products;
6. Identify barriers to establishing material flow exchanges where there is no market for forest sector residues or proposed forest products.

The purpose of achieving these objectives was to evaluate the level of circularity of the forest sector in Quebec. A system, in this case the forest sector of Quebec qualifies as circular if it meets the principles of the circular economy. In Quebec, the definition of the circular economy generally used is that of the Pôle de concertation québécois sur l'économie circulaire (Quebec centre for consultation on the circular economy):

> The circular economy is "a system of production, exchange and consumption aimed at optimizing the use of resources at all stages of the life cycle of a good or service, in a circular logic, while reducing the environmental footprint and contributing to the well-being of individuals and communities." [1]

As this definition illustrates, the circular economy (circularity) encompasses a multitude of elements and implementation strategies that make its evaluation very demanding. Consequently, the evaluation of circularity discussed in this study is in fact only a semi-quantitative assessment of the use of Quebec forestry resources and should therefore not be interpreted as a robust determination of a multi-criterion circularity index.

2. METHODOLOGY

The following tasks were completed to meet the objectives of the mandate.

TASK 1 MATERIAL FLOW ANALYSIS (MFA)

Most of the relevant data from databases and public reports were collected and used to calculate the rates of use of forest sector raw materials and industrial residues (e.g., harvest residues, roundwood, sawmill residues), as well as to provide valorization rates for the main forest products generated and used in Quebec (e.g., paper, paperboard, composite panels, structural panels, lumber).

This study focused specifically on five types of products:

1. Logging residues left in the forest;
2. Raw materials for processing;
3. Main products for processing;
4. Processing by-products;

5. Post-consumer residues.

To some extent, this study also covered forest products shipped outside Quebec as well as imported products.

TASK 2 ANALYSIS OF SYNERGIE QUÉBEC DATA

Synergie Québec (SQ), a network facilitated by the CTTÉI, brings together some twenty industrial and territorial symbiosis projects throughout Quebec. Each of them has partial data[1] on the industrial metabolism of companies in their territory, particularly in the forest sector.

Eight of the member territories of the Synergie Québec network shared their data on companies in the NAICS sectors identified with the client: 113 (Forestry and logging), 321 (Wood product manufacturing) and 322 (Paper manufacturing). This information was used to develop a summary report on forest product issues. Synergie Québec's experience has also made it possible to identify barriers and levers for achieving synergies involving forest sector products. The goal is to gain a better understanding of the reasons that limit and promote the reclamation of residues.

TASK 3 CIRCULAR ECONOMY CASE STUDIES

Based on technical monitoring data, fact sheets highlight opportunities for less commonly developed and innovative wood products in North America. The circular economy strategies examined here focus on process optimization (clean technologies), recycling, composting, material reclamation, and energy reclamation.

In addition, the synergies created through Synergie Québec facilitators are presented in a fact sheet. They demonstrate, with the measured benefits, the diversity of business opportunities that the circular economy represents for Quebec companies.

3. Material Flow Analysis

This section describes the methodology used to perform the MFA and presents the results obtained.

3.1. MFA METHODOLOGY

MFA is "a systematic assessment of the flows and stocks of materials within a system defined in space and time." [2] It essentially consists of carrying out a mass balance of the inputs, outputs, and stocks of a system and its subsystems.

The first step in conducting an MFA is to define the system and its components according to the objective, which in this case is to assess the circularity of the forest sector in Quebec with respect to its main products and materials. Once the system is well defined, relevant information sources (e.g., national databases) are identified and consulted. The material flow data is then extracted and compiled. Then, a balance sheet of the flows is made and analyzed.

Several sources of information were consulted to put together the MFA methodology [2–8].

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[1] The survey coverage of the companies in the territory is partial, i.e., not all the companies were contacted, and the answers received are partial in the sense that only part of the information requested was provided by the companies.

3.1.1. MFA Model Design

The **TABLE 1** following is a description of the main elements considered for the design of the MFA model.

TABLE 1 MFA Model Design

Elements of the MFA model	Description
Material flow system	The system under study includes all processes from the logging/harvesting of raw material (forest biomass) to the valorization of post-consumer products. A simplified diagram is shown at **FIGURE 1**.
System boundaries	The MFA was confined to Quebec's provincial borders. Flows from outside the system were counted as imports, while flows leaving the system boundaries were counted as exports.
Units	The results were reported in dry metric tons (DMT). The conversion factors used are shown in **Appendix I**.
Stages	The stages are the grouping of several processes [3]. The stages included in this analysis are presented in **Appendix II**.
Processes	Processes consist of the transformation, transport, and storage of goods [3]. The processes included in this analysis are presented in **Appendix II**.
Goods or materials	Goods include products, materials, consumer goods, and infrastructure that contain the various substances under study. Goods or materials may consist of one or more substances. The available statistics and data normally refer to goods. [3] The goods included in this analysis are presented in **Appendix II**.
Material flow	Flows are the transfers of goods or substances between stages and processes or between the system and outside it [3]. The stages included in this analysis are presented in **Appendix II**.
Substances	Substances are defined as chemical elements with homogeneous characteristics and properties [3]. For this study, substances were excluded from the analysis as this level of detail was not necessary.
Data types and sources	See **TABLE 2**.
Data quality requirements	To ensure sufficient data quality, the data were mainly obtained from official documents and government and para-governmental databases.
Time-related representativeness	Data is primarily from 2019. No interpretation of previous years' trends and no extrapolation of results was made.
Overall representativeness	On a mass basis, all flows greater than 0.1 M DMT were accounted for. This level of representativeness was deemed acceptable for the purposes of this mandate. In some cases, flows of less than 0.1 M DMT were recorded when the information was readily available and when deemed relevant.
Assumptions and limitations	The study's assumptions and limitations are listed in **TABLE 3**.
Data consolidation	Some MFAs will balance inputs, inventory changes, and outputs based on the principle of conservation of mass. In this study, emphasis was placed on the use and presentation of data as collected from the sources consulted. In doing so, data was consolidated only in cases where figures were missing or inconsistent.
Uncertainty	The calculation of uncertainty was not considered in this study.

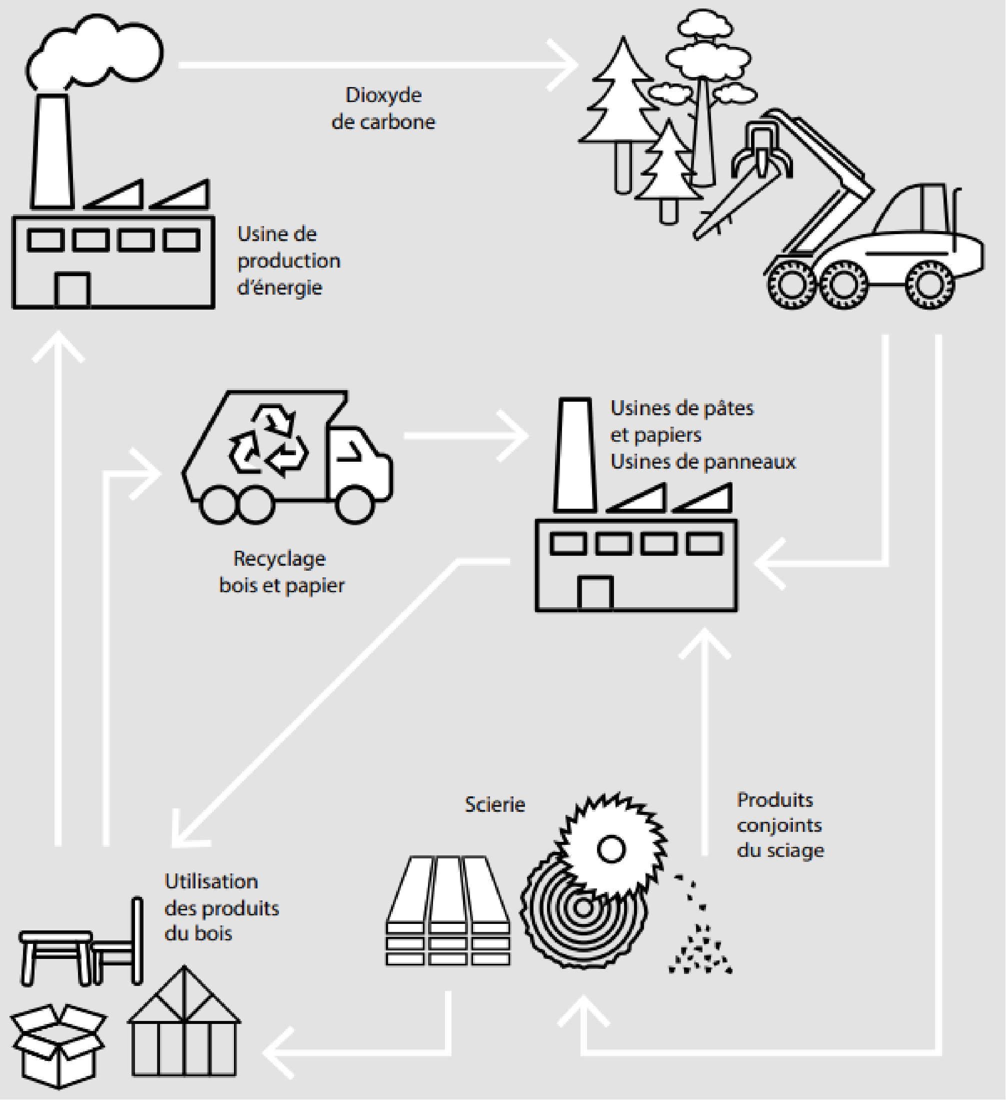


FIGURE 1 Carbon Life Cycle — Forest Sector Diagram (from [9])

3.1.2. Sources of information

TABLE 2 lists the sources of information consulted for the collection of data for the forest products included in the material flow system. The "Portrait statistique 2019 des Ressources et industries forestières du Québec" (the MFFP's 2019 statistical portrait of Quebec forestry resources and industries) served as the main reference, and other sources of information were used to fill in missing information.

TABLE 2 List of information sources consulted

Sources	Information
MFFP • Portrait statistique 2019 [10] • Chiffres clés du Québec forestier 2020 [11] • Inventaire mensuel de copeaux SEPM au Québec [12]	Raw materials, primary and secondary processing, imports/exports, consumption, post-consumption

Sources	Information
- Production et utilisation des sous-produits générés par les entreprises de deuxième transformation du bois du Québec en 2015 [13] - Industrie des panneaux composites à base de bois [14] - Vers la valorisation de la biomasse forestière : un plan d'action (2009) [15]	
National Forestry Database - Wood supply [16–17]	Volume harvested
Natural Resources Canada - Canadian Forest Service (Statistical data) [18]	Volume, imports/exports, primary processing
Statistics Canada - Commodity flows (Tables 980-0044, 980-0047, 980-0048) [19]	Imports/Exports
Chief Forester of Quebec - Compilation des données issues des registres forestiers 2019 [20]	Allowable cut
RECYC-QUÉBEC - Bilan GMR 2018 [21]	Post-consumption, disposal
Fédération des producteurs forestiers du Québec - Report: "La forêt privée chiffrée — 2021 edition" [22]	Firewood
Hydro-Québec - A renewable energy option: Biomass power [23]	Logging residues
The Synergie Québec community - Data provided by symbiosis facilitators - Quebec company directory (icriq.com)	Industrial symbiosis data, case studies, barriers and challenges, company data

3.1.3. Assumptions and limitations

TABLE 3 lists the assumptions made and the limitations associated with this MFA.

TABLE 3 List of assumptions and limitations

Elements	Explanations
Inventories	The MFA is based on the principle of mass conservation and must take into account the inventory variations in each process. For this study, inventory changes associated with the harvesting and processing stages are considered minimal. At the consumption stage, forest product inventories are large, particularly for durable and semi-durable goods. However, the evaluation of wood stocks is beyond the scope of this study. Thus, inventories from previous years and the base year (2019) were not considered.
Data	The data used in this study comes primarily from surveys of businesses. It is therefore reasonable to assume that these data may contain some degree of uncertainty due to participation rates, reporting errors, measurement methods of companies, estimates made by companies, etc.
	Most of the data compiled by government entities is only from industries holding an MFFP permit (inflow of 2001 m^3 and over). Therefore, these data may be somewhat of an underestimate.

Elements	Explanations
	For confidentiality reasons, some products have been amalgamated so that their individual tonnages remain unknown. Due to the limited number of producers of these products, they can be easily identified.
	To simplify data collection, only broad categories of forest products were considered (e.g., roundwood). The lack of completeness thus increases the uncertainties associated with the addition of products of lesser importance. In addition, the various types of trees have sometimes been amalgamated into “softwoods” and “hardwoods.”
	Data collected from years other than the reference year (2019) have been incorporated into the MFA without adjustments since the nonconstant trends in forest products make interpolations and extrapolations imprecise. Since these data are in the minority, however, this assumption was considered acceptable.
Conversion factors	See Appendix I for assumptions.
	The conversion factors used bring a relatively high uncertainty to the MFA results since they come from different sources [24–25] and are not specific to each compiled material. Nevertheless, these are considered acceptable approximations for analyses of this type regarding forest products.

3.2. RESULTS OF THE MFA

The MFA results, expressed in dry metric tons (DMT), have been plotted in a Sankey diagram in **Figure 2** below. This is followed by a detailed description of the inputs and outputs of each process. It should also be noted that the colours shown in the diagram were generated automatically by the software used (SankeyMATIC) and are linked to the source node, i.e., all the flows coming from the same source will have the same colour and will not be retained after connecting to the downstream node. In addition, the material flows were depicted in a linear fashion, from left to right. This was not possible in some cases (e.g., pulp). In fact, to show that pulps are produced by the “Pulp and Paper” process and that some of these pulps are also part of the inputs, an intermediate flow had to be added to the diagram. Therefore, what looks like a recycling stream is not.

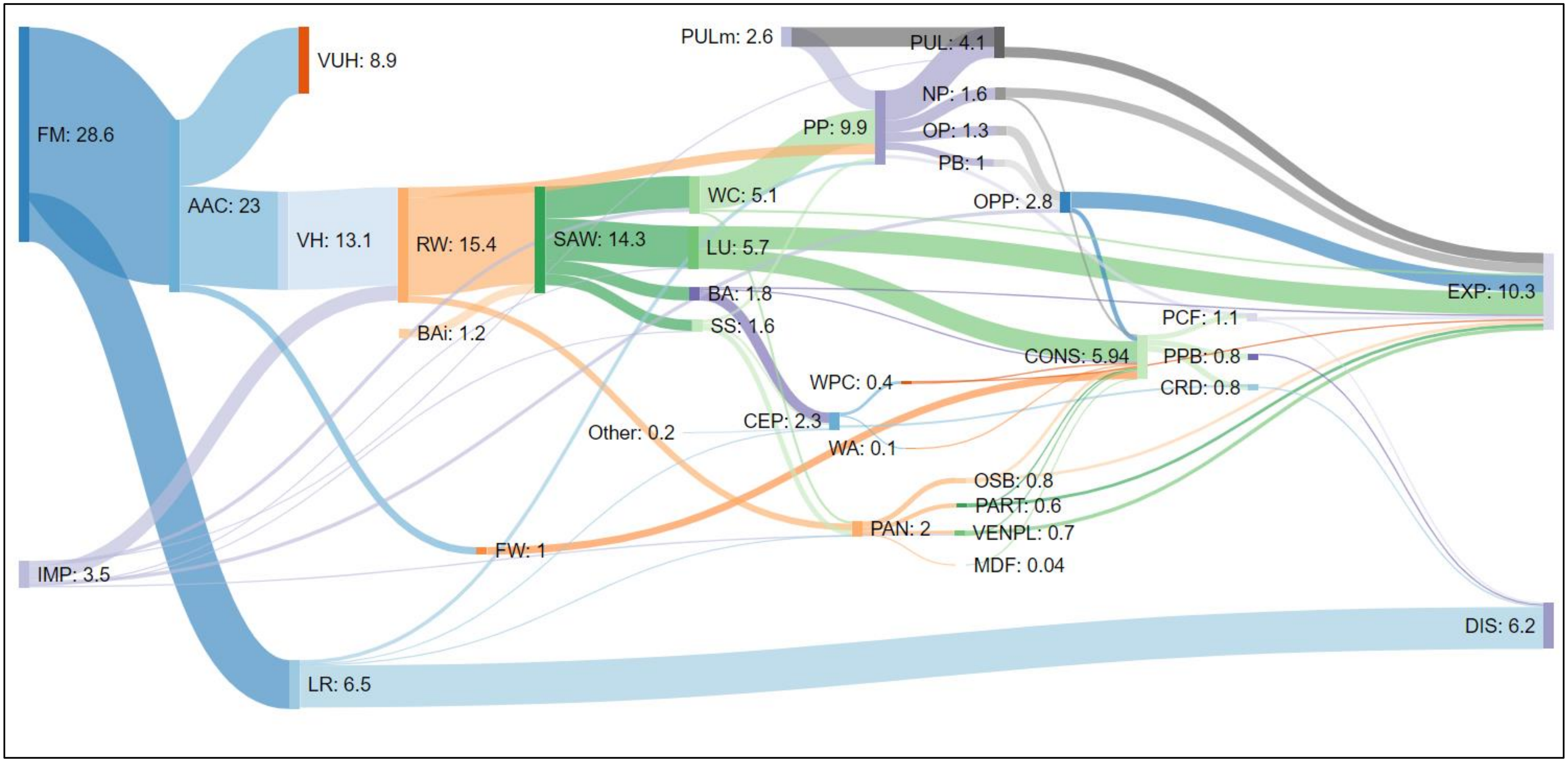


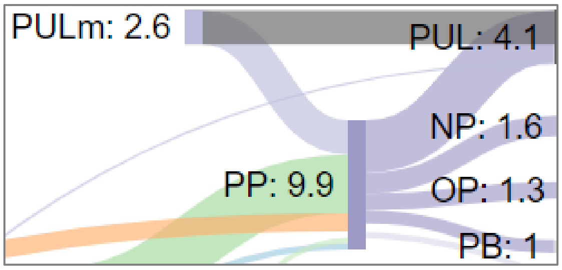
FIGURE 2 Material flows in the forest sector of Quebec

FM	Forest management	**EXP**	Exports	**DIS**	Disposal (landfill or incineration)
AAC	Annual allowable cut (public and private forests)	**SS**	Sawdust and shavings	**Other**	Other wood residues, including wood chips and roundwood
VH	Volume harvested	**PP**	Pulp and paper	**PAN**	Panel manufacturing plants
VUH	Volume unharvested	**PUL**	Pulp (for paper sales and production)	**OSB**	OSB panels
LR	Logging residues	**PULm**	Pulp used in paper manufacturing	**PART**	Particleboard
RW	Roundwood	**NP**	Newsprint	**MDF**	Fibreboard (e.g., MDF)
IMP	Imports	**OP**	Other papers (e.g., printing paper)	**VENPL**	Veneer and plywood
FW	Firewood	**PB**	Paperboard	**CONS**	Residential and industrial, commercial, and institutional (ICI) consumption
SAW	Sawn timber/sawmills	**OPP**	Other paper and paperboard	**PCF**	Post-consumer fibre
WC	Wood chips	**CEP**	Cogeneration and energy products	**PPB**	Paper and paperboard
LU	Lumber or sawtimber	**WPC**	Wood pellets and charcoal	**CRD**	Wood from deconstruction or from the construction, renovation, and demolition (CRD) sector
BA	Bark	**WA**	Wood ash		

Note on paper mill inputs

Exceptionally, in the previous figure, the pulp stream (PUL) should be read from right to left, as shown by the orange arrow on the following enlargement.

This does not represent a recycling stream, but is an indication that of the 4.1 M DMT of pulp produced, 2.6 M DMT is used as input to paper mills.



Forest management

The annual allowable cut (AAC) is defined as “the maximum volume of timber that can be harvested periodically from a given area without altering the productive capacity of the forest environment, in order to meet all forest management objectives.” [26] In 2019, the annual allowable cut in Quebec, which included the contribution of public and private forests, was approximately 22.1 M DMT. The volume harvested (VH), composed entirely of roundwood (RW), was 13.1 M DMT, which represents about 59% of the allowable cut. It should be noted that this amount includes firewood (FW), which accounts for 1.0 M DMT. The volume of unharvested forest biomass (VUH) was 8.9 M DMT.[2]

Logging residues, which include trunks, treetops, and branches, are also included in this process. Forest management is estimated to have generated about 6.5 M DMT of these logging residues and it was calculated that only 0.1 M DMT, or 2%, was recovered in the material flow system. The remainder (98%) was left in the forest, where an estimated 2.1 M DMT would have been used to maintain soil fertility. This is in fact set out in the Sustainable Forest Management Act [27] and in the Regulation respecting the sustainable development of forests [28]. From an energy point of view, the unreclaimed logging residues had a thermal energy production potential of 84 PJ, or 23 TWh.

Primary processing — Sawing

Most harvested and imported roundwood goes through sawmills (SAW) for primary processing. Overall, Quebec sawmills processed 13.1 M DMT of roundwood, of which 1.4 M DMT (11%) came from imports and 0.2 M DMT (2%) from other processing plants. The processing of roundwood by sawmills led to the production of 5.6 M DMT or 42% of lumber (LU), which is used mainly as building and raw material for secondary and tertiary processing industries.

In addition, sawmills generated joint sawmill products: wood chips (WC) (4.3 M DMT or 32%), sawdust and shavings (SS) (1.5 M DMT or 11%), and bark (BA) (1.8 M DMT or 14%). While wood chips, sawdust, and shavings are valorized elsewhere, a relatively large proportion of the bark is used on site by sawmills to dry the roundwood (C. Blais of Créneau d'excellence Collectif Bois, telephone conversation, April 21, 2021).

Although the exact amount of bark input (BAi) to the sawmills is unknown, it was calculated from the volume of roundwood input, without bark, and a weighted expansion factor for wood including bark. A value of 1.2 M DMT was obtained, which represents 9% of the inputs. The 0.6 M DMT difference between inputs and outputs could be explained, apart from the inherent uncertainties in the data, by the fact that the quantities of bark leaving the sawmills may include other forestry residues such as branches.

Primary and secondary processing — Pulp and paper

For the purposes of this study, pulp mills and paper mills (PP) were amalgamated so that pulp is included in both inputs and outputs. Pulp and paper mills obtain their supply from various sources such as sawmills, other pulp and paper mills, post-consumer waste, etc. According to the data collected, the pulp and paper

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[2] The VUH has been represented as a stream for presentation purposes only.

sector consumed 9.9 M DMT of forest materials, while generating 8.0 M DMT of products (a 22% difference). To validate this difference, a compilation of Quebec pulp and paper mill capacities by process type (thermomechanical, chemithermomechanical, and chemical) was performed using Fisher*Solve*® software, and the average weighted yield (90–95%, 85%, and 45–50% yields, respectively) was calculated [29]. A value of approximately 80% was obtained.

The amount of missing material includes, but is not limited to, paper sludge, ash, and wastewater laden with organic material (e.g., black liquor), which was not accounted for. It should also be noted that paper mills feed their biomass boilers with forestry products and residues in order to dry paper pulp and, in some cases, to produce electricity through cogeneration.

That said, pulp and paper mills were supplied with wood chips (4.5 M DMT or 45%), virgin and recycled pulp (PUL) (2.6 M DMT or 26%), roundwood (1.4 M DMT or 14%), or pulpwood, recycled fibre paperboard (0.5 M DMT or 5%) and recycled paper (0.02 M DMT or 0.2%) (PCF), sawdust and shavings (0.4 M DMT or 4%), and wood residues (0.5 million DMT or 5%), including CRD wood and screenings. Pulp and paper mills also use a significant amount of bark for energy purposes, but the exact amount consumed is unknown. However, it is shared with sawmills, as mentioned above, and makes up some of the 1.4 M DMT of bark that has been classified under the “Cogeneration and energy products” process. In addition, it should be noted that nearly 0.3 M DMT of additives are added to paper mill inputs, but since they are not forest products, they were not included in the MFA.

In terms of output, the pulp and paper sector produced 4.0 M DMT (50%) of pulp, 2.9 M DMT (36%) of paper, [of which 1.6 M DMT (20%) was newsprint and 1.3 M DMT (16%) was other papers (OP) such as printing paper], and 1.0 M DMT (13%) of paperboard (PB).

Primary and secondary processing — Cogeneration and energy products

The cogeneration and energy products (CEP) process consumed approximately 2.3 M DMT of forest products, which included 1.4 M DMT (61%) of bark, 0.3 M DMT (13%) of sawdust and shavings, 0.3 M DMT (13%) of CRD wood, 0.1 M DMT (4%) of logging residues, and less than 0.1 M DMT (<4%) of roundwood, wood chips, and other wood residues (Other). The main energy products generated were wood pellets and charcoal (WC), with a combined flow of 0.4 M DMT. The recovery of energy from these woody materials also leads to the production of wood ash (WA). Considering a generation rate of 1% for wood chips and 5% for bark [30], a production of less than 0.1 M DMT was calculated. Densified wood fibre logs were also produced at less than 0.1 M DMT. The output of cogeneration and energy products is therefore about 0.5 M DMT, or 22% of the input.

For information purposes, the thermal energy produced by this process is 5,200 GWh, while it is 1,900 GWh for electrical energy. Energy was not included in the MFA, but it is important to note that a significant amount of forest products is used to generate energy, particularly by sawmills and pulp and paper mills, as mentioned earlier.

Primary and secondary processing — Panel manufacturing

The materials used in the manufacture of wood-based composite and structural panels (PAN), totalling 2.0 M DMT, were roundwood (0.9 M DMT or 45%), sawdust and shavings (0.7 M DMT or 35%), wood chips (0.3 M DMT or 15%), and wood residues (0.1 M DMT or 5%). The main types of panels produced were oriented strand board (OSB) (0.7 M DMT or 39%), particleboard (PART) (0.6 M DMT or 33%), veneer and plywood (VENPL) (0.4 M DMT or 22%), and fibreboard (0.04 M DMT or 2%) of low (LDF), medium (MDF), and high density (HDF), for a total of 1.8 M DMT (90% of inputs). The difference between inputs and outputs could be explained by losses related to the panel manufacturing process, such as sawdust and scrap wood. However, these losses are expected to be partially offset by the fact that resins, glues, and other additives are added to the panels and thus contribute to their mass. Another source of uncertainty is that data used to account for inputs are from 2019, whereas data for outputs are from 2017.

In addition, quantifying inputs by type of panel produced was not possible in this analysis. The results are therefore amalgamated under the “Panels” process, which includes all inputs and types of panels produced. However, depending on the way these panels are manufactured, it is possible to associate inputs with certain types of panels: (i) OSB is produced primarily from roundwood strands, (ii) particleboard is produced from sawdust, shavings, wood chips and recycled wood (wood residues), (iii) veneer and plywood are produced from wood veneer (roundwood), and (iv) densified fibreboard, such as MDF, is produced primarily from wood chips.

Consumption and post-consumption

In total, it was calculated that more than 5.9 M DMT of forest products were consumed by the ICI and residential sectors, which includes the construction sector and household consumption. The main products accounted for were lumber (2.7 M DMT or 47%), paper and paperboard other than newsprint (0.6 M DMT or 11%), firewood (1.0 M DMT or 17%), newsprint (0.3 M DMT or 5%), wood pellets and charcoal (0.2 M DMT or 4%), OSB (0.4 M DMT or 6%), bark (0.2 M DMT or 4%), particleboard (0.2 M DMT or 3%), veneer and plywood (0.2 M DMT or 3%), wood ash and fibreboard (<0.1 M DMT or <1%). Other products, such as wood shingles, horticultural mulch, and densified wood fibre logs, are also part of this process, but were excluded from the calculations because of their small quantities. Energy consumption was also excluded from the MFA.

When not valorized on site or in an industrial symbiosis, end-of-life materials are sent to sorting centres and ecocentres. The data collected indicate that 0.6 M DMT (40%) of paper and paperboard (PPB), 0.5 M DMT (33%) of post-consumer fibre (PCF), and 0.4 M DMT (27%) of CRD wood left these sorting and recovery facilities, for a total of 1.5 M DMT (65% of total output). In this case, PCF represents the portion of paper and paperboard recovered and exported, while PPB represents the portion of paper and paperboard that is recycled by Quebec pulp and paper mills. In addition, some of this material is not sent to sorting centres or ecocentres and goes directly to disposal (DIS), which includes landfills and incineration. According to the results obtained, 0.2 M DMT of PPB, 0.2 M DMT of PCF, and 0.2 M DMT of CRD were disposed of, for a total of 0.6 M DMT (35% of total output). The post-consumer output was therefore 2.3 M DMT.

The significant difference between the inputs and outputs of this process can be explained, at least in part, in several ways. First, some of the materials consumed in large quantities, such as firewood, are recovered for energy purposes and only end up in the output as wood ash, but in negligible quantities. In addition, several materials and products are used as construction materials in infrastructures that can last several years. As a result, what is recovered by CRD sorting centres may be from structures that are quite old. This also applies to certain papers and paperboards. Furthermore, as mentioned at the beginning of this paragraph, materials recovered on site or through an industrial symbiosis are not counted as post-consumption.

Imports/exports

According to the MFFP’s 2019 statistical portrait of forestry resources and industries in the Province, Quebec imported more than 2.3 M DMT/year of “raw materials,” which included roundwood, wood from deconstruction or CRD, wood chips, bark, and sawdust and shavings [9]. However, according to the information available, these raw materials total 2.6 M DMT, which indicates some margin of error in the data. Nevertheless, imports (IMP), which include other products such as paper, paperboard, and panels, totalled about 3.5 M DMT.

That said, the main materials and products making up imports were roundwood (2.0 M DMT), paper (other than newsprint) and paperboard (0.5 M DMT), wood chips (0.5 M DMT), veneer and plywood (0.2 M DMT), pulp (0.1 M DMT), sawtimber or lumber (0.1 M DMT), and sawdust and shavings (0.1 M DMT). Other materials and products imported in negligible quantities were omitted from the equation, namely bark, newsprint, OSB, fibreboard (e.g., MDF), and particleboard.

As for exports (EXP), they were almost three times higher than imports, totalling about 10.3 M DMT. The main materials and products exported from Quebec were lumber (3.0 M DMT), paper (other than newsprint) and paperboard (2.2 M DMT), pulp (1.4 M DMT), newsprint (1.3 M DMT), veneer and plywood (0, 5 M DMT), post-consumer fibre (0.5 M DMT), particleboard (0.4 M DMT), OSB (0.4 M DMT), wood chips (0.3 M DMT), bark (0.2 M DMT), wood pellets and charcoal (0.2 M DMT), and sawdust and shavings (0.04 M DMT). Other materials and products such as roundwood, including pulpwood, and densified fibreboard were excluded because of the small quantities exported.

3.2.1. Rate of use of main forest products

For the purposes of this study, the rate of use is the ratio of the quantities used and exported to the materials generated and imported. The term "use" refers here to processing, consumption, and recovery (regardless of the method) of materials or products. The rate of use therefore takes into account what is generated and used within the system as well as what comes from outside and leaves it. A rate of use lower than 100% means that a certain percentage of the material in question leaves the wood cycle of the forest sector in Quebec, for example by being buried or left in the forest. The Quebec rate of use is the ratio of materials used to materials generated within the system, i.e., in Quebec. It ignores imports and exports.

In this section, it is important to bear in mind the following sources of uncertainty in the data: (i) conversion factors; (ii) different sources with different data collection methodologies; (iii) numerous assumptions made to balance the data; (iv) intrinsic uncertainties in the data. For these reasons, some rates of use are greater than 100%. The reader is therefore invited to consider the overall picture, rather than absolute values. However, the rate of use in Quebec may, by definition, be higher than 100%.

Wood supply

Quebec's allowable cut, including public and private forests, is estimated at 22.1 M DMT. Of this allowable cut, 13.1 M DMT of forest biomass were utilized for a production rate of 59%. This leaves a total of 8.9 M DMT (40%) unutilized.

According to Alexis Achim, a researcher at the Laval University Renewable Materials Research Centre (Quebec), this unused biomass is left behind because of low wood quality, low expected market value, natural disturbances (diseases/pests, fires, strong winds), etc. [31]. Therefore, approximately 50% of the available biomass volume is not harvested for these reasons. Furthermore, according to the Intergovernmental Panel on Climate Change, dead trees would be the best resource for the bioenergy sector to harvest since net GHG emissions would be virtually zero [31].

Roundwood

Quebec's forests produced approximately 13.1 M DMT of roundwood, while 1.4 M DMT was imported. Roundwood used by sawmills, paper mills, cogeneration and energy products plants, and panel/veneer mills used approximately 15.3 M DMT. Therefore, considering the negligible exports, the rate of use of roundwood was 105%. According to an interview with Créneau d'excellence Collectif bois, a certain quantity of hardwood (or pulpwood) is not recovered. However, despite the uncertainty in the data, it is likely that this quantity is relatively small and that the vast majority of roundwood was recovered/used in Quebec. The rate of use in Quebec was 106%.

Logging residues

Forest management led to the production of 6.5 M DMT of logging residues. Of these, 5.6 M DMT (98%) were left behind in the forest, some of which (about 2.1 M DMT) were used to maintain soil fertility, while 0.1 M DMT were used by paper mills and cogeneration and energy products plants. In doing so, the rate of use of logging residues was only 2%, the same as the rate of use in Quebec. These residues thus have a significant recovery potential, particularly for energy recovery (e.g., heating of community buildings) and for the production of second-generation biofuels or the manufacture of bioproducts using green chemistry [31–32].

Bark

Approximately 1.8 M DMT of bark were produced in the primary processing of roundwood, while there were little or no imports. Most of the supply was recovered as energy by sawmills (0.2 M DMT) and paper mills (1.4 M DMT), i.e., 1.6 M DMT (89%). The remaining 0.2 M DMT (11%) was exported. The rate of use of bark was therefore 101%. The rate of use in Quebec was 88%.

Lumber

Lumber produced by Quebec sawmills accounted for a flow of 5.6 M DMT (98% of the total), while only 0.1 M DMT (2% of the total) was imported, for a total of 5.7 M DMT. Lumber exports totalled 3.0 M DMT (53%), and the remaining 2.7 M DMT (47%) is assumed to have been consumed exclusively by the Canadian construction sector (e.g., for flooring, furniture, housing, etc.). In fact, in this specific case, Quebec lumber could have been also used in other provinces since the data collected were not exports in the strict sense. With this assumption, the rate of use for lumber was 100%, while the rate of use in Canada was 49%.

Wood chips

Primary roundwood processing activities led to the production of more than 4.3 M DMT (90%) of wood chips, while 0.5 M DMT (10%) came from imports, for a total of 4.8 M DMT. Most of these wood chips, 4.5 M DMT (87%), were used in the pulp and paper sector, while a smaller proportion, 0.3 M DMT (6%), was used in fibreboard and particleboard manufacturing, and less than 0.1 M DMT (<2%) was used in the cogeneration and energy products process. Other uses of wood chips, such as horticultural mulch preparation, structuring agents for composting, or substrates for mushroom cultivation, were excluded because of their low contribution. In addition, 0.3 M DMT (6%) of wood chips were exported. The rate of use of this material was therefore 108%. Again, according to the representative of the Créneau d'excellence Collectif bois, a certain portion of hardwood chips was not recovered, but it was not possible to validate this statement with the data collected. The rate of use of wood chips in Quebec was 113%.

Sawdust and shavings

Wood preparation by sawmills led to the production of 1.5 M DMT (94% of the total) of sawdust and shavings. Imports of these materials contributed 0.1 M DMT (6% of the total) to the material flow system, for a total of 1.6 M DMT. Sawdust and shavings were used in the manufacture of panels, mainly particleboard (0.7 M DMT or 44%), pulp and paper (0.4 M DMT or 25%), and in cogeneration and energy products (0.3 M DMT or 19%). With less than 0.1 M DMT (<6%) exported, the rate of use of sawdust and shavings was 90% (93% for the rate of use in Quebec). In addition to the uncertainty caused by the data collection, some of the unrecovered sawdust and shavings could be explained by the volatilization of fine particles in the dust collection units and losses during material handling. This result shows that there is room for improvement in the recovery of sawdust and shavings. For example, these wood residues can be used as animal bedding, as a carbon source for organic matter treatment processes such as composting, or as absorbent material.

Newsprint

Quebec newsprint mills produced an estimated 1.6 M DMT. Imports were less than 0.1 M DMT, for a total of just over 1.6 M DMT. The newsprint produced, 0.3 M DMT (19%), was used by the residential/ICI sector, while exports were 1.3 M DMT (81%). However, export data collected, in particular through the Canadian Forest Service statistical portal [18], suggest that they were significantly higher. In fact, 1.8 M DMT of newsprint was exported in 2016. Thus, there appears to be a discrepancy between the quantities of newsprint produced/imported and newsprint used/exported, which could be explained by unreliable data sources. Since it was not possible to reconcile data from different sources for this material, the rate of use was set at 100%. As a result, the rate of use in Quebec was 17%.

Other paper and paperboard

Paper mills produced more than 1.3 M DMT (46%) of paper, other than newsprint, and 1.0 M DMT (36%) of paperboard, for a total production of 2.3 M DMT (82%). In terms of imports, other paper and paperboard together accounted for 0.5 M DMT (18%), for a total of 2.8 M DMT. It was calculated that the consumption of other paper and paperboard was about 0.6 M DMT (21%). Exports were 2.2 M DMT (79%) for other papers and paperboards together, for a total of 2.8 M DMT. The rate of use was therefore 102%, while the rate of use in Quebec was 66%.

Yet, according to Recyc-Québec's 2018 residual materials management report, the diversion rate for paper and paperboard was 71%, meaning that 71% of these materials ended up at the sorting centres, and about 10% were diverted to landfills by the sorting centres [21]. This would have resulted in the disposal of over 0.2 M DMT of paper (including newsprint) and paperboard. The actual rates of use should therefore be lower than those obtained. Since the proportion of newsprint could not be distinguished from other paper and paperboard, their actual rates of use could not be shown.

Pulps

Quebec pulp mills produced 4.0 M DMT (98%) of pulp in the reference year and 0.1 M DMT (2%) was imported, for a total of 4.1 M DMT. Of this pulp, 2.6 M DMT (63%) was used by paper mills, while 1.4 M DMT (34%) was exported, for a total of 4.0 M DMT. Therefore, the rate of use for pulp was 97%. The Quebec rate was 65%.

Post-consumer fibre

It is estimated that 1.0 M DMT of post-consumer fibre came from waste sorting centres. Half of this, or 0.5 M DMT, was exported, while the rest was recycled by pulp and paper mills. According to data from Recyc-Québec [21], the recycling rate of post-consumer fibre was 48% and the export rate was 52%, which is similar to the results obtained by the MFA. Some post-consumer fibre, i.e., approximately 0.2 M DMT, ended up being disposed of instead of being sent to the sorting centres. The rate of use or post-consumer fibre was therefore 84%, while the rate of use in Quebec was 44%. Note that this internal rate for post-consumer fibre could be improved by promoting local recovery channels. For example, these fibres can be processed and used in the manufacture of thermoformed cellulosic pulp packaging and ecoproducts, and local expertise is developing with players such as Innofibre [33].

Firewood

It is estimated that 1.0 M DMT of firewood were used in Quebec in 2017, mainly for residential heating [34]. For the purposes of this study, it will be assumed that these figures are also valid for 2019. In addition, it was not possible to obtain firewood production data from private forest operators since these are not compiled systematically by the government agencies consulted. Thus, the figure of 1.0 M DMT for firewood production will be used. In addition, it was not possible to collect information on firewood imports and exports. It will therefore be assumed that they amounted to zero. The rate of use of firewood would therefore have been 100%, the same as the rate of use in Quebec.

CRD wood

According to the data obtained, approximately 0.8 M DMT of CRD wood was produced in Quebec during the reference year. Of this total, 0.6 M DMT (76%) ended up in CRD sorting centres and ecocentres. A total 0.3 M DMT (32%) was used as input for the cogeneration and energy products process, while smaller amounts were listed as "wood residues" in inputs for paper mills and panel manufacturing plants. It is assumed that the remaining 0.3 M DMT (44%) of output from the sorting centres and ecocentres would have been landfilled. In addition, instead of being sent to the CRD sorting centres and ecocentres, some CRD wood, i.e., 0.2 M DMT (24%), was sent directly for disposal. According to data collected by Recyc-Québec in its 2018 report on residual materials management in Quebec [20], 0.6 M DMT of CRD wood was generated by CRD sorting centres and ecocentres in Quebec. Of this quantity, approximately 0.4 M DMT (67%) was recovered as energy or recycled, while 0.2 M DMT (33%) was landfilled.

In addition, no imports of CRD wood were recorded and exports were negligible. As a result, the rate of use for CRD wood would have been approximately 32%, as was the rate of use in Quebec. This could be explained by the fact that CRD wood recovery is hampered by its high level of contamination in some cases. The development of emerging processes such as gasification, which converts carbonaceous material into a synthesis gas (*syngas*), could improve the rate of use of these residues.

Wood pellets and charcoal

The “energy products” plants produced over 0.4 M DMT of wood pellets and charcoal. In 2019, while no imports were recorded, 0.2 M DMT (50%) were exported [19]. Assuming that the remainder was consumed by the residential and ICI sector, the rate of use in Quebec would have been 52%.

Wood ash

The combustion of forest products, for example in biomass boilers, generates wood ash. According to calculations, approximately 0.1 M DMT of wood ash would have been generated from the combustion of bark, CRD wood, wood pellets and charcoal, firewood, and wood chips. However, it is suspected that this is an underestimate since it is known that, in addition to the materials mentioned above, other materials such as paper sludge and some wood residues can also produce wood ash. Nevertheless, wood ash can be recovered in different ways as fertilizing residual materials or fillers. However, being a product of combustion, it is possible that wood ash is too contaminated for these types of applications, especially when it comes from the burning of CRD wood contaminated with paint, and would therefore be destined for the landfill. Thus, it was not possible to assess the rate of use/recovery of wood ash in this study.

OSB panels

In Quebec in 2017, it is estimated that 0.7 M DMT of OSB were produced from wood strands generated by processing activities. Of this amount, about 0.4 M DMT were exported (57%), while the quantity imported was negligible. For the purposes of this analysis, it is assumed that the remaining 0.3 M DMT (43%) of OSB was consumed by the construction sector with a rate of use of 100%. The rate of use in Quebec was 48%.

MDF fibreboard

In the case of fibreboard (e.g., MDF), it is estimated that <0.1 M DMT were produced mainly from wood chips, while imports and exports were negligible (0.04 M DMT in 2019 [19]). It is assumed that all of these were used for residential/ICI consumption, for example, as insulation panels. The rate of use was therefore 100%, as was the rate of use in Quebec.

Particleboard

It was calculated that the amount of particleboard produced, mainly from sawdust, shavings, wood chips, and recycled wood, was 0.6 M DMT. While imports were negligible for this product, about 0.4 M DMT (67%) were exported. For the purposes of this analysis, it was assumed that the remaining particleboard (0.2 M DMT or 33%) was used in the process of residential/ICI consumption. This translates into a rate of use of 100%. The rate of use in Quebec was 28 %.

Veneer and plywood

About 0.4 M DMT of veneer and plywood were generated from wood veneer processing activities, while 0.2 M DMT were imported, for a total of 0.6 M DMT. Exports amounted to 0.5 M DMT (74%), and it is assumed that the rest of the veneer and plywood (0.2 M DMT or 26%) was used by the construction sector. The rate of use was therefore 100%, while the rate of use in Quebec was 40%.

Overview

Overall, Quebec's public and private forests produced 13.1 M DMT (91%) of roundwood, including 1.0 M DMT of firewood, 0.1 M DMT (1%) of logging residues, and 1.2 M DMT (8%) of bark, for a total of 14.4 M DMT. Including the 2.9 M DMT of imports, a total of 17.3 M DMT of forest products entered or were generated within the material flow system. In addition, 10.3 M DMT (59%) of forest products were exported out of the system. This leaves 7.0 M DMT (41%) of material that was processed and recirculated within the system. Of this, approximately 2.3 M DMT (13%) was converted to energy (and ash), leaving 4.7 M DMT (27%) of material that was recirculated or added to inventories of durable goods. It should be noted, however, that these data excluded inventories and material storage. **TABLE 4** provides a summary of the results and rates of use for the various forest products considered in this study.

TABLE 4 Summary of the use of main forest products

Materials/products	Quantity generated (M DMT)	Quantity imported (M DMT)	Quantity utilized (M DMT)	Quantity exported (M DMT)	Rate of use (%)	Rate of use in Quebec (%)
Wood and joint sawmill products (other than bark)						
Roundwood	13.1	1.4	15.3	-	**105**	**106**
Logging residues	6.5	-	0.1	-	**2**	**2**
Chips	4.3	0.5	4.9	0.3	**108**	**113**
Sawdust and shavings	1.5	0.1	1.4	<0.1	**90**	**93**
Pulp and paper						
Newsprint	1.6	<0.1	0.3	1.3	**100***	**17**
Other paper and paperboard	2.3	0.5	0.6	2.2	**102***	**66**
Pulps	4.0	0.1	2.6	1.4	**97**	**65**
Post-consumer fibre	1.2	-	0.5	0.5	**84**	**44**
Energy recovery						
Bark	1.8	-	1.6	0.2	**101**	**89**
Firewood	1.0	-	1.0	-	**100**	**100**
Wood pellets and charcoal	0.4	-	0.2	0.2	**52**	**52**
Wood ash	0.1	-	-	-	**Unknown**	**Unknown**
Construction**						
Lumber	5.6	0.1	2.7	3.0	**100**	**49**
OSB	0.7	-	0.4	0.3	**100**	**48**
Medium density fibreboard (MDF)	<0.1	-	<0.1	-	**100**	**100**
Particle board	0.6	-	0.2	0.4	**100**	**28**
Veneer and plywood	0.4	0.2	0.2	0.5	**100**	**40**
CRD wood	0.8	-	0.3	-	**32**	**32**

*Different sources of information suggest that these rates of use were likely lower.

**To avoid confusion, rates of use of 100% are explained by the assumption that material losses related to the use of these products (e.g., logging) are recorded elsewhere, such as in sawdust and shavings and in CRD wood.

From these results, it can be seen that a **large proportion of forest materials and products were used (rate of use)** if exports are considered as use. However, the fate of forest products leaving the system is unknown. Therefore, for the purposes of this study, it is assumed that they were recovered in some way, if not landfilled or incinerated without energy recovery. Further analysis would be required to confirm or reject this hypothesis.

From a circularity perspective, **logging residues and CRD wood are the materials with the most room for improvement, with respective rates of use of 2 and 32%**. Sawdust and shavings, with a rate of use of 90%, and post-consumer fibre, with a rate of use of 84%, also have some room for improvement.

However, it is important to put these findings into perspective. In fact, not all uses are equivalent if we refer to the hierarchical principle of the 4 Rs (reduction at source, reuse, recycling and energy recovery) as described in the definition of the circular economy. Therefore, despite the fact that most of these materials are recovered, it is very likely that higher value-added opportunities could be found, with shorter transport distances (short distribution channels). In addition, emphasis could be placed on wood products that are durable, such as structures (e.g., furniture, infrastructure, panels, etc.), rather than on products with short life cycles, such as paper. Further analysis, perhaps using other indicators of circularity, would highlight these subtle differences.

As for the internal situation, that is, not considering imports and exports, the picture changes drastically. In fact, **the rate of use in Quebec for most forest materials/products was relatively low, suggesting significant shortcomings in the local recovery of post-consumer products**. Thus, from a circular economy perspective where short distribution channels and local use are encouraged, **there is significant potential for improvement for most of these products, particularly for logging residues, newsprint, particleboard and CRD wood, with respective rates of use in Quebec of 2, 17, 28 and 32%**.

4. SYNERGIE QUÉBEC SYMBIOSIS DATA

The Synergie Québec network brings together some twenty industrial and territorial symbiosis projects throughout Quebec. These independent projects are mostly led by non-profit and municipal organizations that make their resources available to catalyze the creation of synergies between businesses in their territory (e.g., economic development agencies, regional county municipalities [MRCs], regional environmental councils).

This network is facilitated by the CTTÉI, whose role is to use the data voluntarily shared by the facilitators for applied research and value chain optimization. The members of this community are also partners of the Research Chair in Industrial and Territorial Ecology (CRÉIT). Their experience allows the Chair to focus on the creation of tools to facilitate the transition to the circular economy. These projects are led by facilitators in the field who offer circular economy coaching services to businesses. Each project therefore has valuable data, albeit not exhaustive and not cross-checked by the CTTÉI, on resource input and output ofmaterials.

These data are compiled in a computer tool developed by the CTTÉI and are not publicly available. Facilitators from eight regions in Quebec shared the data collected in the field on materials in the “Wood” category of the Synergie Québec database (FIGURE 3).

The NAICS sectors included in the study are:

- 113 Forestry and logging
- 321 Wood product manufacturing
- 322 Paper manufacturing.

Sources of imprecision and uncertainty

The data collected in the Synergie Québec database is primarily used to create synergies locally, a not to establish a complete national portrait of resources available. To avoid any misunderstanding, limitations on the interpretation of these data are presented in Appendix III.

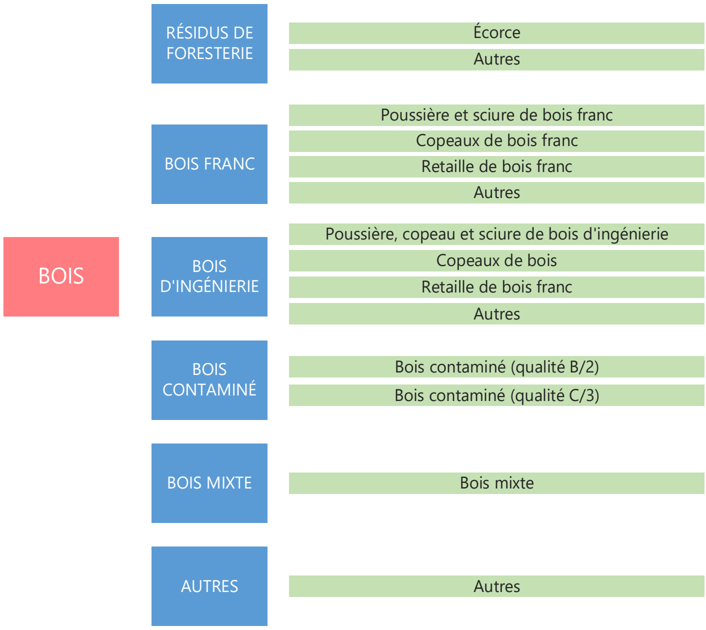

FIGURE 3 Wood categories and subcategories in the Synergie Québec database

4.1. INDICATORS ON RESPONDING COMPANIES

The number of responding companies in Synergie Québec in the targeted sectors and the ratio with CRIQ data are presented in **TABLE 5**. The data provided by the companies is compiled in the Synergie Québec database (SQDB). Regions with the highest ratio of respondents are highlighted in orange.

TABLE 5 Number of Synergie Québec companies by NAICS sector and ratio with CRIQ[3]

REGIONS	Number of companies NAICS 321			Number of companies NAICS 322		
	ICRIQ	SQDB	Ratio	ICRIQ	SQDB	Ratio
Bas-Saint-Laurent (Kamouraska)	62	17	27%	3	1	33 %
Capitale-Nationale	40	4	10 %	8		0 %
Estrie	69	6	9 %	10		0 %
Lanaudière	49	6	12 %	6	2	33 %
Laurentides	66	4	6 %	44		0 %
Mauricie	44	6	14 %	9		0 %
Montreal	27	8	30%	38		0 %
Outaouais	34	9	26 %	3	3	100 %
Other Regions	392	17	4 %	25	2	8 %
TOTAL	**783**	**77**	**10 %**	**146**	**8**	**5 %**

Responding companies in the three NAICS sectors represent 69 of the 94 companies in these same sectors in the SQ database, or 73% (**TABLE 6**). Thus, even though only eight of the 24 symbioses shared their

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[3] The ICRIQ database does not provide information on NAICS code 113.

information, this represents almost 2/3 of the data for these three NAICS sectors in the Synergie Québec database.

Of the three sectors presented, the most documented is Wood product manufacturing. The orange cells indicate the regions with the most respondents by NAICS sector (**TABLE 6**).

TABLE 6 Number of Synergie Québec companies by NAICS sector

REGIONS	NAICS 113 Forestry and logging	NAICS 321 Wood product manufacturing	NAICS 322 Paper manufacturing	TOTAL
Bas-Saint-Laurent (Kamouraska)[4]	1	17	1	19
Capitale-Nationale	1	4		5
Estrie		6		6
Lanaudière	1	6	2	9
Laurentides		4		4
Mauricie		6		6
Montreal		8		8
Outaouais		9	3	12
Other Regions	6	17	2	25
TOTAL	**9**	**77**	**8**	**94**

Company size by number of employees is commonly used to correlate the size of the supply and waste streams. In symbiosis projects, the participation of large companies and major job providers may reflect a greater environmental sensitivity or territorial commitment. The high ratio of the number of jobs in companies identified in the Synergie Québec database by region to the number of jobs in companies identified by the CRIQ (**TABLE 7**) can account for this relationship. Regions with the highest ratio of NAICS sector respondents by number of employees are shown in orange.

TABLE 7 Number of employees of Synergie Québec companies and ratio with the CRIQ

REGIONS	Number of employees								
	NAICS 113[5] Forestry and logging			NAICS 321 Wood product manufacturing			NAICS 322 Paper manufacturing		
	ICRIQ	SQ	Ratio	ICRIQ	SQ	Ratio	ICRIQ	SQ	Ratio
Bas-Saint-Laurent (Kamouraska)	N.A.	N.A.	N.A.	2,550	655	26 %	482	160	33 %
Capitale-Nationale	N.A.	N.A.	N.A.	1,564	369	24 %	383		0 %
Estrie	N.A.	N.A.	N.A.	3,053	518	17 %	2,454		0 %
Lanaudière	N.A.	N.A.	N.A.	1,098	79	7 %	830	719	87 %
Laurentides	N.A.	N.A.	N.A.	1,659	38	2 %	627		0 %
Mauricie	N.A.	N.A.	N.A.	2,352	152	6 %	1,661		0 %

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[4] Please note that some projects have merged their databases, which explains why some data are expressed for Bas-Saint-Laurent and others for Kamouraska.

[5] The ICRIQ database does not provide information on NAICS code 113.

Montreal	N.A.	N.A.	N.A.	903	142	16 %	2,946		0 %
Outaouais	N.A.	N.A.	N.A.	1,065	440	41 %	946	5,080	537%[6]
Other Regions	N.A.	N.A.	N.A.	21,403	481	2 %	7,884	389	5 %
TOTAL				**35,647**	**2,874**	**8 %**	**18,213**	**6,348**	**35 %**

4.2. INDICATORS ON THE NUMBER OF SYNERGIE QUÉBEC SUPPLY OFFERS AND DEMANDS

The data used in the following section are presented in Appendix IV. Significant data for sectors other than 113, 321 and 322 are also available.

Supply Offer Pools (Outputs) — Wood Categories
For Synergie Québec facilitators, a SUPPLY OFFER is a material “generated” by a company (e.g., by-products, co-products, residual materials, loss, waste, non-compliant). This supply offer is available to be valorized internally by the generating company itself or externally by another company located nearby or elsewhere. The nature of these supply offers and the quantities of materials vary according to production. Several factors can therefore influence it (e.g., seasonality, process changes, input changes).

For each NAICS sector, the categories with the most supply offers are highlighted in orange (**TABLE 5**). Since the number of respondents is much higher for sector 321, it also has the most supply offers listed.

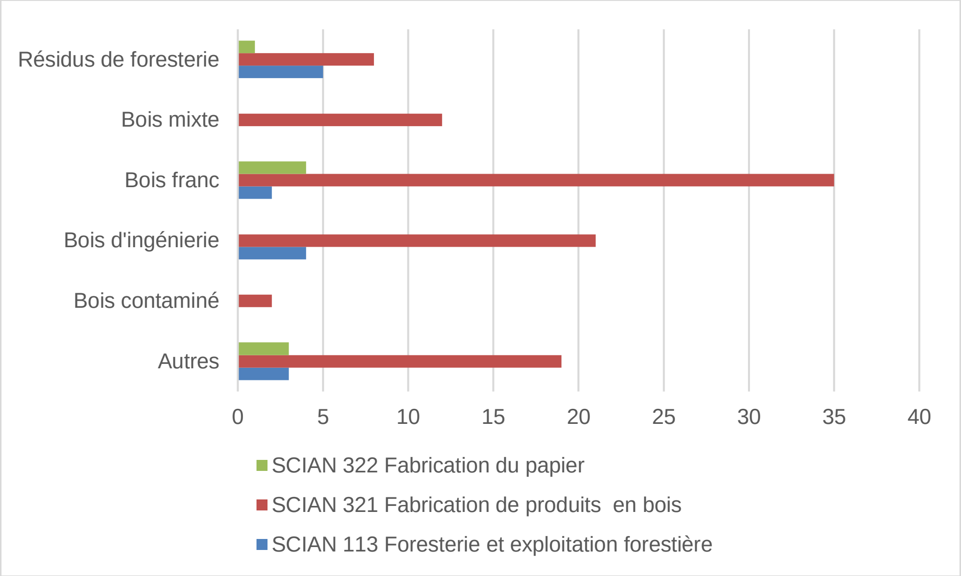

FIGURE 4 Supply offers by wood subcategories for each NAICS sector (119 supply offers)

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[6] The reasons why this figure is over 100 are presented in Appendix III.

Supply Offer Pools (Outputs) — Subcategories

For each NAICS sector, the categories with the most supply offers are highlighted in orange (**TABLE 6**). Since the number of respondents is much higher for sector 321, it also has the most supply offers listed.

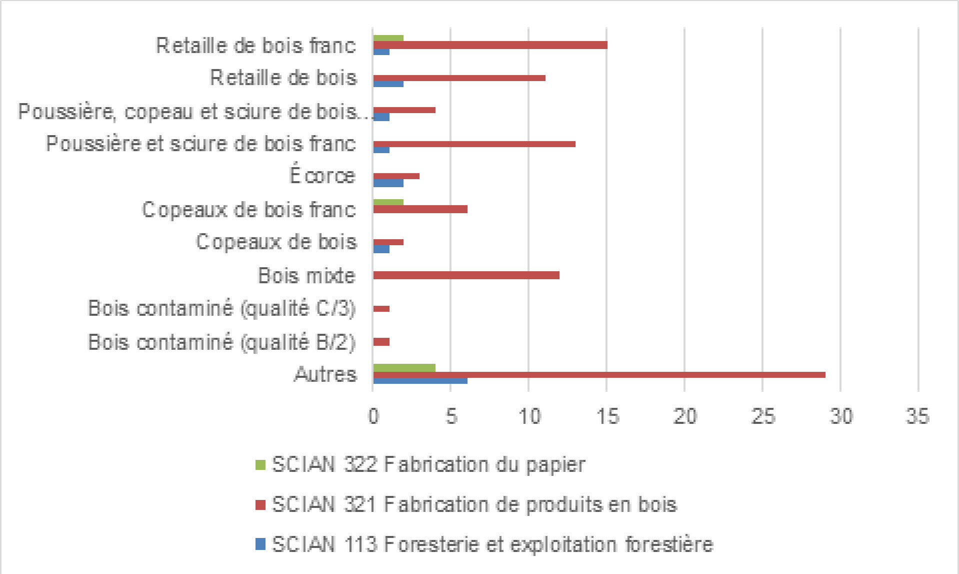

FIGURE 5 Number of supply offers by wood subcategories for each NAICS sector (119 supply offers)

Key facts:

- Hardwood and engineered wood scraps make up a large portion of the supply offers.
- Sectors other than 113, 321, and 322 generate wood residues, mostly mixed wood.
- The number of supply offers exceeds the number of demands, as is observed in symbiosis projects. Thus, companies that formalize a supply offer most often wish to “dispose” of a residual material at a lower cost than through current management services.

Demands (Inputs) — Wood Categories

For Synergie Québec facilitators, a DEMAND is a material “consumed” by a company (e.g., raw material, purchase, supply). In a synergy, this demand is met by a supply offer of materials to be recovered. The nature of the demand (e.g., expected specifications, physicochemical properties, characteristics) must, however, be suitable for this substitution. If required, conditioning activities can make the supply offer compatible.

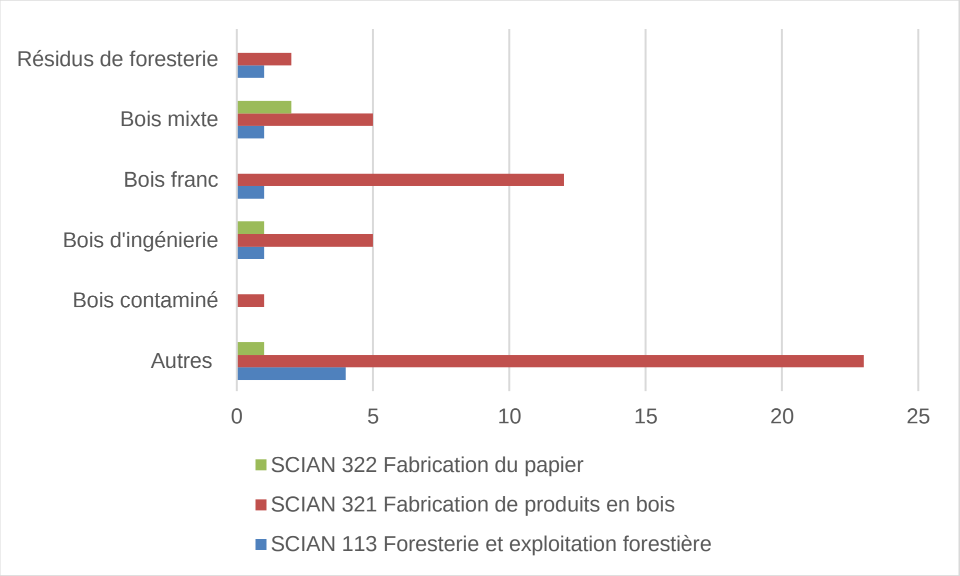

FIGURE 6 Number of Demands by wood category and NAICS sector (60 supply offers)

Demand Pools (Inputs) — Subcategories

For each NAICS sector, the categories with the most demands are highlighted in orange (**TABLE 7**). Since the number of respondents is much higher for sector 321; it also has the most supply offers listed.

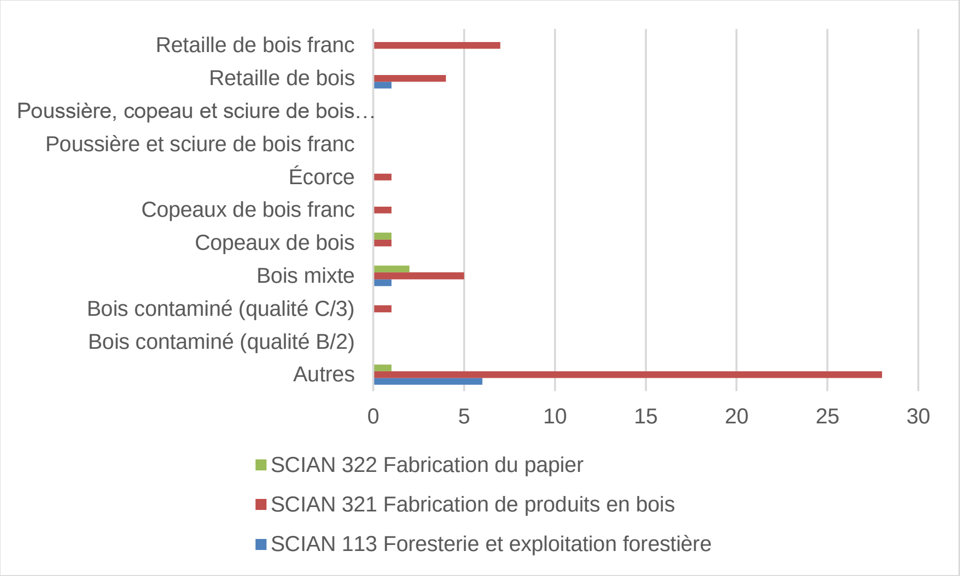

FIGURE 7 Number of demands by wood subcategory and NAICS sector (60 demands)

Key facts:

- Hardwood and engineered wood residues (e.g., engineered flooring and laminate flooring) account for a large portion of the demands made by participating companies.

- Sectors other than 113, 321, and 322 also generate wood residues, mostly mixed wood and other unclassified residues.
- The number of demands is lower than the number of supply offers, which is common in symbiosis projects. Therefore, companies formalizing a demand must ensure that their processes are tolerant of input changes and that the substitution is suitable.

4.3. SYNERGY INDICATORS FOR SYNERGIE QUÉBEC

The industrial fabric and the ecosystem of each area give rise to several inter-company collaborations called "Synergies." There are two types, synergies of substitution and synergies of pooling.

Substitution synergies
In a substitution synergy, a resource replaces another, in whole or in part, for the benefit of both parties.

In the case of a synergy of materials such as wood, a "secondary material" replaces a raw material or the initial input. This exchange extends the life cycle of materials that pass from one hand to another. To meet the technical and physicochemical specifications of the demand, the supply offer often has to be transformed and conditioned by the parties or by a third party (decontamination, cutting, mixing).

Pooling synergy
In pooling (peers-to-peers, peers-to-peer, or peer-to-peers), the companies involved in the synergy coordinate their supply offer and demand of resources in the same value chain.

Upstream, the pooling of resources allows for economies of scale in the purchase of products and services. This aspect is not examined in this study. Downstream, many businesses can, for example, take advantage of collection services for related residual materials. A company can also "appropriate," in whole or in part, the supply available on the territory of a certain material and of a certain quality (e.g., materials for the manufacture of panels). So there is one taker for several generators.

The implementation of pooling may encounter significant logistical and operational challenges that may limit the participation of companies (e.g., quality control, contamination of the supply, traceability, cost and liability sharing, cancellation of current contracts). The concentration and quality of the flows make it possible to reach the critical quantity required for these operations to be economically feasible. The support of an impartial third party, such as an industry symbiosis facilitator, can facilitate collaboration and help develop a plan where everyone's interests are considered.

Downcycling

For the sake of consistency, synergies seek to avoid downcycling, i.e., transforming a residual material into a product of lesser value, lesser quality, and with a reduced life span or possibility of entering other transformation cycles. The challenge of applied research in industrial ecology is rather to identify sorting, conditioning, and enhancement technologies to maximize the value of material resources while avoiding their overqualification.

TABLE 8 shows the number of synergies involving wood supply offer/demand in each of the regions that shared their data. Facilitators can enter the status of a synergy, i.e., its progress, in the computer tool for evaluating synergies.

TABLE 8 Number of synergies by region and by status

REGIONS	Identified	Confirmed	Achieved	Terminated	TOTAL	% completion
Capitale-Nationale	8	4			12	< 1 %
Estrie	15		2		17	12 %
Kamouraska	12	2	5		19	26 %
Lanaudière	239	87	1		327	< 1 %
Laurentides	120				120	< 1 %
Mauricie		21			21	< 1 %
Montreal	57	23	17	1	98	18 %
Outaouais	30		15		45	33 %
Other Regions	234	34	36	3	307	13 %
TOTAL	**715**	**171**	**76**	**4**	**966**	**8 %**

Definition of status

Synergie identified	Synergy identified by Synergie Québec's automatic networking tool but not verified by the facilitator.
Synergy confirmed	Synergy confirmed by the facilitator following an analysis of the supply offer's specificities, the demand's constraints, and the companies' profile.
Synergy achieved	Synergy achieved by the corresponding companies following an analysis on their part.
Synergy terminated	Synergy achieved in the past and which is no longer in place today.

* The percentage of completion represents the number of achieved and terminated synergies out of the total number of potential synergies.

Key facts:

- The Montreal, Outaouais and Bas-Saint-Laurent regions have achieved the most synergies involving wood.
- Lanaudière, Laurentides and Bas-Saint-Laurent are projects that have collected lots of information from companies. This explains the high number of identified synergies. In fact, the more supply offers and demands are documented on a territory, the more networks are identified by Synergie Québec's computer tool.
- The process of bringing synergies to fruition relies on the close support of the companies. Experience shows that, despite a high potential for synergies based on the number of "identified" synergies, such information must be supplied and directed by the territorial facilitator so that companies can transform what they envision into a real opportunity.

4.4. OTHER INDICATORS

The Synergie Québec network has developed a system of indicators to improve the quantitative measurement of the benefits of synergies. For each type of resource, emission factors related to production, transportation, and disposal have been determined. These factors are obtained from various public and recognized databases (e.g., studies on Quebec electricity by the International Reference Centre for the Life Cycle of Products, Processes and Services [CIRAIG], ecoinvent, European Reference Life Cycle Database [ELCD], and Agribalyse).

The CTTÉI has collected numerical data on 420 synergies completed by 13 Quebec industrial symbioses. In this 2019 survey, 55 completed synergies involved forest products. The benefits are presented in **TABLE 9**. Some previously mentioned projects did not exist in 2019 or did not participate in the survey. Also, due to the very heterogeneous nature of the synergies, in terms of type of materials, quantities, and location of the companies involved, it has not been possible to extrapolate these results. It is important to note that these field data represent relatively small volumes compared to total forest sector material flows, as presented in Section 3.

TABLE 9 Synergies by region and status

REGIONS	Number of documented synergies	Reduction of material flows (kg/year)	Greenhouse gases avoided (GHGs) (CO_2 eq/year)	Operating cost reductions ($/yr)
Kamouraska	N.A.	N.A.	N.A.	N.A.
Capitale-Nationale	1	10,920	5,054	3,290
Estrie	1	2,448	492	1,171
Laurentides	N.A.	N.A.	N.A.	N.A.
Lanaudière	23	606,000	135,204	73,713
Mauricie	N.A.	N.A.	N.A.	N.A.
Montreal	6	63,840	130,227	116,767
Outaouais	1	720,000	101,058	9,000
Other Regions	44	237,267	45,964	42,825
TOTAL	**55**	**1,640,475**	**417,999**	**246,766**

The Lanaudière and Outaouais regions reported the highest volumes of material flow reduction.

Environmental circular economy model in Lanaudière centred around the willow tree
Ramo is a company located in Saint-Roch-de-l'Achigan that specializes in the development of environmental technologies based on the cultivation of short-rotation willow.

Through its Evaplant technology, Ramo uses willows to treat and remediate industrial wastewater effluents such as landfill leachate. The resources contained in this wastewater (water, nutrients, metals), which are normally regarded as contaminants to be treated, are absorbed by the willows. This accelerates the growth of willows and increases the carbon capture in the willow biomass. Willows are also used to restore degraded sites such as mines, sand pits, and quarries.

Every three years, the willows are harvested and transformed into visual and noise barriers. They in turn solve environmental problems such as urban noise and visual pollution. These green products have a carbon negative footprint and therefore also act as a carbon sink. Finally, the residues of Ramo's production (branches and leaves) are used as RCW (Ramial Chipped Wood) mulch to improve soil and its structure.

Circular development in the Outaouais – Resolute Forest Products (Maniwaki)
The Resolute Forest Products (RFP) plant located in Maniwaki is a sawmill that specializes in the production of lumber boards. Thanks to computer-assisted cutting, wood residue losses are minimized. The harvested roundwood is used to make lumber. The production residues, which total over 150,000 tonnes/year, are reused as raw material by other companies in the region.

The wood chips are processed by an RFP pulp and paper mill. Sawdust and shavings are transformed into wood panels, and bark is recovered for energy in a biomass boiler. The combustion of bark generates thermal energy which is used to dry the wood at the end of production, while the ashes (500 tonnes/year) are distributed to local farmers to enrich their soils.

This example shows the successive loops of valorization within the company as well as outside, which further diversify the industrial fabric of the region. Thus, the company's circular approach allows it to propose new forms of business and neighbourly relationships to its suppliers, customers, and the community.

Production of biofuels from residual forest biomass in the Mauricie region – Bioénergie La Tuque (BELT)
The biorefinery project in La Tuque aims to transform forestry residues to produce renewable fuel, such as biodiesel, to replace fossil fuels. Forestry residues can produce more than 200 million litres of totally renewable fuel annually.

Currently, the La Tuque biorefinery project has received the support of a large European company specialized in this field that is interested in joining the project. The Bioénergie La Tuque team is working hard to raise the necessary funds for the technical and economic studies that will lead to carrying out this project, which will require an investment of $700 million to $1 billion, in addition to creating 490 jobs in La Tuque. BELT executives are aiming for a 2023 implementation date.

5. EMERGING TECHNOLOGIES AND OPPORTUNITIES

By seeking industrial efficiency to optimize the use of resources and extend their life cycle, the circular economy promotes the development of cleaner technologies. In addition to the major enhancement options identified in the MFA, the CTTÉI has documented some of these technologies (**TABLE 10**). They are presented as a fact sheet in **Appendix V**.

TABLE 10 Emerging Wood Development Technologies

DESCRIPTION	4R-D MANAGEMENT METHOD	DEVELOPER
Technology for producing wood furniture waste-based recycled 3-D printing filament	Recycling and material recovery	Michigan Technological University (USA)
System and method for treating wastewater by means of passive phosphorus capture	Material recovery	CRIQ (Quebec)
Technology for upgrading bark from Quebec forest species	Material recovery	Innofibre (Quebec)
Pyrolysis and biochar production system — CarbonFX technology	Material recovery	Airex Energy (Quebec)
Hydrothermal liquefaction of woody biomass in compressed hot water	Energy recovery	University of Western Ontario

Technology for producing wood furniture waste-based recycled 3-D printing filament
Michigan Technological University has developed a technology to recycle wood waste from the furniture industry by producing a wood polymer composite (WPC). The technology utilizes wood furniture residues as a raw material to produce WPC filaments. The process involves the grinding and milling of two waste materials: medium-density fibreboard (MDF) and particleboard impregnated with phenolic resins. WPC filament is then used in 3-D printing, for example, to produce a wide variety of parts and components for the furniture industry.

System and method for treating wastewater by means of passive phosphorus capture
The process is used in the field of wastewater treatment and more particularly in treatment systems and methods for the dephosphatation of wastewater. The patented method involves the installation of a filter in the wastewater discharge system, lined with wood particles and activated by the impregnation of a metal hydroxide. This filter has a long service life and can be recycled at the end of its useful life by composting.

This innovative process facilitates the compliance of treated wastewater with environmental standards. It can be combined effectively with secondary treatment technologies to handle discharges in sensitive environments such as those upstream of lakes. This innovation helps provide municipalities and industry with access to simple, effective, accessible, and economically viable wastewater treatment processes.

Technology for upgrading bark from Quebec forest species
The bark of trees contains a large number of specialized metabolites and molecules of interest, some of which have biological activity and provide protection against pathogens, insects, and sunlight.

The composition of the bark is complex. To harness the potential of this biomass, the active molecules must be isolated. The Center for the Innovation of Cellulosic Products of Innofibre, a centre for technology transfer, has developed several extraction methods. These are used to obtain various mixtures of specialized metabolites in extracts from several species.

Pyrolysis and biochar production system – CarbonFX technology
CarbonFX technology uses sawdust and bark from fir, spruce, and maple trees to produce biochar via wood torrefaction. This product is delivered and used across Canada for a variety of purposes (e.g., organic farming, commercial horticulture, gardening). This technology can produce a variety of value-added biochar products on an industrial scale.

The patented CarbonFX technology is developed by Airex Energy. It can convert any type of biomass into biochar, a renewable alternative fuel that can replace traditional coal (e.g., power plants, cement plants). The Governments of Canada and Quebec are financial partners in the activities of Airex Energy. Cycle Capital Management and Desjardins Innovatech are venture capitalists.

Hydrothermal liquefaction of woody biomass in compressed hot water
Hydrothermal liquefaction (HTL) is an emerging technique. It converts biomass into biofuels. The process takes place at high pressures (5–20 MPa) and high temperatures (> 400 °C). Water is used as a solvent under subcritical or near-critical conditions.

In HTL, biomass can be converted into bio-oil, biochar, or non-condensable gases. The product characteristics and yields, such as the type of biomass, biomass/water ratio, temperature, pressure, residence time, and the presence or absence of catalysts, are highly dependent on the operating conditions of the HTL.

6. SYNERGIES AND OTHER ACTIVITIES IN THE CIRCULAR ECONOMY

6.1. REGIONAL INITIATIVES AND ACTIONS

The support of facilitators in industrial and territorial symbiosis is a plus to promote and facilitate the transition to a circular economy. Whether in the Synergie Québec network or with partners, several initiatives are aimed at transitioning the Quebec economy to a circular economy. The Quebec government is also showing interest in the opportunities that forest products present (**TABLE 11 and TABLE 13**).

TABLE 11 Quebec government initiatives concerning forest products

AUTHOR	RECOMMENDATIONS	SUMMARY
Circle Economy, for RECYC-QUÉBEC	Measuring circularity: a first step toward reaching objectives	In *The Circularity Gap Report — Quebec*, by Circle Economy [35], the proportion of primary renewable biomass (ecological cycle), including wood, food crops, and agricultural residues, is estimated at 26%.

AUTHOR	RECOMMENDATIONS	SUMMARY
	Developing circularity within the stocks	Promote green building and low-carbon materials (e.g., compare the environmental impact of wood and concrete buildings, recycling of wood products, energy efficiency, and material selection in the building sector).
	Prioritizing natural and light materials	Circle Economy believes that raw material-intensive and emission-intensive materials such as cement should be replaced by regenerative solutions such as lumber - especially if the regenerative capacity of Quebec's vast forests provides these materials in abundance. Example: glulam and cross-laminated timber manufacturing.
	Making manufacturing circular	Reduce material flows at the plant level (recovery of renewable resources, transformation of residual materials into resources).
MELCC	Recommendations of the *2030 Plan for a Green Economy* [35]	The Plan promotes the use of lower carbon footprint materials, such as wood or other bio-based materials.
HYDRO-QUÉBEC [22]	Guaranteeing supply of the resource	Promote forest biomass. To promote the development of forest biomass for energy production, it is important to have a guaranteed supply of the material. Currently, this depends on the roundwood harvest of forest producers.
	Energy recovery from logging residues	Logging residues account for a potential 4,400,000 DMT/year (2011), equivalent to 83.60 PJ. Compared to other forest biomass for which 63% to 100% of the potential has already been harvested, Hydro-Québec estimates that the potential already harvested is zero.

TABLE 12 Examples of circular economy activities related to forest products

ACTIVITIES	SUMMARY	CARRIER
Concerted action of wood sectors	Concerted action by the various players in the local value chain to improve the recovery of wood waste in the Mauricie and Portneuf RCMs (June 2021 to 2022) The data collected by this working group was used to document the barriers and levers presented in this report.	Économie circulaire Mauricie + symbiosis environnementmauricie.com/economie-circulaire-mauricie-2/
Reuse, recycling, material recovery and energy recovery of treated wood	The company recovers treated wood residues for which landfill is not a viable solution (electrical and telephone poles, railway ties, treated wood from the construction, renovation and demolition sector). Materials are sold for reuse or recycling. Some residues are crushed and then sold in the form of wood chips with a high calorific value that can be used, for example, in the production of *syngas* or in cement works Enerkem has valorized a large proportion of railway ties containing creosote and pentachlorophenol (PCP) through gasification and *syngas* production.	Tred'si (Westbury) tredsi.com Enerkem
Recovery, reclamation, marketing of CRD materials	Écochantier is a project set up by Co-éco with the help of a grant from RECYC-QUÉBEC. It consists of two reuse centres and an online store whose goal is to prioritize reuse, eliminate the disposal of recoverable materials in landfills, and preserve raw materials. This project also helps recover heritage materials and offers citizens and entrepreneurs a service to dispose	Écochantier (Saint-Pascal, Rivière-du-Loup) ecochantier.ca

ACTIVITIES	SUMMARY	CARRIER
	of their materials in an environmentally friendly manner while preserving heritage.	
Recycling of wood by-products	Creation of a line of basketry products from post-industrial veneer scraps.	Collaboration between L'Autre Fabrik (Victoriaville) and Nouveau Studio (Montreal) lautrefabrik.ca
Practical guide	Nature Québec has developed a practical guide [37] to help generators and managers of residual materials to contribute to a better use of post-consumer wood in Quebec.	Nature Québec
Practical guide	The 3R MCDQ group has produced a guide to help managers of CRD sorting centres find realistic solutions that can be implemented quickly and at low cost to optimize the recovery of post-consumer wood, thus obtaining a better resale value and establishing and maintaining trust relationships with their buyers.	Regroupement des récupérateurs et recycleurs de matériaux de construction, de rénovation et de démolition (3R MCDQ) [38]
Reuse of pallet wood	Establishment of a network for the recovery, dismantling, packaging, and manufacture of furniture made from pallet wood. The network was set up by Association Initiatives OI which offers support for the creation and development of activities in the social and solidarity economy and the circular economy. The dismantling workshop is located in a detention centre and employs inmates who are being integrated. Les Palettes de Marguerite is responsible for the manufacture of the furniture and is also a social integration association. Écopal also sells unfinished pallet wood to the public.	Écopal (Île de la Réunion, France) ecopal.re

6.2. EXAMPLES OF DOCUMENTED AND QUANTIFIED SYNERGIES

Since 2020, the Synergie Québec Community has invited its members to share the synergies achieved on their territory in a public compendium of synergies (**TABLE 13**). To do this, companies provide information about synergies so that the gains can be calculated.

To view the details of these synergies, the names of the companies, and the measured impact, see the *Book of Synergies 2021* (http://www.cttei.com/en/recueil-de-synergies-2021/).

TABLE 13 Examples of synergies achieved by Synergie Québec

INITIATIVES	SUMMARY	3 R-RD MANAGEMENT METHOD	SYMBIOSIS CARRIERS
Recycling and reuse of decorative items	A creative agency in downtown Montreal called on Écoscéno to handle decor items left behind after a move. Écoscéno has established an inventory of available material and decor items and has put them on sale in its online store.	Recycling and reusing	Écoscéno
Recycling of scrap wood for the manufacture of boats and shelves	The maple and ash scrap wood generated by one cabinetmaker are recycled by another, located nearby, to manufacture products.	Recycling	Synergie Montréal
Recycling of scrap wood for the manufacture of children's furniture and toys	Residual hardwood and Russian plywood scraps generated by one cabinetmaker are recycled by another, located nearby, to manufacture furniture.	Recycling	Synergie Montréal
Engineered wood to heat greenhouses	After validating their regulatory compliance and operability criteria, wood residues are recovered as a source of heating for greenhouses.	Energy recovery	Écosynergie d'affaires Vaudreuil-Soulanges
Recovery of contaminated melamine sawdust	When manufacturing furniture, Groupe Gibo cuts melamine boards and other engineered wood to measure. To manage its waste better, reduction was first explored. The nature of the materials limits their recycling, but the residues have found a market in energy recovery. Research on mycoremediation (decontamination by fungi) has also been conducted with Biopterre.	Energy recovery	Kamouraska Circular Economy

In some of these examples, social economy organizations are involved at different levels (conditioning, transformation, manufacturing, etc.). Already active in many of the circular value chains in Quebec, social economy enterprises are called upon to play a growing role in the transition. The Territoires innovants en Économie sociale et solidaire (TIESS) research centre is conducting research on the relationship between the social economy and the promising business models offered by the circular economy (tiess.ca/economie-circulaire).

7. VALORIZATION IN THE FOREST SECTOR: CHALLENGES AND LEVERS

As the MFA results show, the circularity of wood flows in Quebec is high. However, some sources are poorly or not at all valorized in the sector. Moreover, symbiosis facilitators in the field and the companies they support are constantly bringing forestry residues back to the centre of their regional economic, environmental, and even social considerations. Common issues raised are the lack of supply of quality local secondary materials, the management of post-consumer wood residues and the difficulty of pooling small volumes of residues.

Based on this experience, the CTTÉI has identified the main challenges and levers, both general and specific. (**TABLE 14**) These challenges include those identified during the ECM+ consultation activities. The issues associated with the production of electricity from forest biomass identified by HYDRO-QUÉBEC [23] are also reported.

TABLE 14 Challenges and levers

CHALLENGES	Identified challenges[7]	LEVERS AND SOLUTIONS
PRODUCING QUALITY SECONDARY MATERIALS AND STIMULATING DEMAND		
Having access to a Quebec supply of quality secondary materials (wood by-products). Processing and developing residual materials. Developing new markets. Reducing and amortizing costs.	**Harvesting:** How to coordinate the recovery of maximum biomass from mixed forests and direct the right species to the right plants? How to limit infrastructure costs and address equipment shortages for forest roads? Loss of biodiversity and soil depletion if insufficient logging residue is left on site. Decrease of agricultural surface for human food, intensification of soils, use of pesticides linked to the production of electricity from forest biomass. **Primary processing:** How to improve the sorting of residues to avoid contamination of materials, especially cross-contamination, which impacts the whole flow? **Secondary processing and distribution:** How to ensure the quality of the recycled material coming into the company? How to establish a solid supply chain from Quebec's sorting centres? How to reduce wood processing costs? How to add value to residues? **Use:** How to increase the supply offer of local, accessible, circular wood products? How to encourage agricultural producers to favour forest biomass? How to manage regulatory constraints? For example, the City of Montreal prohibits the installation of non-certified fireplaces and wood stoves that use fuels other than wood pellets, natural gas, and propane. The Communauté métropolitaine de Montréal authorizes the use of virgin wood only, while residual materials could meet these specifications. **Disposal and end of life**: How to operationalize the ban on wood disposal? How to increase the reclamation of pulp and paper residues other than through energy recovery? How to amortize the costs associated with deconstruction for contractors? Production of final residues linked to the transformation of biomass (e.g., wood ash) sometimes difficult to valorize because of the presence of metals.	Establish integrated sorting sites to better direct materials and avoid further transportation. Conduct information, awareness, and educational activities (guides, webinars, training). Train workers in CRD sorting centres. Encourage upstream sorting. Establish clear standardized categories and criteria for the different grades of wood residues. Encourage the community through consultation activities to open dialogue and create solutions. Create structured networks of companies and local actors (e.g., industrial and territorial symbioses, circular economy approach). Create networks of users of forest biomass generated heat (micro-symbioses). Financially support Quebec's industry in the manufacturing of circular wood products. Favour responsible consumption. Support the transition of energy. Take stock of innovative technologies for sorting, conditioning, recycling, and other forms of wood valorization. Identify existing technologies in Europe and Asia where there are more and better examples of valorization. Promote eco-design (e.g., design incorporating easy dismantling aspects, limiting metal hardware, and multi-material products with low recyclability). Set up mechanisms to recover end-of-life wood products (e.g., extended producer responsibility, economy of functionality and cooperation). Implement mechanisms to effectively limit disposal (e.g., polluter pays principle, extended producer responsibility). Limit the expansion of landfill sites. Explore new circular business models to meet new consumer demand (e.g., renting, economy of functionality and cooperation). Give monetary value to wood residues.

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[7] These challenges include those identified during the ECM+ consultation activities.

OPTIMIZE THE SUPPLY CHAIN		
Logistics and transportation Handling and storage	**Harvesting:** When residual materials are taken to the ecocentres, there are significant travel costs. The cost of insurance is considered very high by timber carriers, which limits supply and increases costs. How to manage surplus biomass waste? How to manage inventory variations due to the seasonality of activities? How to better manage the legal aspects of large storage sites for which a certificate of authorization is required? Emission of air contaminants during the combustion and transportation of biomass. Increased road transport for logging residues. Impacts related to the storage of biomass: leaching of contaminants, visual and olfactory nuisances. **Primary processing and distribution:** How to set up viable pooled channels (costs, distances) for the residues of several generators so as to get the resource to the takers? How to avoid cross-contamination? How to valorize the fines? Emission of air contaminants during the combustion and transportation of biomass. Increased road transport for logging residues. **Use:** How to integrate consumers or users into the supply chain? **Disposal and end of life**: How to reduce transportation costs for the disposal of final wood waste? How to ensure the viable return of wood products to the reclamation companies? How to avoid the haphazard disposal of wood in waste and containers?	Establish industrial ecocentres for businesses or adapt municipal ecocentres. A fee could be charged to businesses for these services. The infrastructure must allow for the handling and storage of materials in terms of quantity and quality. Increase the number of drop-off locations in areas where wood waste is generated (industrial parks, curbside collection). Encourage the community through consultation activities to open dialogue and create solutions. Create structured networks of companies and local actors (e.g., industrial and territorial symbioses, circular economy approach). Carry out research and development work to find outlets for final wood waste. Take stock of innovative technologies for sorting, conditioning, recycling, and other forms of wood valorization. Benchmark solutions in Europe and Asia, where there are more and better examples of valorization. Propose adaptations to waste collection containers and partitioning systems.
INCREASE SKILLS		
Knowledge development and sharing	Lack of political will Lack of knowledge about funding programs Labour shortages and staff turnover How to ensure the replacement of skilled workers and bring dynamism to the forest sector when there are not enough graduates from specialized training programs to meet the demand? Ethical questioning about the production of agri-food biomass for energy production rather than for animal feed. How to encourage the sharing of good practices without affecting the competitiveness of companies?	Encourage the community through consultation activities to open dialogue and create solutions. Create structured networks of companies and local actors (e.g., industrial and territorial symbioses, circular economy approach). Conduct information, awareness, and educational activities (guides, webinars, training). Train workers in CRD sorting centres. Encourage upstream sorting. Map biomass supply pools and users. Establish a culture of innovation and collaboration between companies and other ecosystem actors in a territory.

DISCUSSION AND CONCLUSION

The main objective of this mandate was to evaluate the level of circularity of the Quebec forest sector. In order to do so, a material flow analysis identifying the movements and rates of use of the main forest products was performed as well as an overview of the data and experiences of the Synergie Québec Community.

High level of circularity for most forest products in Quebec!

The results of the MFA, presented as a Sankey diagram, show that most of the raw materials, mainly roundwood, from forest management are processed by sawmills. The joint products of sawmills supply pulp and paper mills, mainly with wood chips, wood composite panel plants, and cogeneration and energy products plants, while lumber is consumed in the construction of wood infrastructure. Pulp and paper mills produce pulp from recycled wood and fibre, which in turn is used to produce paper and paperboard. These are then consumed by the residential and ICI sectors. In terms of panels, roundwood, and other wood residues are processed into structural panels (e.g., OSB, veneer and plywood) and non-structural panels (e.g., insulation panels) that are used by the residential and ICI sectors. As for cogeneration and energy products plants, wood residues are transformed into wood pellets, charcoal, and other products such as densified wood fibre logs. They are used by the consumption process. These plants also generate a significant amount of thermal and electrical energy that has not been accounted for in this MFA. Post-consumer materials, such as paper, paperboard, and CRD wood, leave the sorting centres and ecocentres to be recycled or partially recycled by pulp and paper mills, panel plants, and cogeneration and energy product plants. Various forest products are imported and integrated at different points in the wood processing chain, while a significant number of products are exported elsewhere in Canada or internationally.

The results of the rate of use calculations for the major forest products suggest that most of them are fully used/valorized if exports are considered as a form of use. **The products with the lowest rates of use are logging residues (2%) and CRD wood (32%)**. Although not evident from the results, paper and paperboard rates of use should also show some room for improvement, as curbside collection recovery rates are not perfect, nor are sorting facility recycling rates. If we exclude imports and exports from the equation, **Quebec rates of use are significantly lower for most products, particularly for logging residues (2%), newsprint (17%), particleboard (28%), and CRD wood (32%)**. This indicates that exports play an important role in the use of forest products, and that **there appear to be significant gaps in the local valorization of post-consumer products**. Adding the fact that the allowable cut is only about 60% utilized, the potential to produce and utilize more forest products is substantial.

In short, despite the many innovative initiatives put forward, **the results of this study suggest that the level of circularity of the Quebec forest sector, based solely on rates of use, is relatively low for some products yet high for others**. Indeed, some specific products, such as logging residues and CRD wood, have significant room for improvement. However, it is important to remember that there are many uncertainties related to the data, conversion factors, the various sources of information consulted, the assumptions made to simplify the analysis, and the non-exhaustiveness of the MFA. In addition, the evaluation of circularity, which is a subjective assessment by the CTTÉI, was based on the overview of the results and the sources of information consulted, not on a quantitative analysis of the results. Thus, it would have been interesting to use the system of circularity indicators developed by the CTTÉI's Research Chair in Industrial and Territorial Ecology (CRÉIT) to carry out a more quantitative assessment, and to obtain an understanding of the quality of current opportunities based on the 4R principle. Besides using the indicator system, other elements could complement this analysis: (i) refining the data collected, particularly those concerning paper and paperboard, which could not be properly compiled within the framework of this study; (ii) incorporating certain products that were not included, but whose tonnage could be significant, such as paper sludge; (iii) taking into account inventory data; (iv) periodically updating the MFA to see the changes in the level of circularity over time.

The linear economy: not seeing the forest for the trees

The MFA results show that the circularity of the forest sector is relatively low for some products. This renewable resource lends itself to all circularity strategies without exception. The experience of the Synergie Québec network shows that regional initiatives represent only a fraction of the real potential of the wood residues still available. Nevertheless, these synergies testify to the remarkable dynamism of local businesses and the close support of the organizations that support them. There is a great deal of inventiveness and willingness. To take this to another level, investing efforts to give structure to the sector would help guide the actors in the co-creation of solutions.

The recent impacts of COVID-19 on the growing demand for wood are not yet well documented. There has been an impact on prices but also on the end-of-life of all these products, which are still in an economy that is too linear. These challenges are in addition to the issues and considerations already facing companies and organizations working in the Quebec forest sector. To respond to this, the best-informed territories are investing in support and backing local initiatives. Several other possible solutions were presented.

This study presented some emerging technologies and opportunities drawn primarily from Canada and the United States. But what about Europe or Asia? Many of these countries have a head start in the circular economy, especially in terms of legislation. To further explore advances in the forest sector, the CTTÉI recommends that clients look beyond our borders.

REFERENCES

[1] Center for Intersectoral Studies and Research on the Circular Economy (CERIEC). (n.d.). Enjeux et définition. Accessed at https://www.quebeccirculaire.org/static/Enjeux-et-definition.html

[2] Compaore, U. L. (2017). Analyse de flux de matière du cuivre au Québec pour le développement de stratégies de circularité (Doctoral dissertation, École Polytechnique de Montréal).

[3] P. H. Brunner et H. Rechberger. (2004). *Practical handbook of material flow analysis*, vol. 9.

[4] Nissing, C. & Von Blottnitz, H. (2007). A material flow analysis of wood and paper in Cape Town: is there potential to redirect flows in formal and informal sectors to foster use as a renewable resource? International journal of environment and sustainable development, 6(2), 147–157.

[5] Parobek, J., Paluš, H., Kaputa, V., & Šupín, M. (2014). Analysis of wood flows in Slovakia. BioResources, 9(4), 6453–6462.

[6] Ghafghazi, S., Lochhead, K., Mathey, A. H., Forsell, N., Leduc, S., Mabee, W. & Bull, G. (2017). Estimating mill residue surplus in Canada: a spatial forest fiber cascade modeling approach. Forest Products Journal, 67 (3–4), 205–218.

[7] Lenglet, J., Courtonne, J. Y. & Caurla, S. (2017). Material flow analysis of the forest-wood supply chain: A consequential approach for log export policies in France. Journal of Cleaner Production, 165, 1296–1305.

[8] Marques, A., Cunha, J., De Meyer, A., & Navare, K. (2020). Contribution Towards a Comprehensive Methodology for Wood-Based Biomass Material Flow Analysis in a Circular Economy Setting. Forests, 11(1), 106.

[9] Gouvernement du Québec. (2018). Les produits forestiers, une richesse à cultivar — Stratégie de développement de l'industrie Québécoise des produits forestiers 2018-2023. Accessed at https://mffp.gouv.qc.ca/wp-content/uploads/Strategie-industrie-foret-2018-2023.pdf

[10] Ressources et industries forestières du Québec, portrait statistique 2019, MFFP, décembre 2020.

[11] MFFP. (2020). Chiffres-clés du Québec forestier — Édition 2020. Accessed at https://mffp.gouv.qc.ca/wp-content/uploads/chiffres-cles.pdf

[12] MFFP. (2021). Inventaire mensuel de copeaux SEPM au Québec — Février 2021. Accessed at https://mffp.gouv.qc.ca/wp-content/uploads/Inventaire-copeaux.pdf

[13] MFFP. (2016). Production et utilisation des sous-produits générés par les entreprises de deuxième transformation du bois du Québec en 2015. Accessed at https://mffp.gouv.qc.ca/publications/forets/entreprises/sous-produit-bois-2015.pdf

[14] MFFP. (2018). Industrie des panneaux composites à base de bois : Produits et potential de marché en Amérique du Nord. Accessed at https://mffp.gouv.qc.ca/publications/forets/entreprises/Industrie_panneaux.pdf

[15] Ministère des Ressources naturelles et de la Faune (MNRF). (2009). Vers la valorisation de la biomasse forestière : Un plan d'action. Accessed at https://mffp.gouv.qc.ca/publications/forets/entreprises/plan-action-biomasse.pdf

[16] Canadian Council of Forest Ministers (CCFM). (n.d.). National Forestry Database — Wood Supply. Accessed athttp://nfdp.ccfm.org/en/data/woodsupply.php

[17] CCFM. (n.d.). National Forestry Database — Harvest. Accessed athttp://nfdp.ccfm.org/en/data/harvest.php

[18] Natural Resources Canada (NRCan). (n.d.). Canadian Forest Service — Statistical data Accessed at https://scf.rncan.gc.ca/statsprofile/forest/QC

[19] Statistics Canada. (n.d.). Canadian International Merchandise Trade Database — Table 980-0047.

[20] MFFP. (2020). Compilation des données issues des registres forestiers 2019. Accessed at https://mffp.gouv.qc.ca/wp-content/uploads/registres-forestiers.pdf

[21] Recyc-Québec. (2020). Bilan 2018 de la gestion des matières résiduelles au Québec. Accessed at https://www.recyc-quebec.gouv.qc.ca/sites/default/files/documents/bilan-gmr-2018-complet.pdf

[22] Fédération des producteurs forestiers du Québec (FPFQ). (2021). La forêt privée chiffrée. Accessed at https://www.foretprivee.ca/wp-content/uploads/2021/07/La-foret-privee-chiffree-2021.pdf

[23] Hydro-Québec. (2021). A renewable energy option: Biomass power. Accessed at https://www.hydroquebec.com/data/developpement-durable/pdf/file-biomass.pdf

[24] Kostiuk, Alan P. et Pfaff, F. (1997). Conversion factors for the forest products industry in eastern Canada.

[25] Food and Agriculture Organization of the United Nations (FAO). (2010). Forest product conversion factors for the UNECE region. Accessed at http://www.fao.org/3/ca7952en/CA7952EN.pdf

[26] Office Québécoise de la langue française (OQLF). (2016). Fiche terminologique — Possibilité de coupe [Terminology record — Allowable cut]. Accessed at http://gdt.oqlf.gouv.qc.ca/ficheOqlf.aspx?Id_Fiche=17494292

[27] *Sustainable Forest Development Act*, R.S.Q., c. A -18.1.

[28] *Regulation respecting the sustainable development of forests in the domain of the State*, A-18.1, r. 0.01.

[29] Appita. (2015). Technology of pulping and paper making. *Australia & New Zealand Pulp & Paper Industry Guide 2015*. Accessed at https://appita.com/images/training/Glossary_papermaking_terms_used.pdf

[30] NRCan. (2020). AshNet. Accessed at https://www.nrcan.gc.ca/science-data/research-centres-labs/forestry-research-centres/great-lakes-forestry-centre/ashnet/20279

[31] Achim, A. (2021). *Bioenergy as a solution to improve forest management*. A virtual presentation given at the Biomass Technology Laboratory Seminar, Laval, Quebec, Canada. Accessed at https://www.youtube.com/watch?v=NEYTWaYHlZA

[32] MFFP. (2021). L'économie circulaire : l'exemple du secteur forestier Québécois. Accessed at https://www.lesoleil.com/la-vitrine/la-foret-dici-plus-verte-que-jamais/leconomie-circulaire-lexemple-du-secteur-forestier-quebecois-b5119dafc51cb579389365bf9215c954

[33] Innofibre. (n.d.). Thermoformed cellulosic pulp eco-products. Accessed at https://innofibre.ca/en/services/thermoformed-cellulosic-pulp-eco-products/

[34] Dulac, S. (2017). Ce qu'il est important de savoir sur le chauffage au bois! Accessed at https://www.spbestrie.qc.ca/wp-content/uploads/2014/09/INFO-BOIS-DE-CHAUFFAGE2.pdf

[35] Circle Economy (2021). THE CIRCULARITY GAP REPORT — Quebec. Accessed at https://www.recyc-quebec.gouv.qc.ca/sites/default/files/documents/rapport-indice-circularite-en.pdf

[36] MELCC. (2020). Politique-cadre d'électrification et de lutte contre les changements climatiques. Accessed at https://cdn-contenu.quebec.ca/cdn-contenu/adm/min/environnement/publications-adm/plan-economie-verte/plan-economie-verte-2030.pdf?1605549736

[37] Nature Action. (2017). Guide pratique de gestion du bois post-consommation — Faire flèche de tout bois. Accessed at https://naturequebec.org/projets/faire-fleche-de-tout-bois

[38] 3R MCDQ. (2020). Guide de meilleures pratiques — Bois de CRD en centre de tri. Accessed at www.recyc-quebec.gouv.qc.ca/sites/default/files/documents/guide-meilleures-pratiques-bois-CRD-centre-de-tri.pdf

APPENDIX I

Conversion Factors

Products[1]	Conversion factor	Note
Roundwood	444 kg/m^3	Calculated based on the proportion of softwood (78%) and hardwood (22%) harvested and their respective density of 420 kg/m^3 (international average) and 527 kg/m^3 (US). Dry basis, without bark
Firewood	563 kg/m^3	Dry basis
Paper, paperboard, and pulp	0.9 DMT/MT	A moisture content of 10% is assumed for these products
Wood from deconstruction (CRD)	420 kg/m^3	The same density as softwood lumber is assumed
Wood particles (e.g., wood chips)	444 kg/m^3	Wood particles are assumed to have the same density as roundwood
Chipboard panels	637 kg/m^3	For a mixture of OSB, waferboard, and non-OSB panels. Average calculated based on a density of 661 kg/m^3 for non-OSB panels and 613 kg/m^3 for others
Plywood	614 kg/m^3	For a mixture of softwood and non-softwood plywood. Average calculated based on a density of 584 kg/m^3 for softwood plywood and 643 kg/m^3 non-softwood.
Veneer — Softwood	9.64 kg/m^2	For a thickness of 0.0165 m and a density of 584 kg/m^3
Other forestry products	444 kg/m^3	Other forest products are assumed to have the same density as roundwood.

1: Materials included in the analysis but not included in this table were already available in the correct units in the information sources consulted, and therefore did not require conversion.

APPENDIX II

Stages, Processes, Goods, and Flows

Process	Inflows	Outflows
Forest management		
Mobilization	Allowable cut	Harvested volume
		Unharvested volume
Felling and harvesting	Harvested volume	Roundwood
		Logging residues
Processing		
Sawing	Roundwood	Lumber
	Bark	Wood chips
		Sawdust and shavings
		Bark
Pulp and paper (PP)	Roundwood	Newsprint
	Wood chips	Other paper
	Sawdust and shavings	Pulps
	Recycled paperboard	Paperboard
	Recycled paper	
	Pulps	
	Wood residues	
	Bark	
Cogeneration and energy products	Wood chips	Electrical energy
	Sawdust and shavings	Thermal energy
	Bark	Wood pellets and charcoal
	CRD wood	Densified wood fibre logs
	Wood residues	Wood ash
Veneer and plywood and chipboard panels	Roundwood	Particle board
	Wood chips	Veneer and plywood
	Wood residue	OSB
	Sawdust and shavings	Medium density fibreboard (MDF)

Consumption		
Residential and ICI consumption	Newsprint	Paper and paperboard
	Other paper	Post-consumer fibre
	Paperboard	CRD wood
	Shingles	Railway ties
	Horticultural mulch	Wood ash
	Firewood	
	Wood pellets and charcoal	
	Densified wood fibre logs	
	Wood ash	
	Lumber	
	Bark	
	Particleboard	
	Veneer and plywood	
	OSB	
	Medium density fibreboard (MDF)	
	Thermal energy	
	Electrical energy	
System boundary		
Imports/Exports	Wood chips	Wood chips
	Sawdust and shavings	Bark
	Bark	Roundwood
	Roundwood	Other paper and paperboard
	Pulpwood	Newsprint
	Newsprint	Pulps
	Other paper and paperboard	Plywood
	Pulps	Veneer
	Lumber	Post-consumer fibre
	Particleboard	Lumber
	Veneer and plywood	Sawdust and shavings
	OSB	Particle board
	Medium density fibreboard (MDF)	Veneer and plywood
		OSB

APPENDIX III

Sources of Imprecision and Uncertainty in Synergie Québec Data

Any attempt at characterization based on external data sets contains sources of bias and uncertainty. While it is not possible to precisely quantify this margin of error, it is important to identify the sources of imprecision so as to better interpret the results.

Response rate

The data collection questionnaire in Synergie Québec's software did not necessarily have the same response rate for all of its sections. The search for "hot spots" and waste supply and management issues is often prioritized over the completeness of material flows in companies. The response rate also varies from region to region depending on the resources invested in data collection.

Representativeness of activity sectors and materials by sector

In all cases, due to the small sample size and frequently partial answers of the respondents, it is not possible to obtain a varied range of generated residual materials.

Quantity of materials (inputs and outputs)

Indicators expressing the quantity of materials in supply and in demand are not presented in this report to maintain the confidentiality of the respondent companies. Although not specifically named, the regional nature of the data may indirectly identify the companies. Data on material quantities cannot be extrapolated due to the unrepresentative nature of the sample.

CRIQ data and interpretation

The CRIQ database is not exhaustive and therefore does not include all jobs in a region. For ICRIQ, it is possible that jobs are attributed to the administrative region of a company's headquarters rather than its branch office. In Synergie Québec's database, it is possible that a symbiosis could be documenting companies located outside its territory. For these reasons, it is normal that the ratio between jobs in the Synergie Québec database and those in ICRIQ exceeds 100%.

APPENDIX IV

Synergie Québec Data

Supply Offer Pools (Outputs) — Wood Categories and Subcategories

For each NAICS sector, the categories with the most supply offers are highlighted in orange (**TABLE 15**). Since the number of respondents is much higher for sector 321, it also has the most supply offers listed.

TABLE 15 Supply offers by wood subcategories for each NAICS sector (119 supply offers)

Categories	NAICS 113 Forestry and logging	NAICS 321 Wood product manufacturing	NAICS 322 Paper manufacturing
Other	3	19	3
Contaminated wood		2	
Engineered wood	4	21	
Hardwood	2	35	4
Mixed wood		12	
Forestry residues	5	8	1
TOTAL	**14**	**97**	**8**

Sectors other than 113, 321, and 322 account for 339 supply offers in the Synergie Québec database, the most important of which (by number) are presented in **TABLE 16**.

TABLE 16 Supply offers by wood categories for other NAICS sectors (90 supply offers out of 339)

Categories	NAICS 332 Fabricated metal product manufacturing	NAICS 337 Furniture and related product manufacturing	NAICS 562 Waste management and remediation services
Other	6	11	4
Contaminated wood		1	1
Engineered wood	3	15	3
Hardwood	8	18	
Mixed wood		5	12
Forestry residues			3
TOTAL	**17**	**50**	**23**

Supply Offer Pools (Outputs) — Subcategories

For each NAICS sector, the categories with the most offers are highlighted in orange (**TABLE 17**). Since the number of respondents is much higher for sector 321, it also has the most supply offers listed.

TABLE 17 Supply offers by wood subcategories for each NAICS sector (119 bids)

Categories	NAICS 113 Forestry and logging	NAICS 321 Wood product manufacturing	NAICS 322 Paper manufacturing
Other	6	29	4
Contaminated wood (B/2 grade)		1	
Contaminated wood (B/3 grade)		1	
Mixed wood		12	
Wood chips	1	2	
Wood chips		6	2
Bark	2	3	
Hardwood dust and sawdust	1	13	
Dust, wood chips, and sawdust from engineered wood	1	4	
Scrap wood	2	11	
Scrap hardwood	1	15	2
TOTAL	**14**	**97**	**8**

Sectors other than 113, 321, and 322 account for 339 supply offers, the largest of which (in number) are shown in **TABLE 18**. These data should also be considered as evidence of the presence of wood in the residual materials of other sectors. It is also possible that the facilitators who collected the information did not assign the correct NAICS code.

TABLE 18 Supply offers by wood subcategories for each NAICS Other sector (90 bids 339)

Categories	NAICS 332 Fabricated metal product manufacturing	NAICS 337 Furniture and related product manufacturing	NAICS 562 Waste management and remediation services
Other	8	12	7
Contaminated wood (B/2 grade)		1	1
Contaminated wood (B/3 grade)			
Mixed wood		5	12
Wood chips		1	1
Wood chips		3	
Bark			
Hardwood dust and sawdust		8	
Dust, wood chips, and sawdust from engineered wood		5	
Scrap wood	3	9	2
Scrap hardwood	6	6	
TOTAL	**17**	**50**	**23**

Demands (Inputs) — Wood Categories and Subcategories

For each NAICS sector, the categories with the most demands are highlighted in orange (**TABLE 22**). Since the number of respondents is much higher for sector 321, it also has the most demands listed.

TABLE 19 Demands by wood subcategories for each NAICS sector (60 demands)

Categories	**NAICS 113** Forestry and logging	**NAICS 321** Wood product manufacturing	**NAICS 322** Paper manufacturing
Other	4	23	1
Contaminated wood		1	
Engineered wood	1	5	1
Hardwood	1	12	
Mixed wood	1	5	2
Forestry residues	1	2	
TOTAL	**8**	**48**	**4**

Sectors other than 113, 321, and 322 account for 67 demands, the largest of which (in number) are shown in **TABLE 20**. These data should also be considered as evidence of the presence of wood in waste materials from other sectors. It is also possible that the facilitators who collected the information did not assign the correct NAICS code.

TABLE 20 Demands by wood categories for other NAICS sectors (67 demands)

Categories	**NAICS 111** Crop production	**NAICS 337** Furniture and related product manufacturing	**NAICS 562** Waste management and remediation services	**NAICS 710** Arts, entertainment and recreation
Other	1	6	6	3
Contaminated wood				
Engineered wood	4	5	3	3
Hardwood	8		3	3
Mixed wood	7		4	2
Forestry residues	5	2		2
TOTAL	**25**	**13**	**16**	**13**

Demand Pools (Inputs) — Subcategories

For each NAICS sector, the categories with the most demands are highlighted in orange (**TABLE 21**). Since the number of respondents is much higher for sector 321, it also has the most supply offers listed.

TABLE 21 Demands by wood subcategories for each NAICS sector (60 demands)

Categories	NAICS 113 Forestry and logging	NAICS 321 Wood product manufacturing	NAICS 322 Paper manufacturing
Other	6	28	1
Contaminated wood (B/2 grade)			
Contaminated wood (B/3 grade)		1	
Mixed wood	1	5	2
Wood chips		1	1
Wood chips		1	
Bark		1	
Hardwood dust and sawdust			
Dust, wood chips, and sawdust from engineered wood			
Scrap wood	1	4	
Scrap hardwood		7	
TOTAL	8	48	4

Sectors other than 113, 321, and 322 account for 191 demands, the largest of which (in number) are shown in **TABLE 22**.

TABLE 22 Demands by wood subcategories for other NAICS sectors (42 demands)

Categories	NAICS 337 Furniture and related product manufacturing	NAICS 562 Waste management and remediation services	NAICS 710 Arts, entertainment and recreation
Other	12	6	5
Contaminated wood (B/2 grade)			
Contaminated wood (B/3 grade)			
Mixed wood		4	2
Wood chips			1
Wood chips		1	1
Bark			
Hardwood dust and sawdust		1	1
Dust, wood chips, and sawdust from engineered wood		1	1
Scrap wood	1	2	1
Scrap hardwood		1	1
TOTAL	**13**	**16**	**13**

ANNEXE V

Débouchés émergents pour la mise en valeur des sous-produits du secteur forestier

La hiérarchie des 3RV-E

Selon la *Politique québécoise de gestion des matières résiduelles,* les 3RV-E sont la hiérarchie des actions à privilégier pour une saine gestion des matières résiduelles soit la Réduction à la source, le Réemploi, le Recyclage-compostage et la valorisation. L'Élimination des matières constitue le dernier recours.

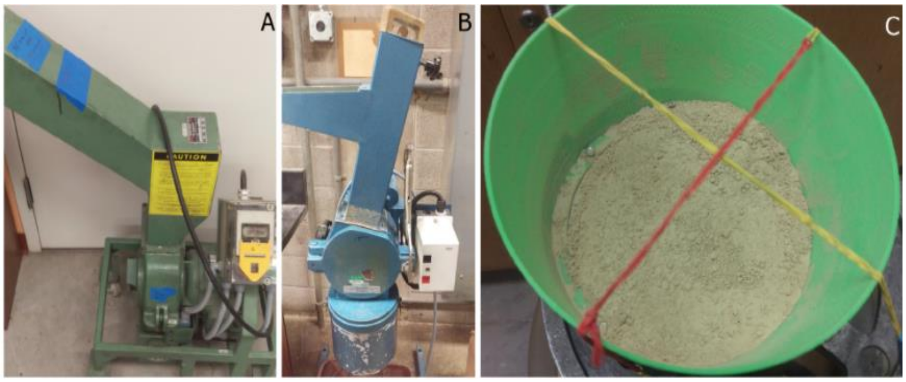
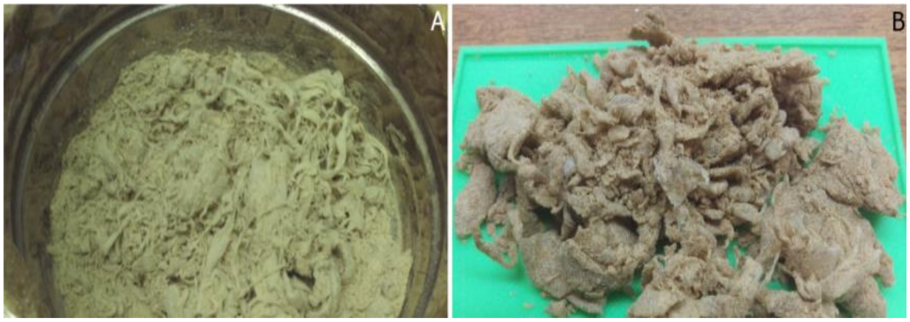
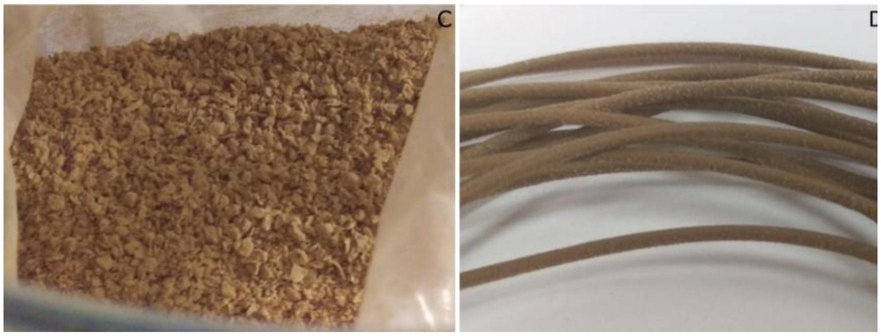
Les fiches suivantes utilisent cette typologie.

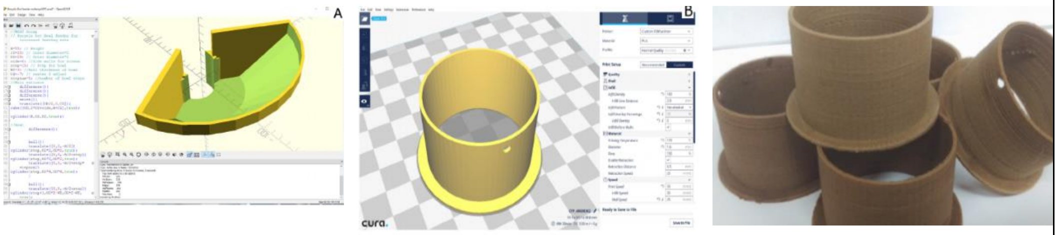
Hiérarchie de 3RV-E

MODES DE GESTION	DÉFINITION
Réduction à la source	Action permettant de prévenir ou de réduire la génération de résidus lors de la conception, de la fabrication, de la distribution et de l'utilisation d'un produit.
Réemploi	Utilisation répétée d'un produit ou d'un emballage, sans modification importante de son apparence ou de ses propriétés
Recyclage-compostage	Série d'opérations menant à la réintroduction d'une matière résiduelle dans un processus de fabrication ou de transformation menant à un produit de même nature, y compris la réintroduction des matières organiques putrescibles dans le cycle biologique.
Valorisation matière	Utilisation d'une matière résiduelle en remplacement d'une autre matière pour en faire un produit différent du produit initial.
Valorisation énergétique	Utilisation des matières qui ne peuvent être réemployées, recyclées ou valorisées (valorisation matière), mais qui ont suffisamment de potentiel calorifique pour produire de l'énergie utile (chaleur, vapeur ou électricité), sous réserve du respect des critères établis.

Technologie de production de filament d’impression 3D recyclé à base de déchets de meubles en bois

RECYCLAGE ET VALORISATION MATIÈRE

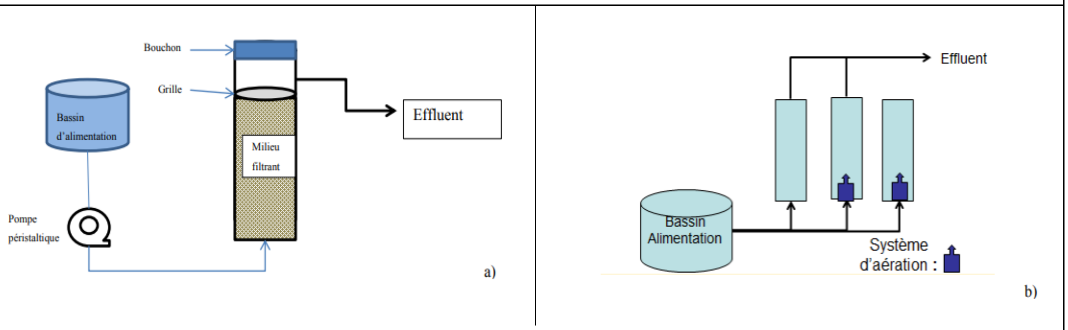
DESCRIPTION DE LA TECHNOLOGIE	
Mise en contexte	L’Université technologique de Michigan (Département de science et d’ingénierie des matériaux, École des ressources forestières et des sciences de l’environnement, Département de génie électrique et informatique) a développé une technologie pour valoriser les résidus de bois de l’industrie de l’ameublement en produisant un composite (*wood polymer composite*, WPC).
Présentation	La présente technologie vise à utiliser les résidus de meubles en bois comme matière première pour fabriquer du filament WPC. Le procédé utilise le broyage et le fraisage de deux matières résiduelles : des panneaux de fibres de bois MDF (*medium-density fiberboard*) et de particules de papier imprégné de résines phénoliques. Le filament WPC est utilisé par la suite dans l’impression 3D, pour, par exemple, produire une grande diversité de pièces et de composants pour l’industrie du meuble.
Procédé	Quatre étapes sont nécessaires pour la production de WPC à partir des résidus de bois ainsi que de la sciure de bois (taille ≤ 1 mm).
Étape 1	 Réduction et mise à l’échelle à l’aide d’un déchiqueteur de bois. La taille des particules à atteindre est de 80 microns.
Étape 2	 Mélange de la poudre de bois obtenue à l’étape dans 1 avec le polymère (acide polylactique $[C_3H_4O_2]_n$).
Étape 3	 Extrusion du mélange en filament de densité et d’épaisseur homogènes pour lui donner des propriétés uniformes.

DESCRIPTION DE LA TECHNOLOGIE	
Étape 4	 Chargement de l'imprimante 3D avec le filament et impression. L'objet à fabriquer doit être préalablement modélisé dans un logiciel de modélisation 3D, importé dans un logiciel de découpage, puis téléchargé dans le logiciel de l'imprimante 3D.
ASPECTS TECHNIQUES	
Dimensions d'impression	Hauteur de la couche : 0,15 mm Épaisseur de la couche : 1 mm Épaisseur supérieure/intérieure : 1 mm
Densité de remplissage	33 %
Température d'impression	185 °C
Diamètre du filament	1,65 mm
Vitesse d'impression	62,5 mm/s
Vitesse de déplacement	100 mm/s
AVANTAGES ET LIMITES	
Avantages	• Être implantée dans n'importe quelle industrie de manière simple ; • Ne pas avoir de contraintes environnementales particulières ; • Avoir une flexibilité de production : L'impression 3D permet de produire différents objets en modifiant la géométrie, les dimensions, etc.
Limites	• Peu de maturité technologique : La méthode a été développée en laboratoire. Plusieurs paramètres sont à contrôler (p. ex. température d'impression, vitesse d'impression, modélisation 3D) ; • Le mélange de matières peut affecter la recyclabilité des produits en fin de vie s'ils ne peuvent réintroduire des procédés compatibles. La séparation par recyclage chimique semble peu envisageable ; • Qualité de filament : Le filament WPC est moins homogène que le filament « neuf ou pur ». Des problèmes de colmatage pendant l'impression ont été observés. Cela a un impact sur la diversité et le type de pièces qui peuvent être produites. Pour éviter le sous-cyclage, de la recherche et du développement sont nécessaires pour améliorer cet aspect.
DÉVELOPPEMENT COMMERCIAL	
Technologie brevetée	s.o.
Coûts	Le marché de vente de meubles à base de bois WPC devrait être évalué.
RÉFÉRENCES	
Adam Pringle, Mark Rudnicki, Joshua M Pearce, Forest Products Journal 68 – November 2017 pearce@mtu.edu	

Système et méthode de traitement des eaux usées utilisant la capture passive de phosphore

DESCRIPTION DE LA TECHNOLOGIE	
Présentation	Le procédé concerne le domaine du traitement des eaux usées et plus particulièrement les systèmes et méthodes de traitement effectuant la déphosphatation des eaux usées. La méthode brevetée consiste à installer, dans les dispositifs de rejet des eaux, un filtre garni de **particules de bois** activé par l'imprégnation d'un métal sous forme d'hydroxyde. Ce filtre possède une grande longévité et peut être valorisé en fin de vie utile entre autres par le compostage. Ce procédé innovant facilite la conformité des eaux usées traitées aux normes environnementales. Il peut être combiné avantageusement à des technologies de traitement secondaire pour des rejets en milieux sensibles tels ceux en amont des lacs. Cette innovation contribue à donner accès aux municipalités et à l'industrie à des procédés de traitement des eaux usées simples, performants, accessibles et économiquement viables.
Procédé	Le centre de recherche industriel du Québec (CRIQ) a développé cette technologie passive de capture du phosphore des eaux usées municipales afin de compléter le traitement effectué par un procédé de biofiltration Biosor^{MD}. Considérant la présence de copeaux de bois dans le biofiltre Biosor^{MD} et le faible coût du matériel sur le territoire, l'utilisation d'un média activée à base des broyures de bois a été favorisée par rapport à d'autres médias de captation. Les broyures activées sont recouvertes d'hydroxyde de fer pour augmenter leur affinité chimique avec le phosphore. Une technique d'activation des broyures a été développée et optimisée par Thibault (2012). Celle-ci consiste à mélanger les broyures dans une solution de chlorure ferrique puis à l'exposer à du NH_3 gazeux pour former des oxydes de fer en surface des broyures.
Technique d'activation	Critères optimaux : • Utiliser une solution de chlorure ferrique à 1,5 mole/l (240 g $FeCl_3$/l) ; • Utiliser un temps d'imprégnation de 1 heure ; • Utiliser un ratio massique liquide d'imprégnation/broyures de 0,6 : 1 ; • Ne pas prétraiter à la carboxyméthylcellulose (CMC ou carmellose, un gel synthétique très hygroscopique)

Photos et schémas



a) Schéma de fonctionnement d'une colonne

b) Schéma global de fonctionnement

Montage de l'essai sur les conditions d'aération

<table>
<tr><th colspan="3">DESCRIPTION DE LA TECHNOLOGIE</th></tr>
<tr><td></td><td>Résidus dans le bassin d’alimentation</td><td>Montage des trois colonnes immergées</td></tr>
<tr><td rowspan="2">Performance</td><td>Plusieurs paramètres peuvent influencer la performance du procédé dont :
La qualité de l’eau (concentration en azote, sous forme de nitrates [NO_3], demande chimique en oxygène [DCO] et la quantité de phosphore des solutions testées) ;
Le pH de l’effluent ;
La température de l’effluent ;
La granulométrie des broyures.</td><td>Performance globale de déphosphatation<table><tr><th></th><th>Total
(mg $P\text{-}PO_4$)</th><th>Performance
(%)</th></tr><tr><td>Entrée totale</td><td>850,2</td><td>100</td></tr><tr><td>Capté par le système</td><td>808,7</td><td>95</td></tr></table></td></tr>
<tr><td colspan="2">Des essais en colonne réunissant les conditions déterminées idéales ont démontré qu’il était possible d’abaisser la concentration en phosphore d’une eau concentrée à 5 mg P_{tot}/l à des concentrations inférieures à 0,2 mg/l sur toute la durée du suivi.
Il a cependant été mis en évidence que des matières en suspension étaient relarguées des colonnes.</td></tr>
<tr><th colspan="3">ASPECTS TECHNIQUES</th></tr>
<tr><td>Dimensions des colonnes</td><td colspan="2">Hauteur de garnissage : 25 cm
Diamètre nominal : 4 cm</td></tr>
<tr><td>Garnissage</td><td colspan="2">Pour un volume de garnissage approximatif de 315 ml, masse de médias :
Bran de scie : 75,2 grammes
Broyures : 64,3 grammes
Planures activées : 24,7 grammes</td></tr>
<tr><td>Pompage et conduites d’alimentation</td><td colspan="2">Pompe Masterflex
Conduites de PVC transparent — diamètre nominal de 31,18 mm</td></tr>
<tr><td>Bassin d’alimentation</td><td colspan="2">26 litres</td></tr>
<tr><td>Température de l’eau</td><td colspan="2">4 à 10 °C</td></tr>
<tr><td>Concentration en phosphore</td><td colspan="2">5 mg/l</td></tr>
<tr><th colspan="3">AVANTAGES ET LIMITES</th></tr>
<tr><td>Avantages</td><td colspan="2">Implantation aisée : le processus peut être combiné facilement à des technologies de traitement secondaire ;
Conformité aux normes de rejet : le processus est performant notamment pour les rejets en milieux sensibles (normes de rejets sévères), tels ceux en amont des lacs ;
Sans contraintes environnementales et recyclabilité : le filtre possède une grande longévité et peut être valorisé en fin de vie utile, entre autres par le compostage (médias naturels).</td></tr>
<tr><td>Limites</td><td colspan="2">Maturité technologique : les résultats ont été obtenus dans une étude de type laboratoire où la majorité des paramètres sont constants et où la solution est synthétique. Les variations de température, de débit et de concentration en phosphore pourraient avoir des impacts majeurs sur le procédé et sur le potentiel de déphosphatation ;
Coûts de fabrication du bois actif : l’étude technicoéconomique possède plusieurs limites.</td></tr>
<tr><th colspan="3">DÉVELOPPEMENT COMMERCIAL</th></tr>
<tr><td>Technologie brevetée</td><td colspan="2">Thibault, 2012
Brevet canadien # CA2, 889, 513C</td></tr>
</table>

DESCRIPTION DE LA TECHNOLOGIE

Coûts estimés

Une étude technicoéconomique a démontré que l’utilisation de sous-produits du bois activés pour la déphosphatation des eaux usées avait du potentiel quand elle est comparée aux technologies conventionnelles.

Coûts estimés

Frais	Coûts annuels ($)
Frais d’acquisition de l’équipement	26 000
Frais reliés aux ressources humaines	100 000
Total	**126 000**

RÉFÉRENCES

CRIQ – Mémoire de maîtrise — Thomas Thibault, 2012

CRIQ — Mémoire de maîtrise — Gabriel Roy-Dumensil, 2017

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CRIQ

Technologie de valorisation des écorces d'essences forestières québécoises

VALORISATION MATIÈRE

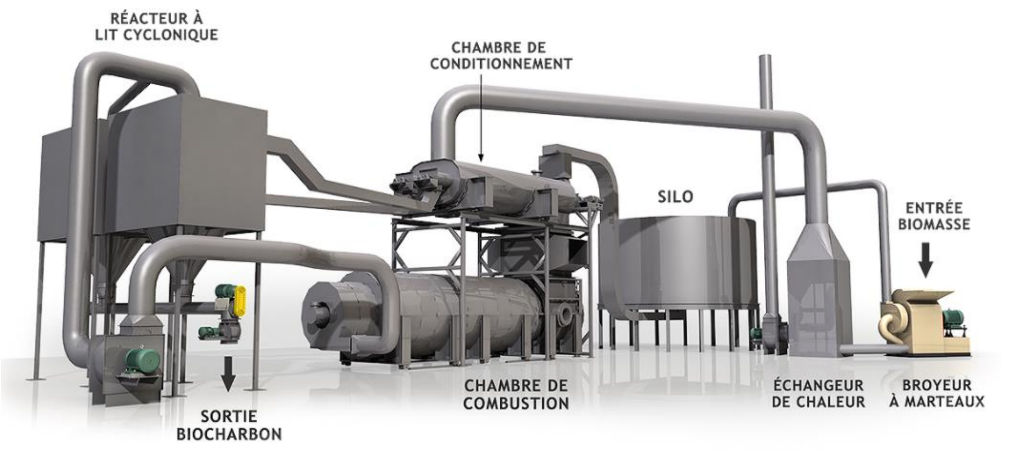
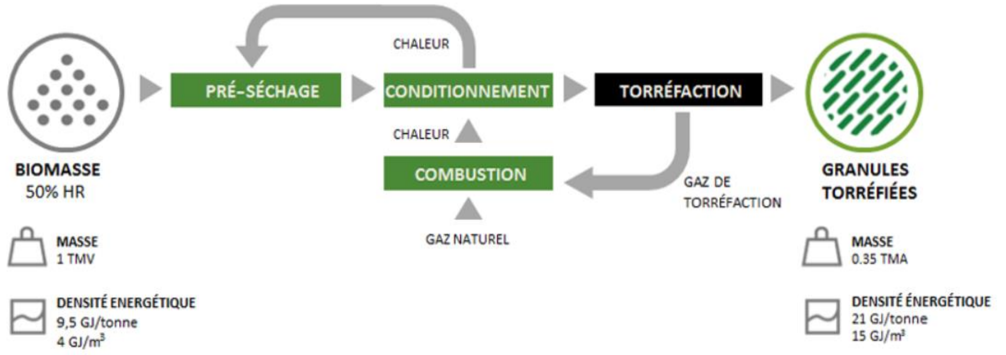
DESCRIPTION DE LA TECHNOLOGIE	
Présentation	L'**écorce** est la partie de l'arbre où se retrouve une grande quantité de métabolites spécialisés et molécules d'intérêt dont certains ont une activité biologique et assurent une protection contre différents stress tels que les pathogènes, les insectes et le rayonnement du soleil. La composition des écorces est complexe. Pour exploiter le potentiel de cette biomasse, les molécules actives doivent être isolées. Le centre de transfert de technologie Innofibre, le Centre d'innovation des produits cellulosiques, a développé plusieurs méthodes d'extraction. Celles-ci permettent d'obtenir différents mélanges de métabolites spécialisés qui composent un extrait, et ce, pour plusieurs espèces.
Procédé	Une méthode de tamisage et de broyage permettant d'assurer la qualité de la matière première utilisée pour l'extraction a été développée. L'utilisation de lessiveurs papetiers a permis de développer une méthode d'extraction aqueuse surcritique efficace où l'augmentation de la température et de la pression accroit les rendements d'extraction tout en revalorisant un équipement disponible dans l'industrie papetière. Un réacteur haute pression de 100 litres a été installé dans une salle anti-déflagration pour pouvoir effectuer des extractions de plus gros volume et avec une plus large variété de solvants. La nouvelle méthode d'extraction a permis de concentrer les proanthocyanidines dans les extraits d'écorce d'épinette noire. Les résultats obtenus dans le cadre de projets de recherche démontrent que l'efficacité de cet extrait permet d'atteindre les normes de Santé Canada en matière de désinfectants de surface. Des travaux de caractérisation chimique, réalisés en collaboration avec des centres de recherche spécialisés dans ce domaine, ont permis d'identifier les composés susceptibles d'être à l'origine de l'activité biologique. Des essais sur ces molécules isolées ont montré qu'elles étaient toutes antimicrobiennes, mais pas autant que l'extrait lui-même. Il existe donc un effet synergique entre les composés de l'extrait. Des travaux sont encore en cours afin d'étudier les interactions positives entre les molécules de ce mélange complexe.
Photos et schémas	 **Réacteur Solinox haute pression de 100 litres**  **Extrait d'écorce d'épinette noire**  **Extraits de peuplier faux-tremble, bouleau blanc et épinette noire**
AVANTAGES ET LIMITES	
Avantages	• Domaines d'application variés et forte demande du marché : Les extraits d'écorces possédant une activité antioxydante sont très sollicités comme additifs alimentaires pour la santé humaine et animale ou encore comme ingrédients actifs dans les cosmétiques pour protéger la peau. • Impact environnemental positif : Les produits antimicrobiens sont également utilisés dans les cultures pour protéger les plants contre les maladies. Certaines molécules des écorces pourraient apporter une solution plus naturelle pour remplacer les pesticides chimiques de synthèse.
Limites	• Projet pilote en voie de développement. Peu de maturité technologique ou de littérature.

DÉVELOPPEMENT COMMERCIAL	
Technologie brevetée	s.o.

RÉFÉRENCES
Annabelle St-Pierre, chercheuse — Centre d’innovation des produits cellulosiques — Innofibre 819 376-5075 Innofibre@cegeptr.qc.ca innofibre.ca

Système de pyrolyse et de production de biochar — Technologie CarbonFX

VALORISATION ÉNERGÉTIQUE

DESCRIPTION DE LA TECHNOLOGIE	
Présentation	La technologie CarbonFX utilise de la **sciure et d'écorces provenant de sapins, d'épinettes et d'érable pour produire du biocharbon par torréfaction du bois**. Le produit est livré et utilisé partout au Canada pour différents usages (p. ex. agriculture biologique, horticulture commerciale, jardinage). Elle permet de produire une variété de produits de biocarbone à valeur ajoutée à l'échelle industrielle. La technologie brevetée CarbonFX est développée par Airex Énergie. Elle permet de convertir tout type de biomasse en biocharbon, un combustible alternatif renouvelable pouvant remplacer le charbon traditionnel (p. ex. centrales électriques, cimenteries). Le gouvernement du Canada et le gouvernement du Québec sont partenaires financiers dans les activités d'Airex Énergie. Cycle Capital Management et Desjardins Innovatech sont des investisseurs en capital de risque.
Procédé	La torréfaction, un procédé de pyrolyse modérée, est un traitement thermique de la biomasse réalisé entre 250 °C et 320 °C avec peu ou pas d'oxygène. La torréfaction a pour objectif d'enlever l'humidité et les composés organiques volatils (COV) de la biomasse brute. Elle la transforme ainsi en matériel noirci, solide et hydrophobe (résistant à l'eau). Le produit fini est une biomasse torréfiée ou de biocharbon (sous forme de granules torréfiées ou de morceaux). La masse du produit fini s'élève habituellement à environ 70 % de celle de la matière brute, alors que sa teneur en énergie est égale à 90 % de celle de la matière avant torréfaction. Le contrôle précis de la température du réacteur et du temps de séjour permet de créer des produits de meilleure qualité, plus uniformes et plus homogènes.
Photos et schémas	Le processus de torréfaction CarbonFX  

ASPECTS TECHNIQUES

Aspects techniques

Préséchage : La biomasse, d'une taille comparable à celle de la sciure, est introduite dans l'unité. Elle est préséchée dans un circuit aéraulique en utilisant la chaleur résiduelle du processus de combustion. Le taux d'humidité de la biomasse est ainsi réduit passant de 50 % à 25 %.

Conditionnement : La chambre de conditionnement possède quatre vis sans fin et une double paroi. Les gaz de combustion circulent à l'intérieur de la double paroi et réchauffent la biomasse par contact indirect. L'humidité de la biomasse se transforme en vapeur, et la biomasse est conditionnée dans une atmosphère de vapeur saturée. Ensuite, les gaz de combustion chauds entraînent la biomasse de la chambre de combustion vers le réacteur de torréfaction.

Réacteur de torréfaction : La biomasse est introduite dans la partie supérieure du réacteur et descend en spirale le long d'un lit cyclonique. Elle termine sa course à la base du réacteur c'est-à-dire l'anneau de sustentation. Celui-ci garde la biomasse en suspension dans le réacteur grâce à l'équilibre entre la force centrifuge de l'effet cyclonique, la force gravitationnelle de la biomasse et la poussée de l'anneau de sustentation. Le temps de séjour de la biomasse dans le réacteur est d'environ deux à trois secondes.

Autres aspects techniques du CarbonFX

Rendement matière	25 %
Taux de carbone	> 60 %
Température des réacteurs	1 000 °F
Productivité	0,5 t/h

AVANTAGES ET LIMITES

Avantages

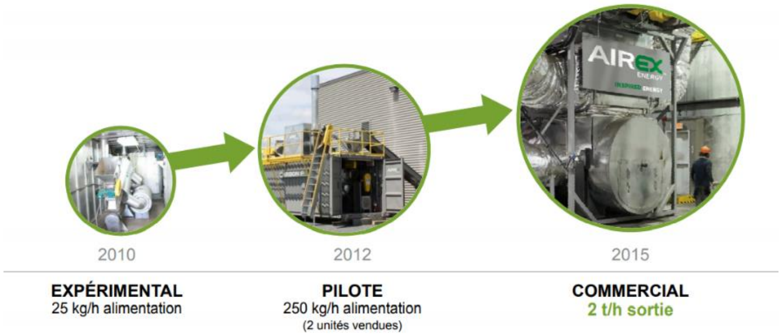
- Transport et assemblage facilités : La conception modulaire permet aux composantes d'être expédiées sur le site par rail ou train dans des conteneurs standard avec l'assemblage final sur site.
- Coût compétitif : Le CarbonFX ne nécessite pas de vaisseaux sous pression, de chaudière à biomasse, de séchoir à tambour ou d'échangeur de chaleur à huile thermique. Utilise des intrants (de type sciures) disponibles à faible coût, comparativement aux copeaux de bois. Sans contraintes environnementales particulières.
- Vitesse de réaction : Le temps de séjour des particules de biomasse à l'intérieur des réacteurs est de 3 secondes. La durée moyenne est de 30 minutes avec les technologies de torréfaction concurrentes.
- Taille de l'équipement réduite par rapport aux équipements comparables sur le marché.
- Haute efficacité énergétique : La chaleur résiduelle du procédé est utilisée pour présécher la biomasse dans un système intégré.

Limites

- Selon la littérature, malgré les nombreux avantages du biochar, son utilisation peut présenter certains risques pour l'eau, l'air, les sols, la santé ou la biodiversité. À titre d'exemple, l'utilisation du biochar peut modifier le pH du sol et changer ainsi les caractéristiques du milieu naturel des espèces qui y vivent, ce qui peut menacer la biodiversité.
- De même, collecter du petit bois et des rémanents des forêts pour produire du biochar prive les forêts d'une source naturelle de carbone et conduit ainsi à les appauvrir.

DÉVELOPPEMENT COMMERCIAL

	Nom du brevet	Pays	Statut	Date
Technologie brevetée	Appareil de filtration de récupération d'énergie	États-Unis Canada États-Unis	Accordé Accordé Accordé	27 mars 2012 12 mars 2013 3 novembre 2015
	Méthode et appareil pour la Torréfaction de la biomasse avec un réacteur de lit cyclonique	États-Unis Canada Europe	En attente En attente En attente	Demande soumise le 25 mai 2012

<table>
<tr><td>Développement technologique</td><td>
</td></tr>
<tr><td colspan="2">RÉFÉRENCES</td></tr>
<tr><td colspan="2">Sylvain Bertrand, président-directeur général
AIREX – Energie
450 661-6498
sbertrand@airex-energie.com
airex-energy.com</td></tr>
</table>

Liquéfaction hydrothermale de la biomasse ligneuse dans l'eau chaude comprimée | VALORISATION ÉNERGÉTIQUE

<table>
<tr><th colspan="2">DESCRIPTION DE LA TECHNOLOGIE</th></tr>
<tr><td>Présentation</td><td>

La liquéfaction hydrothermale (LHT) est une technique émergente. Elle permet la conversion de la biomasse en biocarburants. Le procédé se déroule à haute pression (5-20 MPa) et haute température (> 400 °C). L'eau est utilisée comme solvant dans des conditions sous-critiques ou quasi-critiques.

Dans la LHT, la biomasse peut être convertie en biohuile, biochar ou gaz non condensables. Les caractéristiques et les rendements des produits dépendent fortement des conditions d'exploitation de la LHT comme le type de biomasse, le rapport biomasse/eau, la température, la pression, le temps de séjour et la présence ou l'absence de catalyseurs.

</td></tr>
<tr><td>Procédé</td><td>

Le procédé LHT ci-après présenté a été réalisé dans le cadre d'un programme de doctorat en génie chimique à l'Université Western (Ontario).

Le procédé a été appliqué sur un mélange de boue et de sciure de bois local de type bouleau. Les conditions expérimentales (température, temps de rétention, concentration de la matière organique et catalyseur) ont été optimisées en utilisant une méthodologie de conception expérimentale.

Différents catalyseurs ont été testés (KOH, $FeSO_4 7H_2O$, K_2CO_3, MgO, hydrotalcite synthétique et colémanite moulue) à 300 °C pour 30 min.

La biohuile produite a été caractérisée à l'aide des instruments d'analyse thermique : chromatographie en phase gazeuse — spectrométrie de masse (GC-MS), spectroscopie infrarouge à transformer de Fourier (FT-IR), chromatographie par perméation de gel (GPC) et analyse thermogravimétrique TGA.

Une procédure de séparation est appliquée afin d'extraire la biohuile des autres produits générés par LHT.

</td></tr>
<tr><td rowspan="2">Photos et schémas</td><td>

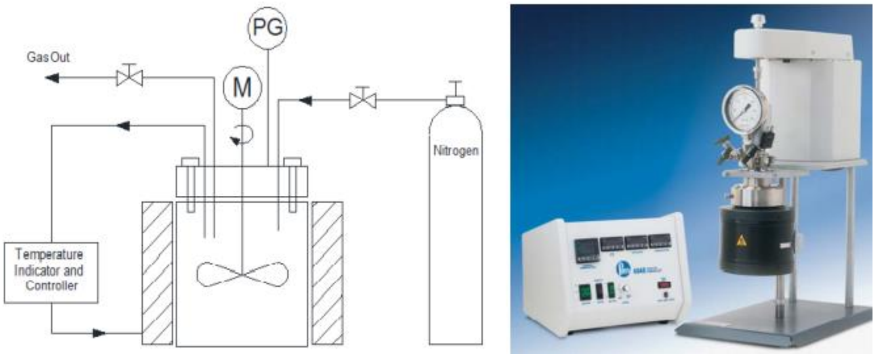
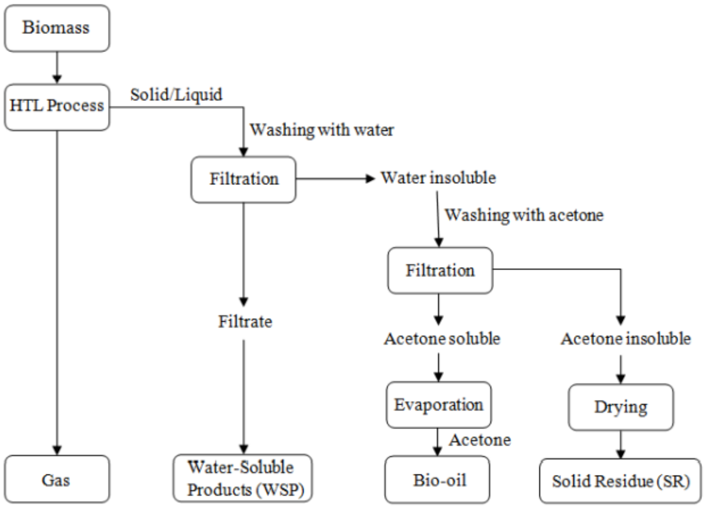


Schéma de réacteur discontinu, Jauge de pression (PG), Mélangeur (M)
Photo de réacteur bicontinu de 100 ml et de 500 ml

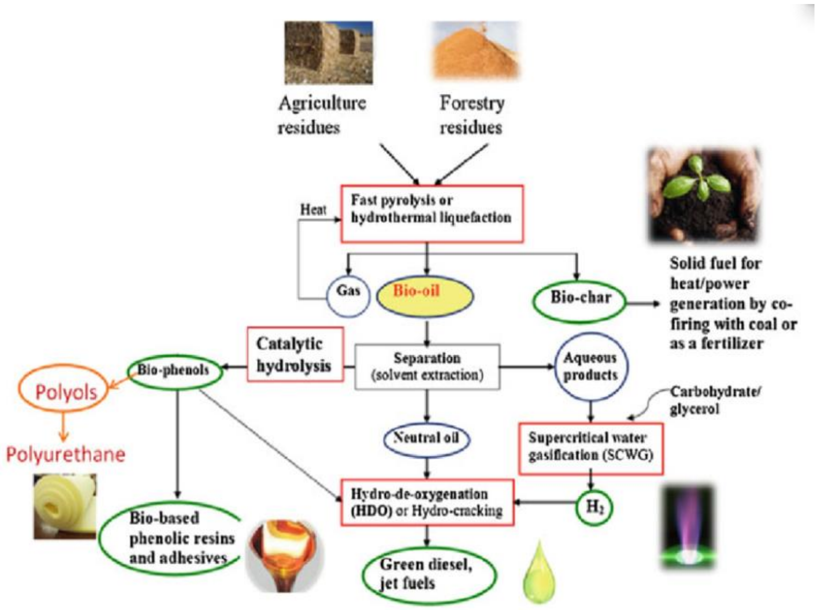
</td></tr>
<tr><td>



</td></tr>
</table>

DESCRIPTION DE LA TECHNOLOGIE

Procédure de séparation des produits générés par LHT



Arbre des processus de production de biohuile par LHT

Performance

- Les catalyseurs (KOH, K_2CO_3 et le colémanite) ont montré les meilleures performances étant donné le rendement en huile et en résidus solides.
- La caractérisation de la biohuile a révélé que la teneur en oxygène est considérablement réduite par rapport à celle de la biomasse d'origine conduisant à une augmentation des valeurs calorifiques.
- Le tableau suivant présente la valeur énergétique de biohuile obtenue par la LHT du bois de bouleau en présence ou non de différents types de catalyseurs :

	Decomposition start temp.(°C)	Decomposition end temp.(°C)	Decomposition peak temp. (°C)	VM[a] (wt%)	Ash[a] (wt%)	FC[a,b] (wt%)
Sawdust	300	881	374	83.45	0.23	16.32
Bio- oils						
Blank	208	873	394	64.66	NG[c]	35.34
HT	222	883	388	65.90	NG	34.10
KOH	212	882	367	59.29	NG	40.71
$FeSO_4$	226	885	394	62.26	NG	37.74
HT/KOH	211	882	387	66.03	NG	33.97

ASPECTS TECHNIQUES

Aspects techniques

- Volume du réacteur : 100 ml (Parr 4590 Benchtop, microréacteur de paillasse)
- Mélange typique : 4 grammes de biomasse, 33 grammes d'eau (10 % du poids de la biomasse solide, compte tenu de l'humidité de la biomasse), 0,2 gramme de catalyseur (5 % du poids de la biomasse)
- Conduites de purge : Purge-vide N2
- Température et pression appliquées : 300 °C, 2 MPa
- Pression à l'intérieur du réacteur : 9 MPa

AVANTAGES ET LIMITES

Avantages

- Permettre de produire un carburant carboneutre et renouvelable ;
- Avoir un pouvoir calorifique élevé ;
- Ne pas avoir de contraintes environnementales particulières.

Limites

- Peu de maturité technologique : le procédé doit être testé avec un réacteur à flux continu pour augmenter le rendement.

DESCRIPTION DE LA TECHNOLOGIE	
	- Des calculs de consommation d’énergie plus détaillés ainsi qu’une analyse technico-économique de l’ensemble du processus doivent être conduits avant sa commercialisation.
DÉVELOPPEMENT COMMERCIAL	
Technologie brevetée	s.o.
RÉFÉRENCES	
Nazari, Laleh, *Hydrothermal Liquefaction of High-Water Content Biomass and Waste Materials for the Production of Biogas and Bio-Crude Oil* (2016). Electronic Thesis and Dissertation Repository. 4069 https://ir.lib.uwo.ca/etd/4069 https://ir.lib.uwo.ca/etd	

Forest Sector in Quebec – Circularity Assessment and Market Opportunities
March 2022

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