Environmental Benefits Report for Autarcycle's Project

Presented to:

Autarcycle inc.

534 de la chevauchée

Levis, Quebec, G6C 1W8

Phone: (581) 745-1080

https://autarcycle.com/

By:

Enviro-access Inc.

268 Aberdeen Street, Suite 204

Sherbrooke, Quebec, J1H 1W5

Phone: (819) 823-2230

www.enviroaccess.ca

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Summary

As the world increasingly seeks sustainable energy solutions and that fuel consumption is not showing signs of slowing down, biodiesel has emerged as a promising alternative to fossil-based diesel. Autarcycle has recently developed a microfactory which can be implemented locally (near farms) to transform vegetable oils, animal fats, and waste oils, into biofuel which can replace traditional diesel.

Enviro-access was mandated to carry out the greenhouse gas (GHG) emission reductions and other environmental benefits quantification of the project. This report is based on the principles and requirements of ISO 14064-2:2019.

Enviro-access' analysis shows a reduction of 1 607 kgCO_2e per kL of biofuel when compared to diesel production, resulting in a 55.7% decrease in GHG emissions. Reductions were also observed for all criteria air contaminants (CAC) quantified: total particulate matter (TPM), sulfur oxides (SOx), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC) and carbon monoxide (CO).

In the associated spreadsheet, the environmental benefits were also quantified for a scenario in which one of the process' inputs, dimethyl carbonate, is produced locally. The GHG emissions reductions for this scenario are estimated at 2 349 kgCO_2e per kL of biofuel when compared to diesel production, resulting in an 81.4% decrease in GHG emissions.

The following table outlines the estimated environmental benefits associated with the deployment of Autarcycle's technology, with dimethyl carbonate being produced abroad. These forecasts are based on the expected annual production of biofuel, which will ramp up from 80 kL/year in 2025 to 293 280 kL/year in 2034. The data highlights the potential reductions in greenhouse gas emissions, providing insights into the positive outcomes of scaling up Autarcycle's biofuel production.

Technology Deployment Projection

Deployment			GHG		Total CAC Reduction				
Year	Expected production (kL)	Cumulative production (kL)	Annual GHG Reductions (tCO_2e/yr)	Cumulative GHG Reductions (tCO_2e)	TPM (t/yr)	SOx (t/yr)	NOx (t/yr)	NMVOC (t/yr)	CO (t/yr)
2025	80	80	129	129	0.24	0.10	0.61	0.08	0.28
2026	880	960	1 414	1 542	2.61	1.11	6.68	0.92	3.10
2027	3 280	4 240	5 270	6 812	9.71	4.15	24.9	3.43	11.5
2028	11 280	15 520	18 123	24 935	33.4	14.3	85.7	11.8	39.7
2029	27 280	42 800	43 828	68 763	80.8	35	207	28.5	96
2030	55 280	98 080	88 813	157 576	164	70.0	420	57.8	194
2031	95 080	193 160	152 756	310 332	282	120	722	99.4	334
2032	147 280	340 440	236 621	546 953	436	186	1 119	154	518
2033	213 280	553 720	342 657	889 610	632	270	1 620	223	750
2034	293 280	847 000	471 185	1 360 795	868	371	2 228	307	1 032

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1. Introduction

As the world increasingly seeks sustainable energy solutions and that fuel consumption is not showing signs of slowing down, biodiesel has emerged as a promising alternative to fossil-based diesel. Autarcycle has recently developed a microfactory which can be implemented locally (near farms) to transform vegetable oils, animal fats, and waste oils, into biofuel which can replace traditional diesel.

Enviro-access was mandated to carry out the greenhouse gas (GHG) emission reductions and other environmental benefits quantification of the project. This report is based on the principles and requirements of ISO 14064-2:2019.

2. Project information

2.1. Project title

Production of biofuel in Autarcycle's microfactories.

2.2. Project description

Autarcycle has developed a microfactory, which can be implemented near farms, which can transform vegetable oils (such as canola or soy) or other types of fats into a biofuel.

2.3. Project objectives

The project objective is to produce biofuel from grains in microfactories which are closer to farms, in order to reduce transportation and the use of fossil-based diesel.

2.4. Conditions prior to project initiation

Currently, farm equipment mainly use fossil-based diesel and grain farmers send their grain to a mill to recover the meal. The oil produced from milling is then used in a variety of applications.

2.5. Strategy to reduce greenhouse gas emissions

GHG emissions reductions are mainly achieved through the replacement of fossil-based diesel by Autarcycle's biofuel.

2.6. Identification of risks that may affect emission reductions

As emissions reductions mainly come from the replacement of fossil-based fuel diesel by biofuel, the origin of the diesel used in the baseline and the percentage of biodiesel in the diesel-biodiesel mix could have a significant impact on the GHG emissions from the baseline. On the project's side, the main parameter which could affect the emissions is the origin of the dimethyl carbonate used, since a significant amount of emissions is due to transportation and local dimethyl carbonate could be produced with a smaller carbon footprint.

2.7. Project location

At the moment, the first microfactory is planned to be located in Quebec. However, microfactories could eventually be built elsewhere in Canada and the United States.

2.8. Technologies, products, services and expected level of activity

The quantification is based on one kiloliter of biofuel produced, in order to allow a comparison based on production, which can be scaled up. The functional unit is therefore the volume produced and GHG emissions are quantified in $kgCO_2e/kL$. The level of activity of the project is based on the expected biofuel production per year.

2.9. Project duration and reports produced

A first microfactory has been implemented by Autarcycle and the company plans to implement more in the upcoming years. At the moment, no post project reports are planned.

2.10. Roles and responsibilities

Autarcycle inc.
Role: Development of the biofuel microfactory
Contact: Dr Alain Rouillard, Ph.D., Pharm.D.
Phone: (581) 745-1080
https://autarcycle.com

3. Identification of sources relevant to the project

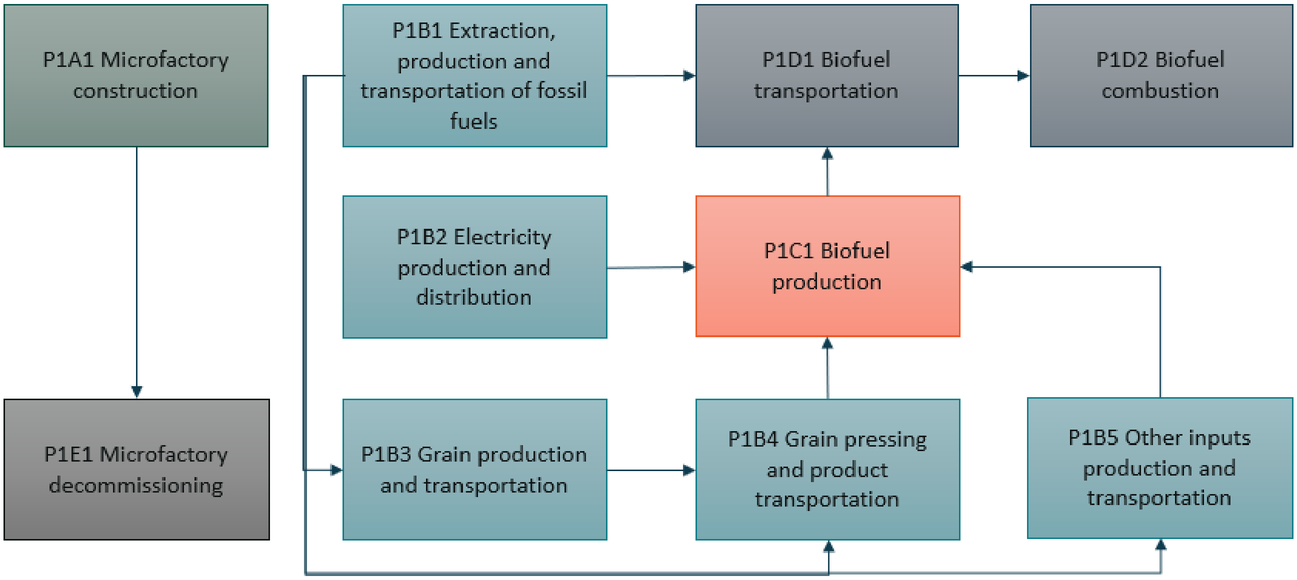
3.1. Identification of project elements

The following systems approach was followed to determine the boundaries and elements attributable to each system. The same procedure was followed for project and baseline systems. This procedure allows one to identify all types of activities (e.g. production, transportation, installation, operation, maintenance, utilization, and decommissioning) that may be attributable to the system.

The systems approach consists of the systematic application of the following steps:

1. Identify the project model based on the processes included in the project.
2. Identify the direct elements for the system (i.e. those directly controlled or owned in the project), including the primary (i.e. those elements that immediately generate or provide the system function) and secondary elements.
3. Identify main inputs and outputs (products, energy and materials) associated with the direct elements.
4. Identify additional elements by tracking materials and energy inputs/outputs upstream to origins in natural resources and downstream along life cycle. Classify elements as primary (i.e. those elements that immediately generate or provide the system function) or secondary (e.g. purchased supplies, contracted services, contracted waste processing, use of goods or services by other entities)
5. Identify main inputs and outputs (products, energy and materials) associated with all remaining elements.
6. Define system boundaries.
7. Classify elements as owned and/or controlled by the project; related to the project, and elements affected by the project.
8. Identify the GHG inputs and outputs for each element, and identify the parameters required to estimate or measure GHGs.
9. Review all elements and flows to ensure all relevant information is within the system boundaries.

In order to determine boundaries and identify the elements attributable to this project, the main objectives were considered in light of the procedure described above. The application of this procedure to the project resulted in the following figure. Each element is associated with the main project named P1.



A. **UPSTREAM ELEMENTS PRIOR TO PROJECT OPERATION**
B. **UPSTREAM ELEMENTS DURING PROJECT OPERATION**
C. **ELEMENTS DURING PROJECT OPERATION**
D. **DOWNSTREAM ELEMENTS DURING PROJECT OPERATION**
E. **DOWNSTREAM ELEMENTS AFTER PROJECT OPERATION**

Figure 1: Selection of Project P1 Elements

3.2. Description of project elements

The following section presents the description of each source, sink or reservoir (SSR) presented in Figure 1 and whether the element is related, controlled or affected by the project.

Table 1: Description of Project Elements

SSR	Name	Description	Nature
A. Upstream elements prior to project operation			
P1A1	Microfactory construction	This element includes emissions related to the production of materials used for the construction of Autarcycle's microfactory. Emissions from the machinery's fuel consumption were deemed negligible.	Related
B. Upstream elements during project operation			
P1B1	Extraction, production and transportation of fossil fuels	This element includes the upstream processes required to produce the fuel combusted for the transportation in the project.	Related
P1B2	Electricity production and distribution	This element includes the production of the electricity consumed by the project (in element P1C1). For the purpose of this report, electricity is assumed to come from the Quebec grid.	Related
P1B3	Grain production and transportation	This element includes the emissions related to the production and the transportation of the grains from the farm to the location where they will be pressed.	Related
P1B4	Grain pressing and product transportation	This element includes the emissions related to the operation of the milling equipment and the transportation of the products (meal and oil) from the milling facilities to the final user.	Related
P1B5	Other inputs production and transportation	This element includes the emissions related to the production and transportation of the other inputs required to manufacture the biofuel, namely methanol and dimethyl carbonate.	Related
C. Elements during project operation			
P1C1	Biofuel production	The process only uses electricity, which is produced offsite. Therefore, there are no GHG emissions associated with this element, as emissions are considered in element P1B2.	Related
D. Downstream elements during project operation			
P1D1	Biofuel transportation	This element includes the emissions related to diesel consumption for the biofuel transportation between the microfactory and the end user.	Related
P1D2	Biofuel combustion	This element includes the emissions related to the consumption of the biofuel. CO_2 emissions emitted from this source are biogenic since the fuel is made from biomass, which means the emissions were not considered in the total as they would naturally occur during the decomposition of organic matter.	Related
E. Downstream elements after project operation			
P1E1	Microfactory decommissioning	This element includes the machinery required to decommission the facility as well as the end-of-life treatment of waste generated.	Related

4. Identification of sources relevant to the baseline

4.1. Selection of the GHG baseline

By definition, the baseline situation represents the best and most appropriate estimate of GHG emissions that would have occurred in the absence of the project. The approach used to establish the baseline follows current good practice guidance, including:

- ✓ The Greenhouse Gas Protocol for Project Accounting; Dec. 2005; WBCSD/WRI.
- ✓ ISO 14064-2:2019: Specification for the quantification, monitoring and reporting of project emissions and removal.

Good practice guidance suggests developing several alternative baseline scenarios and assessing these against a variety of implementation barriers or investment rankings. Potential scenarios were developed considering project objectives and design; data availability and limitations; and temporal, economic and technical conditions.

The following options were analyzed:

- ✓ Autarcycle's biofuel production (project).
- ✓ Petroleum diesel production and sending oil abroad (option 1).
- ✓ Producing biodiesel abroad from oil (option 2).

Table next page shows baseline selection.

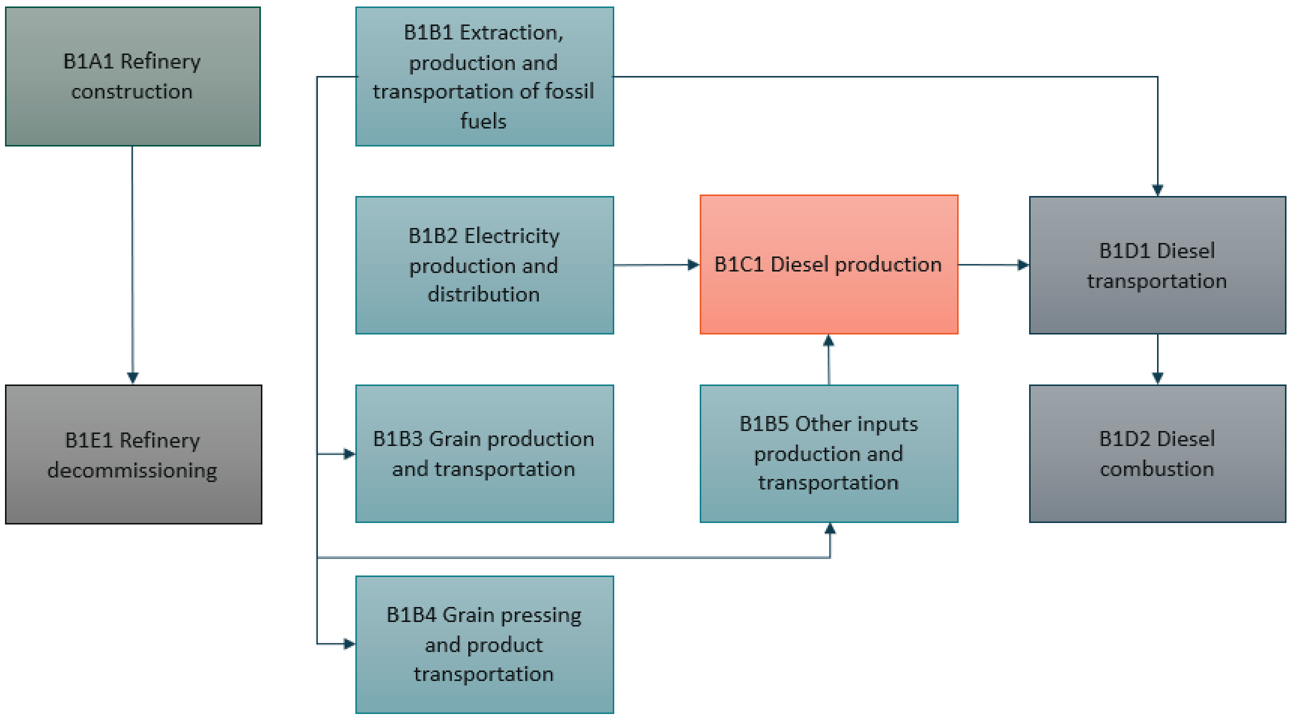
Table 2: Barrier Test

Barrier	Project: Autarcycle's biofuel production	Option 1: Petroleum diesel production and sending oil abroad	Option 2: Producing biodiesel abroad from oil
Financial	Barrier: *There is a high initial investment cost to put in place the microfactories.*	Barrier: *Additional transportation fees must be paid by farmers to press the grain and buy petroleum diesel.*	Barrier: *Biodiesel is usually more expensive than petroleum diesel.*
Technology	Barrier: *This is a new technology, and its efficiency as an automated continuous process still needs to be demonstrated.*	No barrier	Barrier: *Biodiesel factories are not as widely spread as refineries (the technology is still being developed).*
Resources	No barrier	No barrier	Barrier: *Traditional biodiesel production can use lands which could've been used for food production, and can threaten local water supplies.*
Legal	No barrier	No barrier	No barrier
Infrastructure	Barrier: *The appropriate infrastructure for the microfactories must be implemented.*	No barrier	Barrier: *This technology is not widely used, therefore infrastructure is not currently in place.*
Social	No barrier	Barrier: *With growing environmental awareness, the consumption of fossil-based products is becoming less acceptable.*	No barrier
Total	3	2	4

Since option #1 has the fewest barriers among the scenarios assessed, it is the option that represents the best and most appropriate estimate of the GHG emissions that would have occurred in the absence of the project.

4.2. Identification of baseline scenario elements

In order to determine the limitations and identify the elements attributable to the baseline scenario, the procedure described in section 3.1 was applied. The application of this procedure for the baseline scenario has resulted in Figure 2. Each element is associated with the baseline scenario B1 in the figure.



A. UPSTREAM ELEMENTS PRIOR TO BASELINE OPERATION
B. UPSTREAM ELEMENTS DURING BASELINE OPERATION
C. ELEMENTS DURING BASELINE OPERATION
D. DOWNSTREAM ELEMENTS DURING BASELINE OPERATION
E. DOWNSTREAM ELEMENTS AFTER BASELINE OPERATION

Figure 2: Selection of Baseline B1 Elements

4.3. Description of baseline scenario elements

The following section describes each element of the baseline scenario.

Table 3: Description of Baseline Elements

SPR	Name	Description
A. Upstream elements prior to baseline operation		
B1A1	Refinery construction	This element includes emissions related to the production of materials and the fuel consumption of machinery used for the construction of a diesel refinery.
B. Upstream elements during baseline operation		
B1B1	Extraction, production and transportation of fossil fuels	This element includes the upstream processes required to produce the fuel combusted for the transportation in the baseline scenario. This excludes the production of the diesel used as replacement of the biofuel produced in the project, which is considered in element B1C1.
B1B2	Electricity production and distribution	This element includes the production of the electricity consumed by the baseline (in element B1C1).
B1B3	Grain production and transportation	This element includes the emissions related to the production and the transportation of the grains from the farm to the location where they will be pressed.
B1B4	Grain pressing and product transportation	This element includes the emissions related to the operation of the milling equipment and the transportation of the products (meal and oil) from the milling facilities to the final user.
B1B5	Other inputs production and transportation	This element includes the emissions related to the production and transportation of inputs required to manufacture the diesel.
C. Elements during baseline operation		
B1C1	Diesel production	This element includes the emissions related to the production of diesel and biodiesel which are replaced by the project's biofuel.
D. Downstream elements during baseline operation		
B1D1	Diesel transportation	This element includes the emissions related to diesel consumption for the transportation of the diesel to the end user.
B1D2	Diesel combustion	This element includes the emissions related to the consumption of the diesel by farm equipment in replacement of the project's biofuel.
E. Downstream elements after baseline operation		
B1E1	Refinery decommissioning	This element includes the machinery required to decommission the refinery as well as the end-of-life treatment of waste generated.

5. Selection of SSRs for the estimation of GHG emissions

The following systems approach was followed to select SSRs included in the quantification. SSRs that are not likely to have an impact on GHG emission reductions were not selected for quantification. To ensure an adequate comparison of the GHG emissions of the project and the baseline scenario, the following criteria were established to select the relevant SSRs.

When the project does not result in any changes to an SSR from the baseline scenario, that SSR has been excluded from the quantification process. In addition, the following conditions had to be met in order to exclude a source:

1. The source is not controlled by the project.
2. The magnitude of emissions was considered negligible for the project and the baseline scenario (less than 0.5% of the project and baseline emissions).
3. The exclusion of the source respects the conservativeness principle of the ISO 14064-2:2019 standard.

The result of the selection of the relevant SSRs and the rationale for the exclusion of some of them is presented in the table below:

Table 4: Justification of Sources Exclusion

SPR	Name	Scenario	Included/ Excluded	Justification
A.	Upstream elements before project and baseline operation			
A1	Facility construction	P, B	Excluded	Project: Emissions from steel production for the microfactory construction represent less than 0.05% of the project's emissions. Baseline: Since the diesel is produced in an existing refinery, no emissions were considered for the construction of the refinery.
B.	Upstream elements during project and baseline operation			
B1	Extraction, production and transportation of fossil fuels	P, B	Included	As the diesel quantities consumed were quantified for elements B3, B4. B5 and D1 and therefore readily available, emissions from this source were included.
B2	Electricity production and distribution	P, B	Included (P) Excluded (B)	Project: Emissions from electricity production may vary based on the location of the project (and therefore may be significant). Emissions were therefore included. Baseline: Emissions from the production and distribution of electricity required for diesel production are included in the emission factor used for B1C1. No separate emissions were calculated for this source.

B3	Grain production and transportation	P, B	Included	Only the emissions related to grain transportation were included. Emissions related to grain and gum production are the same for both scenarios and were therefore excluded.
B4	Grain pressing and product transportation	P, B	Included	Only the emissions related to oil and meal transportation were included. The energy consumption of the milling equipment was estimated to be the for both scenarios, therefore no GHG emissions were considered for this step.
B5	Other inputs production and transportation	P, B	Included (P) Excluded (B)	Project: This element represents most of the emissions for the project. It was therefore included. Baseline: Emissions from the production and transportation of inputs required for diesel production are included in the emission factor used for B1C1. No separate emissions were calculated for this source.
C.	Elements during project and baseline operation			
C1	Fuel production	P, B	Excluded (P) Included (B)	Project: All emissions related to the process are generated upstream. Baseline: This element is the equivalent of the biofuel's production for the baseline. It was therefore included.
D.	Downstream elements during project and baseline operation			
D1	Fuel transportation	P, B	Included	This source was included as it represents more than 0.5% of project and baseline emissions.
D2	Fuel combustion	P, B	Included	This source generates significant GHG emissions. It was therefore included.
E.	Downstream elements after project and baseline operation			
E1	Facility decommissioning	P, B	Excluded	As materials will likely be recycled at the end-of-life, no emissions were considered for this source.

6. Quantification of GHG emissions

The GHG emissions assessment was carried out using the *Greenhouse Gas Protocol*, established by *the World Business Council for Sustainable Development*, and the Guidelines for the quantification of the impacts of GHG reduction projects, which follow the principles of the international standard ISO 14064-2:2019.

To ensure functional equivalency between the project and the baseline scenarios, the calculations are based on one kiloliter of fuel produced. The data for the project comes mainly from a mass balance provided by Autarcycle, while the data for the baseline scenario was obtained from the literature. Transportation distances for both scenarios were estimated.

In this report, emissions from the project were calculated assuming that the dimethyl carbonate was produced in China, which is actually the case. However, as Autarcycle's microfactory may allow the production of dimethyl carbonate onsite in a near future, emissions were also quantified for a scenario where the dimethyl was produced locally in the associated calculation spreadsheet.

Most of the emission factors used were derived from the following sources:

- Environment and Climate Change Canada's (ECCC) 1990-2022 National Inventory Report, the most recent at the time of carrying out the mandate
- GHGenius 5.02a Software
- EcoInvent v.3.10.1
- USEPA's Emission Factors for Greenhouse Gas Inventories

GHG emissions from each scenario were quantified by multiplying the data by appropriate emission factors, using the following formula:

$$GHG_i = Q_i \times EF_i$$

The global warming potentials (GWPs) used are those of the 6th report of the Intergovernmental Panel on Climate Change (IPCC) published in 2022:

Table 5: Global Warming Potentials

GHG	GWP
CO_2	1
CH_4	27.9
N_2O	273

The following sections detail the data and emission factors used for each emission source in the project and baseline scenarios.

6.1. Quantification of the project's GHG emissions

P1B1 Extraction, production and transportation of fossil fuels

The quantity of diesel produced equals the diesel consumed by trucks for the transportation of the inputs and the biofuel.

Table 6: P1B1 Data and Emission Factor

Input	Quantity (L/kL)	Uncertainty	Emission factor ($kgCO_2e/L$)	Uncertainty
Diesel	96.5	High	0.82	Low

The diesel consumption was converted from tonne-kilometers transported based on an emission factor ratio. The emission factor is from GHGenius.

P1B2 Electricity production and distribution

The quantity of electricity produced equals the quantities consumed by Autarcycle's process. Emissions are considered upstream since the electricity is not generated onsite during the process.

Table 7: P1B2 Data and Emission Factor

Input	Quantity (kWh/kL)	Uncertainty	Emission factor ($kgCO_2e/kWh$)	Uncertainty
Electricity	1 340	Low	0.002	Low

Since this report covers the quantification for a microfactory in Quebec, the emission factor from the National Inventory Report from ECCC (specific to Quebec) was used.

P1B3 Grain production and transportation

Fuel consumption for the transportation of the grains was calculated based on the weight of grains transported and the distance traveled by the grains. The quantity of grain to be transported, based on the amount required to produce one kiloliter of biofuel, was provided by Autarcycle, while an average distance of 20km was estimated.

Table 8: P1B3 Data and Emission Factors

Input	Quantity (TKT/kL)	Uncertainty	Emission factor ($kgCO_2e/TKT$)	Uncertainty
Tonnes-kilometers traveled	37.7	Medium	0.13	Low

The emission factor for this source, as well as for P1B4 and P1D1, comes from USEPA's Emission Factors for Greenhouse Gas Inventories.

P1B4 Grain pressing and product transportation

As for element P1B3, fuel consumption for the transportation of the oil and meal was calculated based on the weight transported, provided by Autarcycle, and the distance traveled, estimated to be 20km for the meal and 0km for the oil, as it will be transformed to biofuel onsite.

Table 9: P1B4 Data and Emission Factors

Input	Quantity (TKT/kL)	Uncertainty	Emission factor ($kgCO_2e/TKT$)	Uncertainty
Tonnes-kilometers traveled	22.2	Medium	0.13	Low

P1B5 Other inputs production and transportation

The quantities of inputs required to produce the biofuel were provided by Autarcycle and distances were estimated based on the probable location of the suppliers. The production of canola oil, to be equivalent to the baseline, is also included.

Table 10: P1B5 Data and Emission Factors

Input	Quantity	Unit	Uncertainty	Emission factor ($kgCO_2e/unit$)	Uncertainty
Dimethyl Carbonate production	175	kg/kL	Low	3.50	Medium
Methanol production	2.00	kg/kL	Low	0.95	Medium
Tonnes-kilometers traveled by inputs - Boat	4 598	TKT/kL	High	0.05	Low
Tonnes-kilometers traveled by inputs - Truck	35.2	TKT/kL	High	0.13	Low
Canola oil production (in replacement of the baseline)	753	kg/kL	Low	0.42	Medium

Emission factors for the inputs (dimethyl carbonate and methanol) come from the Ecoinvent database, while the emission factor for fuel consumption comes from USEPA's Emission Factors for Greenhouse Gas Inventories and the emission factor for canola oil production comes from the Canola Council of Canada.

P1D1 Biofuel transportation

Emissions were calculated based on the density of the biofuel (to calculate the weight transported by kiloliter of fuel), and the average distance traveled by the fuel to the final user, which was estimated to be 20km.

Table 11: P1D1 Data and Emission Factor

Input	Quantity (TKT/kL)	Uncertainty	Emission factor ($kgCO_2e/TKT$)	Uncertainty
Tonnes-kilometers traveled	17.9	Medium	0.13	Low

P1D2 Biofuel combustion

This source includes emissions related to the combustion of one kiloliter of biofuel. As the emissions from the combustion of Autarcycle's biofuel are unknown, the emission factor used was obtained from ECCC's National Inventory Report.

Table 12: P1D2 Data and Emission Factor

Input	Quantity (kL/kL)	Uncertainty	Emission factor ($kgCO_2e/kL$)	Uncertainty
Biofuel consumed	1	Low	8.04	Low

Total GHG emissions from the project

Based on the previously identified quantities and emissions factors, the emission results for each GHG and GHG SPR are presented in the table below:

Table 13: GHG Emissions from the Project

Element	CO_2 Emissions (kg)	CH_4 Emissions (kg)	N_2O Emissions (kg)	GHG emissions ($kgCO_2e$)	% of total emissions
A. UPSTREAM ELEMENTS PRIOR TO PROJECT OPERATION					
P1A1 Microfactory construction					
Steel production	-	-	-	0.43	0.03%
B. UPSTREAM ELEMENTS DURING PROJECT OPERATION					
P1B1 Extraction, production and transportation of fossil fuels					
Diesel production	66.5	0.4399	0.0021	79.3	6.20%
P1B2 Electricity production and distribution					
Electricity production (biofuel production)	1.61	-	-	2.28	0.18%
P1B3 Grain production and transportation					
Tonnes-kilometers traveled by grain	4.8	0.0000	0.0001	4.8	0.38%
P1B4 Grain pressing and product transportation					
Tonnes-kilometers traveled by oil and meal	2.8	0.0000	0.0001	2.9	0.22%
P1B5 Other inputs production and transportation					
Dimethyl Carbonate production	-	-	-	613	47.86%
Methanol production	-	-	-	1.90	0.15%
Tonnes-kilometers traveled by inputs - Boat	242	0.0976	0.0063	247	19.30%
Tonnes-kilometers traveled by inputs - Truck	4.48	0.0000	0.0001	4.52	0.35%
Canola oil production (in replacement of the baseline)	-	-	-	314	24.6%
D. DOWNSTREAM ELEMENTS DURING PROJECT OPERATION					
P1D1 Biofuel transportation					
Tonnes-kilometers traveled by the biofuel	2.28	0.0000	0.0001	2.3	0.18%
P1D2 Biofuel combustion					
Biofuel consumed	*2 472*	0.0730	0.0220	8.04	0.63%
			Total GHG emissions	**1 280**	**$kgCO_2e/kL$**

6.2. Quantification of the baseline's GHG emissions

B1B1 Extraction, production and transportation of fossil fuels

The quantity of diesel produced equals the diesel consumed by trucks for the transportation of the inputs and the diesel produced in replacement of the project's biofuel.

Table 14: B1B1 Data and Emission Factor

Input	Quantity (L/kL)	Uncertainty	Emission factor ($kgCO_2e/L$)	Uncertainty
Diesel	13.1	High	0.82	Low

The diesel consumption was converted from tonne-kilometers transported based on an emission factor ratio. The emission factor is from GHGenius.

B1B3 Grain production and transportation

Fuel consumption for the transportation of the grains was calculated based on the weight of grains transported and the distance traveled by the grains. To guarantee functional equivalence with the project, the same quantity of grain as the project was considered, while an average distance of 20km was estimated.

Table 15: B1B3 Data and Emission Factors

Input	Quantity (TKT/kL)	Uncertainty	Emission factor ($kgCO_2e/TKT$)	Uncertainty
Tonnes-kilometers traveled	37.7	Medium	0.13	Low

The emission factor for this source, as well as for B1B4 and B1D1, comes from USEPA's Emission Factors for Greenhouse Gas Inventories.

B1B4 Grain pressing and product transportation

As for element B1B3, fuel consumption for the transportation of the oil and meal was calculated based on the weight transported, provided by Autarcycle, and the distance traveled, estimated to be 20km for the meal and 100km for the oil, as it will be likely sent further than meal to a specialized company.

Table 16: B1B4 Data and Emission Factors

Input	Quantity (TKT/kL)	Uncertainty	Emission factor ($kgCO_2e/TKT$)	Uncertainty
Tonnes-kilometers traveled	97.5	Medium	0.13	Low

B1C1 Diesel production

The amount of diesel produced was calculated based on the amount of biofuel produced in the project, the percentage of biodiesel in the diesel mix as well as the energy content of the biofuel, diesel and biodiesel. Emission factors were taken from GHGenius.

Table 17: B1C1 Data and Emission Factor

Input	Quantity (L/kL)	Uncertainty	Emission factor ($kgCO_2e/L$)	Uncertainty
Amount of diesel produced	807	Low	0.82	Low
Amount of biodiesel produced	51.5	Low	0.15	Low

B1D1 Diesel transportation

Emissions were calculated based on the density of the diesel and biodiesel (to calculate the weight of diesel-biodiesel mix transported), and the average distance traveled by the fuel to the final user, which was estimated to be 200km.

Table 18: B1D1 Data and Emission Factor

Input	Quantity (TKT/kL)	Uncertainty	Emission factor ($kgCO_2e/TKT$)	Uncertainty
Tonnes-kilometers traveled	145	Medium	0.13	Low

B1D2 Diesel combustion

This source includes emissions related to the combustion of the diesel-biodiesel mix equivalent to one kiloliter of biofuel. The emission factors used were obtained from ECCC's National Inventory Report.

Table 19: B1D2 Data and Emission Factor

Input	Quantity (L/kL)	Uncertainty	Emission factor ($kgCO_2e/L$)	Uncertainty
Diesel consumed	807	Low	2.69	Low
Biodiesel consumed	51.5	Low	0.01	Low

Total baseline GHG emissions

The emission results for each element and each GHG are presented in the table below:

Table 20: GHG Emissions from the Baseline

Element	CO_2 Emissions (kg)	CH_4 Emissions (kg)	N_2O Emissions (kg)	GHG emissions ($kgCO_2e$)	% of total emissions
B. UPSTREAM ELEMENTS DURING BASELINE OPERATION					
B1B1 Extraction, production and transportation of fossil fuels					
Diesel production	9.04	0.0598	0.0003	10.79	0.37%
B1B3 Grain production and transportation					
Tonnes-kilometers traveled by inputs	4.80	0.0000	0.0001	4.84	0.17%
B1B4 Grain pressing and product transportation					
Tonnes-kilometers traveled by oil and meal	12.4	0.0001	0.0004	12.5	0.43%
C. ELEMENTS DURING BASELINE OPERATION					
B1C1 Diesel production					
Amount of diesel produced	556	3.6767	0.0172	663	23.0%
Amount of biodiesel produced	-2.13	0.0369	0.0324	7.74	0.27%
D. DOWNSTREAM ELEMENTS DURING BASELINE OPERATION					
B1D1 Diesel transportation					
Tonnes-kilometers traveled by diesel to the farm	18.5	0.0002	0.0005	18.6	0.65%
B1D2 Diesel combustion					
Diesel consumed	2 162	0.0589	0.0177	2 169	75.1%
Biodiesel consumed	*127*	0.0038	0.0011	0.41	0.01%
			Total GHG emissions	**2 886**	**$kgCO_2e/kL$**

7. Quantification of GHG emission reductions

7.1. Quantification results

The table presents the expected results for the project in comparison to the baseline scenario. Details of the calculations are presented in the associated spreadsheet.

Table 21: Expected GHG Emissions Reductions

Element	P1 GHG Emissions ($kgCO_2e/kL$)	B1 GHG Emissions ($kgCO_2e/kL$)	B1-P1 GHG Reductions ($kgCO_2e/kL$)
B1 Extraction, production and transportation of fossil fuels			
Diesel production	**79.3**	**10.8**	**-68.5**
B2 Electricity production and distribution			
Electricity production (biofuel production)	**2.28**	**-**	**-2.28**
B3 Grain production and transportation			
Tonnes-kilometers traveled by grain	**4.84**	**4.84**	**0.00**
B4 Grain pressing and product transportation			
Tonnes-kilometers traveled by oil and meal	**2.85**	**12.5**	**9.67**
B5 Other inputs production and transportation			
Dimethyl Carbonate production	**613**	**-**	**-613**
Methanol production	**1.90**	**-**	**-1.90**
Tonnes-kilometers traveled by inputs - Boat	**247**	**-**	**-247**
Tonnes-kilometers traveled by inputs - Truck	**4.52**	**-**	**-4.52**
Canola oil production (in replacement of the baseline)	**314**	**-**	**-314**
C1 Fuel production			
Amount of diesel produced	**-**	**663**	**663**
Amount of biodiesel produced	**-**	**7.74**	**7.74**
D1 Fuel transportation			
Tonnes-kilometers traveled by the fuel	**2.30**	**18.6**	**16.3**
D2 Fuel combustion			
Diesel consumed	**-**	**2 169**	**2 169**
Biofuel consumed	**8.04**	**0.41**	**-7.63**
Total	**1 280**	**2 886**	**1 607**

This analysis shows that the expected GHG emission reductions from the project are of 1 607 $kgCO_2e/kL$ of biofuel which represents a 55.7% of reduction when compared to the baseline. It must be noted that many parameters could influence the actual reductions of this project, namely the origin of the diesel used in the baseline (in replacement of the biofuel), the percentage of biodiesel in the diesel-biodiesel mix, as well as the origin of the dimethyl carbonate used for the project. As mentioned in section 6, emissions were also quantified for the eventuality that the carbonate would be produced onsite. In that case, reductions of 2 349 $kgCO_2e/kL$ of biofuel could be achieved, resulting in an 81.4% reduction when compared to the baseline. Further details on the calculations can be found in the associated spreadsheet.

7.2. Uncertainty analysis

Parameter error propagation for GHG reductions is calculated using the following equation found in the *IPCC Good Practice and Uncertainty Management Recommendations for National Inventories* (IPCC (Intergovernmental Panel on Climate Change), 2000).

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + \cdots + (U_n \times x_n)^2}}{x_1 + x_2 + \cdots + x_n}$$

Where: Utotal = Percentage uncertainty of the sum of quantities

xi = Uncertain quantities (of potential reductions)

Ui = Percentages of uncertainty (associated with quantities)

The uncertainty levels are defined as follows:

- ⇒ Low uncertainty: The industrial sectors of interest are well known, the processes are similar across manufacturers, and data for Canada are available;
- ⇒ Medium uncertainty: General data are available, but there are few local data and conditions may vary from one production site to another;
- ⇒ High uncertainty: Few general data are available, little information on local production facilities, and wide variations between manufacturing processes.

The uncertainty levels were affected by the following orders of magnitude:

- ✓ Low = ± 5%;
- ✓ Average± 15%; and
- ✓ High= ± 30%.

These values were used in the uncertainty analysis. Using these orders of magnitude, it was possible to assess the potential impact on overall GHG emissions from the project and the baseline scenarios (note that uncertainties on parameters and uncertainties in the model were qualitatively assessed together). The error propagation and its impact on predicted GHG emissions and reductions are presented in the following table.

Table 22: Uncertainty Analysis

Element	P1 GHG Emissions ($kgCO_2e/kL$)	+/-	B1 GHG Emissions ($kgCO_2e/kL$)	+/-
B1 Extraction, production and transportation of fossil fuels				
Diesel production	79.3	15%	10.8	30%
B2 Electricity production and distribution				
Electricity production (biofuel production)	2.28	5%	-	-
B3 Grain production and transportation				
Tonnes-kilometers traveled by grain	4.84	30%	4.84	15%
B4 Grain pressing and product transportation				
Tonnes-kilometers traveled by oil and meal	2.85	5%	12.5	30%
B5 Other inputs production and transportation				
Dimethyl Carbonate production	613	15%	-	-
Methanol production	1.90	15%	-	-
Tonnes-kilometers traveled by inputs - Boat	247	30%	-	-
Tonnes-kilometers traveled by inputs - Truck	4.52	30%	-	-
Canola oil production (in replacement of the baseline)	314	15%	-	-
C1 Fuel production				
Amount of diesel produced	-	-	663	5%
Amount of biodiesel produced	-	-	7.74	5%
D1 Fuel transportation				
Tonnes-kilometers traveled by the fuel	2.30	15%	18.6	15%
D2 Fuel combustion				
Diesel consumed	-	-	2 169	5%
Biofuel consumed	8.04	5%	0.41	5%
Total	**1 280**	10.0%	**2 886**	3.9%
Uncertainty effect	127.7		114	

As presented above, the uncertainty on the project if 10.0% while the uncertainty on the baseline is 3.9%. The higher uncertainty for the project is due to the uncertainty on the distance traveled by the dimethyl carbonate as well as the uncertainty on the emission factors for dimethyl carbonate and canola oil production.

8. Expected deployment of the technology and impacts

The following table presents the anticipated results of the deployment of Autarcycle's project.

Table 23: Technology Rollout

Deployment			GHG		Total CAC Reduction				
Year	Expected production (kL)	Cumulative production (kL)	Annual GHG Reductions (tCO_2e/yr)	Cumulative GHG Reductions (tCO_2e)	TPM (t/yr)	SOx (t/yr)	NOx (t/yr)	NMVOC (t/yr)	CO (t/yr)
2025	80	80	129	129	0.24	0.10	0.61	0.08	0.28
2026	880	960	1 414	1 542	2.61	1.11	6.68	0.92	3.10
2027	3 280	4 240	5 270	6 812	9.71	4.15	24.9	3.43	11.5
2028	11 280	15 520	18 123	24 935	33.4	14.3	85.7	11.8	39.7
2029	27 280	42 800	43 828	68 763	80.8	35	207	28.5	96
2030	55 280	98 080	88 813	157 576	164	70.0	420	57.8	194
2031	95 080	193 160	152 756	310 332	282	120	722	99.4	334
2032	147 280	340 440	236 621	546 953	436	186	1 119	154	518
2033	213 280	553 720	342 657	889 610	632	270	1 620	223	750
2034	293 280	847 000	471 185	1 360 795	868	371	2 228	307	1 032

9. Information on the GHG quantification team

Organization name and contact information

268 Aberdeen Street, Suite 204
Sherbrooke, Quebec J1H 1W5
Tel.: 819 823-2230
www.enviroaccess.ca

The following table shows the names and contact information of the team members who completed the quantification report.

Roles	Names and title	Contact details
Calculations and reporting	Melissa Windsor, B.Sc.A GHG Advisor and Auditor	268 Aberdeen Street, Suite 204 Sherbrooke, Quebec J1H 5W1 Tel.: 819 823-2230 mwindsor@enviroaccess.ca
Review of calculations and report	Vickie-Lisa Angers, P.Eng., M.Env. GHG Advisor and Auditor	268 Aberdeen Street, Suite 204 Sherbrooke, Quebec J1H 5W1 Tel.: (819) 823-2230 vlangers@enviroaccess.ca

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