GHGenius 5.02b User Guide:

Carbon Intensity of Hydrogen

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Executive Summary

This guide is intended to assist hydrogen producers and suppliers in determining the carbon intensity (CI) of hydrogen fuel supplied to British Columbia (BC) under the Low Carbon Fuel Standard (LCFS) using the GHGenius 5.02b model.

The guide outlines the steps required to model hydrogen production pathways in GHGenius, including setting up the model, selecting appropriate regions and model years, applying Global Warming Potentials (GWPs) consistent with BC requirements, and entering facility-specific data.

It also provides guidance on modelling key life cycle stages such as feedstock sourcing, hydrogen production, compression or liquefaction, transportation, and end use in BC.

Where hydrogen production pathways span multiple regions or involve multiple stages, the guide explains how to perform multiple model runs and combine results to determine overall carbon intensity.

Example pathways are provided to illustrate the application of the modelling approach.

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Glossary

ATR	Autothermal Reforming
BC	British Columbia
CCS	Carbon Capture and Sequestration
CH_2	Compressed Hydrogen
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide-equivalent greenhouse gas emissions
DOE	Department of Energy
FT	Fischer-Tropsch Process
GJ	Giga Joule (10^9 Joules)
GWP	Global Warming Potential
H_2	Hydrogen
HHV	Higher Heating Value
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
Kg	Kilogram
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
LCFS	Low Carbon Fuel Standard
LFG	Landfill Gas
LH_2	Liquid Hydrogen
LPG	Liquified Petroleum Gas
MJ	Mega Joule
NG	Natural Gas
PADD	Petroleum Administration for Defense Districts
PEM	Polymer Electrolyte Membrane
PSA	Pressure Swing Adsorption
RNG	Renewable Natural Gas
SMR	Steam Methane Reforming
SOEC	Solid Oxide Electrolyzer Cells
WGS	Water Gas Shift Reaction

1 Introduction

This guidance is intended to assist hydrogen producers and suppliers in determining the carbon intensity (CI) of hydrogen fuel to British Columbia (BC) under the Low Carbon Fuel Standard (LCFS) using GHGenius 5.02b.

GHGenius is a Microsoft Excel-based LCA model that has been developed over the past 20 years. It is available for download at www.ghgenius.ca.

Fuel producers must follow the procedures and requirements outlined in this document and incorporate all relevant information into their application form and Technical Report, as applicable.

1.1 Process Overview

Hydrogen can be produced from a variety of feedstocks and production processes. In GHGenius, hydrogen production is modelled based on the primary feedstock and the associated production pathway. The selection of the appropriate pathway is a key step in determining the (CI).

The following hydrogen production pathways are directly represented in GHGenius and are supported by this guidance:

- **Hydrogen from natural gas**, including processes such as steam methane reforming (SMR), autothermal reforming (ATR), and methane pyrolysis
- **Hydrogen from electrolysis of water**, where electricity is the primary energy input

- **Hydrogen from biomass**, including gasification of wood, wood residue, and other biomass feedstocks
- **Hydrogen from coal**, modelled using the coal-based hydrogen pathway

For these pathways, users can model hydrogen production by entering facility-specific data as described in Sections 2 through 4.

- Other hydrogen production routes are not explicitly defined as standalone pathways in GHGenius. These include:
    - Hydrogen produced from intermediate fuels (e.g., methanol, ethanol, gasoline)
    - Hydrogen recovered from industrial waste gas streams
    - Emerging or novel hydrogen production technologies

These pathways are considered indirect or non-standard pathways for the purposes of this guidance. They must be modelled using combinations of existing pathways or appropriate proxy assumptions. Applicants must clearly describe the modelling approach, system boundaries, and key assumptions in the Technical Report submitted with the CI Application. For guidance on modelling indirect or novel hydrogen pathways, contact LCFS@gov.bc.ca.

Heat might be generated and recovered during hydrogen production process. Heat that is used within the hydrogen production process reduces the facility's energy requirements and should be reflected in the modelling of energy inputs. Where heat is exported outside the system boundary (e.g., as electricity or steam generation), it may be treated as a co-product. In such cases, the treatment of exported energy, including any allocation of emissions, must be consistent with the approach described in Section 4.3 (Co-products) and must be clearly documented in the Technical Report.

Carbon capture and sequestration (CCS) may be applied to reduce emissions associated with hydrogen production from natural gas. Where CCS is implemented, users must input capture rates, energy requirements, and associated emissions as described in Section 4.4. All assumptions and data sources related to CCS must be clearly documented in the Technical Report.

1.1.1 Fossil Natural Gas

Hydrogen produced from fossil-derived natural gas is modelled in GHGenius using the hydrogen from natural gas pathway. This pathway represents hydrogen production processes where natural gas is the primary feedstock.

Hydrogen from natural gas is typically produced through processes such as steam methane reforming (SMR) and autothermal reforming (ATR). In these processes, methane (CH_4) reacts with steam and/or oxygen at high temperature to produce hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2). The carbon monoxide is further converted to CO_2 and additional hydrogen through the water-gas shift reaction. Methane pyrolysis is an alternative process that produces hydrogen and solid carbon.

In GHGenius, these production processes are represented within a single hydrogen from natural gas pathway. Differences between process configurations, including SMR, ATR, and methane pyrolysis, are reflected through facility-specific input data such as energy use, hydrogen yield, and process emissions.

Carbon dioxide generated during hydrogen production from fossil natural gas is fossil-derived and is included in the carbon intensity (CI) of the hydrogen. As a result, the CI is influenced by process efficiency, fuel inputs, and the management of process emissions.

This guidance applies to hydrogen produced from fossil-derived natural gas. Where renewable natural gas (RNG) is used as a feedstock, the modelling approach may differ and additional considerations may apply. Applicants proposing the use of RNG must clearly describe their approach and supporting assumptions in the Technical Report and may be required to seek additional guidance.

Detailed instructions for modelling hydrogen from natural gas are provided in Sections 2 through 4.

1.1.2 Electrolysis of Water

Hydrogen produced from the electrolysis of water is modelled in GHGenius using the water pathway, where electricity is the primary energy input.

Electrolysis is a process in which electrical energy is used to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). Common electrolysis technologies include alkaline electrolysis, polymer electrolyte membrane (PEM) electrolysis, and solid oxide electrolysis cells (SOEC). In GHGenius, these technologies are represented within a single electrolysis pathway. Differences between technologies are reflected through facility-specific input data, including electricity consumption and hydrogen yield.

The carbon intensity (CI) of hydrogen produced via electrolysis is primarily determined by the source and emissions intensity of the electricity used. By default, GHGenius applies regional grid electricity emissions based on the selected modelling region. Where electricity is sourced from non-grid or facility-specific sources, users may define custom electricity emissions as described in Section 4.2. Any adjustments to default electricity emissions must be supported with appropriate data and clearly documented in the Technical Report.

Electricity generated and consumed within the hydrogen production facility (e.g., from onsite generation) must be accounted for in the calculation of net electricity inputs. Only net electricity consumption should be entered into the model. Where electricity is exported outside the system boundary, it may be treated as a co-product, subject to the requirements described in Section 4.3 (Co-products).

Electrolysis produces oxygen as a co-product. Where oxygen is captured and used or sold outside the system boundary, it may be treated as a co-product. The treatment of oxygen, including any allocation of emissions, must be consistent with Section 4.3 (Co-products) and must be clearly documented in the Technical Report.

Detailed modelling instructions are provided in Sections 2 through 4.

1.1.3 Gasification

Hydrogen produced from the gasification of solid feedstocks is modelled in GHGenius using pathways corresponding to the selected feedstock. Gasification is a high-temperature process in which carbon-based materials react with oxygen and/or air to produce synthesis gas (syngas), primarily composed of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2). The carbon monoxide is further converted to hydrogen and CO_2 through the water-gas shift reaction.

In GHGenius, hydrogen production from gasification is represented through feedstock-specific pathways, including biomass (e.g., wood, wood residue, and wood pellets) and coal. While the underlying gasification process is similar, the carbon intensity (CI) of hydrogen produced depends significantly on the feedstock used.

For biomass-derived feedstocks, a portion or all the carbon may be considered biogenic, which can result in lower CI values depending on the pathway and system boundary. For fossil-derived feedstocks such as coal, carbon emissions are treated as fossil-derived and are fully included in the CI.

Differences in process configuration, including gasification technology, hydrogen yield, and energy use, are reflected through facility-specific input data. Users must ensure that all relevant inputs, including feedstock quantities, energy use, and process emissions, are accurately represented in the model.

Carbon capture and sequestration (CCS) may be applied to gasification-based hydrogen production to reduce emissions. Where CCS is implemented, users must input capture rates, energy requirements, and associated emissions as described in Section 4.4. All assumptions and data sources related to CCS must be clearly documented in the Technical Report.

Detailed instructions for modelling hydrogen from gasification are provided in Sections 2 through 4.

Hydrogen may be recovered from industrial processes where it is generated as a by-product or contained within waste gas streams. Examples include hydrogen-containing streams from chlor-alkali production and other chemical processes. These pathways do not represent primary hydrogen production from a dedicated feedstock, but rather the capture and upgrading of hydrogen that would otherwise be vented, flared, or used for low-value applications.

Waste product capture and upgrade is not represented as a standalone hydrogen production pathway in GHGenius. Instead, these pathways must be modelled using appropriate proxy pathways and facility-specific inputs that reflect the upgrading, purification, compression, and handling of the recovered hydrogen. Waste hydrogen capture and upgrading from chlor-alkali production is modelled using the electrolysis pathway

A key consideration in modelling these pathways is the definition of the system boundary and the treatment of upstream emissions. Where hydrogen is recovered from a waste stream that would otherwise be vented or flared, upstream emissions associated with the original industrial process may not be attributed to hydrogen, provided this treatment is justified. Where the hydrogen-containing stream has an existing use or economic value, the allocation of upstream emissions may be required. Applicants must clearly describe the basis for their system boundary and any assumptions related to the treatment of upstream emissions in the Technical Report.

Energy and material inputs associated with capturing, upgrading, and delivering the hydrogen must be included in the modelling. This includes, but is not limited to, electricity use, compression, purification, and transportation

1.1.4 Indirect pathways

Hydrogen may be produced from intermediate fuels or processes that are not explicitly defined as standalone hydrogen production pathways in GHGenius. These pathways are referred to as indirect pathways.

Examples of indirect pathways include hydrogen produced from:

- methanol (including methanol derived from landfill gas)
- ethanol (including wheat, corn and cellulosic ethanol)
- gasoline
- Fischer-Tropsch diesel
- liquefied petroleum gas (LPG)

In these cases, hydrogen is produced through additional processing of an intermediate fuel that has its own upstream lifecycle emissions. As a result, indirect pathways typically require a combination of existing GHGenius pathways and facility-specific inputs to represent the full lifecycle.

Detailed modelling instructions for indirect pathways are not provided in this guide. Applicants proposing to model hydrogen using indirect pathways must clearly describe their modelling approach, system boundaries, and key assumptions in the Technical Report submitted with the CI Application.

Given the variability of these pathways, additional information or justification may be required to support the proposed approach. Applicants are encouraged to contact the Low Carbon Fuels Branch at LCFS@gov.bc.ca for guidance prior to submission.

2 GHGenius – Download, Setup and Initialization

This section outlines how to obtain the model and the steps that need to be taken to initialize it prior to inputting values for LCA modelling.

2.1 Model Overview

GHGenius is a Microsoft Excel-based LCA model. Features of GHGenius that users should be aware of include:

- The use of time-based data series rather than static data: This means the selection of Target year will alter the CI value of fuels modelled in GHGenius. Users must select the appropriate Target year for their modelling (see Section 2.3.2 and Section 4.1)
- The inclusion of region and country specific datasets: This means that the selection of Region will alter the CI value of fuel modelled in GHGenius. Users must select the appropriate Region for their modelling. If different life cycle stages occur in different regions, multiple runs of the model may be required (see Section 2.3.1)

2.2 Downloading the Model

GHGenius 5.02b is available to download at the Downloads tab of the GHGenius webpage. There is no cost to users; however, registration is required to download the model.

The downloaded file is provided as a zipped [.xls] excel file. After unzipping the file, do not save as a [.xlsx] file as this will deactivate the macros that the model requires to operate correctly.

Although the file can be saved as a macro enabled [.xlsm] format, this may result in loss of functionality. More specifically, some macro buttons may stop working unless manually reassigned. As such, to ensure full functionality it is strongly recommended to save and run the model in its original [.xls] format.

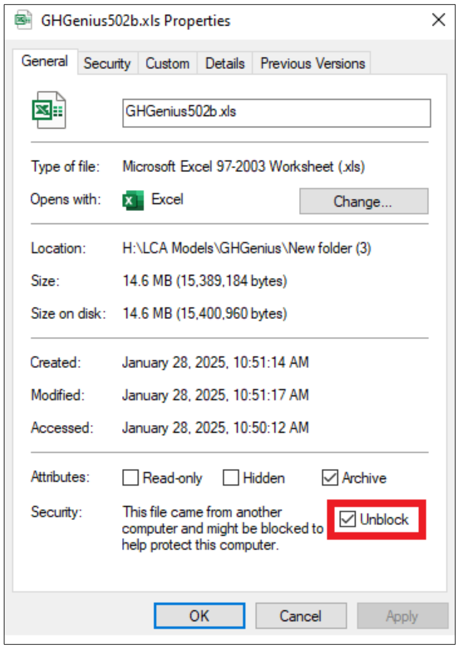
2.2.1 Unblocking Macros

GHGenius relies on macros to set up appropriate Excel settings, calculate many of the output values, and provide additional tools for users. The model will not function properly without macros enabled.

To make Microsoft Office more secure, macros are now blocked by default on files downloaded from the internet. To unblock macros:

1. Navigate to the file in File Explorer
2. Right-click on the file’s icon and select [Properties]
3. Select [Unblock] at the bottom of the General tab in the Properties window

Figure 2-1 Unblocking Macros



For more information about this change and alternative ways to unblock macros please visit the Macros from the internet are blocked by default in Office webpage.

2.3 Initializing the Model

Before entering any facility specific data to model a fuel pathway, users must first initialize the model as outlined in the sections below.

2.3.1 Model Region

Users must select the appropriate modelling region from the dropdown list in Cell B4 on the Input sheet. After selecting, users must click the “Install Regional Defaults” button located to the right of the dropdown list (near Cell C4). This action will run macros to populate region-specific data for the current modelling run. Before proceeding, users must verify that the correct region has been applied in the model. Check Cell B10 on the Input sheet, which displays the currently active region, to confirm.

The selected region must correspond to where the relevant process (fuel life cycle stage(s)) occurred. Because fuel pathways often span multiple regions, most carbon intensity assessments will require two or three model runs to reflect the geographic locations of each life cycle stage. For example, if the feedstock originates from one region and the fuel is produced in another region outside British Columbia, the user must complete the following three modelling runs to determine the CI of the fuel:

1. Feedstock production and transportation – use the region where the feedstock originates.
2. Fuel production, transportation, storage and distribution – use the region where the production facility is located.
3. Fuel distribution, storage, dispensing and end use – use the region where the fuel is used (British Columbia).

For processes occurring within Canada, although the model allows selection of broader regions (e.g. Canada West/Central/East), users must select the specific province to accurately determine the fuel's carbon intensity.

The United States regions in GHGenius align with the US Energy Information Administration's Petroleum Administration for Defense Districts (PADDs) as shown in Figure 2-2 and Table 2-1 below.

Figure 2-2 US Model Regions – PADDs

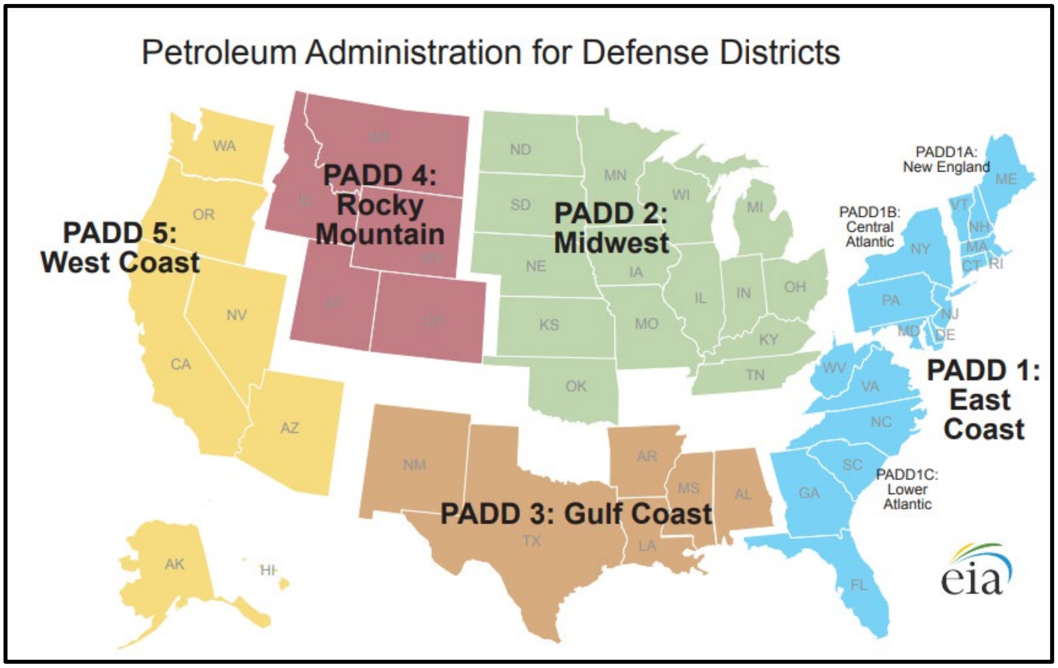


Table 2-1 PADD and corresponding GHGenius region

PADD	GHGenius Region
4 & 5	US West
2 & 3	US Central
1	US East

If a process occurs outside of Canada or the USA, users must select the appropriate country from the dropdown list. If the country is not available in the model, users must select the most appropriate proximate region within the model and provide a clear rationale for their selection.

2.3.2 Model Year

The model target year must be set to match the year the input data was collected or which the data represents. If the supporting data was collected over multiple years, set the model for the latest year in the dataset.

Users must enter the modelling year in two locations in the model, both on the Input sheet:

- Target Year: Cell B7
- Base year for Alt Fuel Production: Row 241 – column will vary depending on feedstock type. For hydrogen the columns are V, W, BR, BS, BT, BU, BV, BW, BX, or BY.

2.3.3 Global Warming Potentials (GWPs)

By default, the model uses GWP values from the International Panel on Climate Change (IPCC) 5th Assessment Report (2013 100 years) and sets the treatment of short-lived gases as "Carbon Weighted".

To change the GWP settings, users can select different values in Cells B11 and D11 on the Input sheet. However, for the purposes of fuel CI modelling under the BC LCFS, the selected GWP settings must align with those provided in Information Bulletin RLCF-011: Approved Version of GHGenius and Global Warming Potentials.

3 Feedstock

Since the model incorporates region-specific data, users must model each feedstock type and origin combination separately to calculate an accurate fuel carbon intensity.

For hydrogen pathways, the relevance of feedstock inputs depends on the production method.

- For hydrogen produced from natural gas or electrolysis of water, no feedstock input is required in the model, as upstream emissions for these pathways are incorporated through the natural gas and electricity inputs. Input sheet, column V (Water) row 247 and 248; or column W (NG) cell 247 and 248 should be left as 0.00.
- For hydrogen produced from solid feedstocks (biomass or coal), users must model feedstock production and transportation as described below.

3.1 Feedstock Transportation

The transportation distances and modes of transportation for the feedstocks used in hydrogen production must be entered in the Input sheet in Rows 76 to 86.

- For each feedstock, enter the one-way transportation distance in kilometers in Rows 76 to 80 on the Input sheet in the column corresponding to the specific feedstock type.

- In rows 82 to 86, enter the tonnes-shipped/tonnes-produced for each mode of transport. This number represents the fraction of total feedstock used in fuel production that was transported by that mode of transport.

For pathways that use coal as a feedstock, there is a specific column (E) for transportation of coal to the hydrogen plant, shown in Figure 3-1 below.

For biomass feedstocks, column J for wood to plant, or column AR for wood pellets to plant should be used.

Figure 3-1 Feedstock Transportation Inputs

	A	B	C	D	E	F	G	H
73	TRANSPORTATION OF FEEDSTOCKS							
74		Crude Oil	Coal	Coal	Coal	Corn	Whole Corn	Elevator
75	Average km shipped		to power	to liquid fuel	to H2	to Plant	to Elevator	to plant
76	By Rail	54	451	0	0	0	200	0
77	Domestic water	Calculated	594	0	0	0	0	0
78	International water	Calculated	Calculated	0	0	0	0	0
79	Pipeline, tram, conveyor	1,698	0	10	10	0	0	0
80	Truck (Defaults)	7	2	0	0	100	200	80
81	Tonnes-shipped/tonne-produced							
82	By Rail	0.46	0.40	0.00	0.00	0.00	0.50	0.00
83	Domestic water	0.01	0.34	0.00	0.00	0.00	0.00	0.00
84	International water	Calculated	Calculated	0.00	0.00	0.00	0.00	0.00
85	Pipeline, tram, conveyor	0.85	0.00	1.00	1.00	0.00	0.00	0.00
86	Truck	0.58	0.62	0.00	0.00	1.00	0.50	1.00

3.2 Feedstock Production

For pathways requiring feedstock inputs (e.g., biomass or coal), GHGenius applies default regional data for feedstock production. Where facility-specific data is not available, these default values must be used.

Where users have reliable data for additional processing required to prepare feedstocks for hydrogen production (e.g., drying, size reduction, or upgrading prior to gasification), these energy and material inputs should be included in the hydrogen production stage outlined in Section 4.2 below, rather than modifying the default feedstock production values.

This approach ensures that emissions are not double counted and that all inputs are consistently represented within the system boundary of hydrogen production.

4 Hydrogen Production

4.1 Year

The target year and the fuel production year (base year) must reflect the year that data used to generate the modelling inputs was collected. If the supporting data was collected over multiple years, set the model for the latest year in the dataset. If design data is used, the application year should be used.

- Set the target year in cell B7 of the Input sheet.
- Set the fuel production year in row 241 of the Input sheet in the column that corresponds to the feedstock type (see Table 4-1 below).

4.2 Mass and Energy

Enter mass and energy inputs in rows 243 to 248 of the Input sheet in the column that corresponds to the feedstock type, as outlined in Table 4-1 below.

Table 4-1 Feedstock Type and Input Sheet Columns

Hydrogen Feedstock	GHGenius Input Sheet Column
Water (electricity)	V
NG	W
Methanol	BR
Gasoline	BS

Hydrogen Feedstock	GHGenius Input Sheet Column
Ethanol	BT
FT Diesel	BU
LPG	BV
Coal	BW
Biomass	BX
Wood Pellets	BY

4.2.1 Electricity

Enter net electricity purchased in row 243 of the Input sheet in the column that corresponds to the feedstock type (see Table 4-1 above). In all cases, applicants enter the kilowatt-hours of electricity required per gigajoule of hydrogen produced (kWh/GJ_{H2}).

By default, the model assumes the electricity is from the grid and applies the regional defaults for grid emissions. If electricity is from an off-grid source, users must apply custom electricity emissions by setting cell B34 of the Input sheet to 'Local Grid' then setting the appropriate fractions in row 21 of the Power Generation sheet. If users adjust the grid emissions justification for the adjustment must be included in the Technical Report.

Some production facilities generate electricity internally as part of their production process to use on site or sell to the grid and/or have solar panels on site. The instructions for calculating net electricity in these cases are below.

First calculate the net electricity:

$$\text{Electricity}_{\text{net}} = \text{Electricity}_{\text{purchased}} - \text{Electricity}_{\text{sold}}$$

$\text{Electricity}_{\text{purchased}}$ is electricity purchased for use at the facility (e.g. grid electricity).

$\text{Electricity}_{\text{sold}}$ is the electricity produced on site that is sold back to the grid. This cannot include solar electricity produced on site and does not include electricity produced and consumed internally.

The equation above will calculate whether the net electricity is greater than, equal to or less than zero. This information is used to determine how to model the electricity:

$\text{Electricity}_{\text{net}}$ greater than zero

If $\text{Electricity}_{\text{net}}$ is greater than zero solar electricity produced on site can be added to the equation:

$$\text{Electricity}_{\text{net}} = \text{Electrictiy}_{\text{purchased}} - \text{Electrity}_{\text{sold}} - \text{Electricity}_{\text{solar}}$$

$\text{Electricity}_{\text{solar}}$ is the electricity produced by solar panels on site. Note that solar panels are outside of the system boundary and therefore $\text{Electricity}_{\text{solar}}$ cannot reduce $\text{Electricity}_{\text{net}}$ to less than zero. Any solar electricity produced that reduces $\text{Electricity}_{\text{net}}$ to less than zero should be excluded from the above equation.

Once this input is calculated the value must be inserted into row 243 of the Input sheet in the column that corresponds to the feedstock type (see Table 4-1 above). In this case no co-product credit would be claimed for the electricity even if some electricity will be sold to the grid.

$Electricity_{net}$ less than zero

If $Electricity_{net}$ is less than zero enter zero into row 243 of the Input sheet in the column that corresponds to the feedstock type (see Table 4-1 above) and claim a coproduct credit equal to $Electricity_{net}$ (see section 4.3). In this case, any solar electricity produced on site is excluded from the $Electricity_{net}$ calculation.

$Electricity_{net}$ is equal to zero

Enter zero in row 243 of the Input sheet in the column that corresponds to the feedstock type (see Table 4-1 above). In this case, any solar electricity produced is excluded from the $Electricity_{net}$ calculation.

4.2.2 Diesel Fuel

Enter diesel fuel use into row 244 of the Input sheet in the column that corresponds to the feedstock type (see Table 4-1 above), if applicable.

The units for diesel fuel use are liters of diesel fuel per gigajoule of hydrogen produced (L_{Diesel}/GJ_{H2}).

Diesel use should include all diesel fuel used in equipment such as rail car shuttles, front end loaders, and any other diesel-fueled equipment at the hydrogen production facility.

4.2.3 Natural Gas

For hydrogen from natural gas pathways, the natural gas value should be entered into Input sheet cell W245 (Natural gas). The unit for natural gas use is megajoules of natural gas (calculated on a higher heating value – HHV basis) per gigajoule of hydrogen produced ($MJ_{Natural\ Gas\ (HHV)}/GJ_{H2}$).

For the coal, biomass and wood pellets pathways, use row 245, columns BW to BY for any natural gas consumed (see Table 4-1 above).

For the methanol, gasoline, ethanol, FT diesel and LPG pathways, row 245 is used for feedstock input as described in 4.2.4 below. No input for natural gas can be entered.

4.2.4 Feedstock

For the electricity and natural gas pathways there is no feedstock value entered.

For the coal, biomass and wood pellets pathways; the feedstock quantities are entered in row 246 (coal) or row 247 (biomass and wood pellets). The units for coal and biomass feedstock inputs are kilograms of feedstock per gigajoule of hydrogen produced ($kg_{Feedstock}/GJ_{H2}$).

Feedstock quantities for the methanol, gasoline, ethanol, FT diesel and LPG pathways are entered in row 245, columns BR to BV. As noted in cell BR249, while the row is labelled for NG inputs, it is used for feedstock inputs for these pathways. In this case, the units are megajoules of feedstock fuel per gigajoule of hydrogen produced ($MJ_{fuel\ feedstock}/GJ_{H2}$).

4.2.5 Chemicals

To model the chemical additives used for hydrogen production, the user must use the Alt Fuel Prod worksheet of GHGenius. Enter the values into rows 29-78 that correspond to the chemical used and the column that correspond to the hydrogen feedstock, as outlined in Table 4-2 below.

The input units are kilogram of chemical per GJ hydrogen produced ($kg_{Chemical}/GJ_{H2}$) unless otherwise stated in column A. All chemical inputs must reflect 100% purity. If the chemical is less than 100% pure, adjust the input value before entering it into the model (e.g. if using a 93% pure sulphuric acid additive, multiply the input weight by 0.93 before inputting into the model).

Table 4-2 Hydrogen Alt Fuel Prod Sheet Columns for Chemical Additives

Hydrogen Feedstock	GHGenius Alt Fuel Prod Sheet Column
Water (electricity)	V
NG	W
Methanol	X
Gasoline	Y
Ethanol	Z
FT Diesel	AA
LPG	AB
Coal	AC
Wood	AD
Wood Pellets	AE

4.3 Co-products

4.3.1 Electricity

A coproduct credit can sometimes be claimed when a facility produces and sells electricity to the grid. Refer to Section 4.2.1 to confirm that a coproduct credit can be claimed.

4.3.1.1 Electricity from coal, wood and wood pellets

Excess electricity generated as a coproduct of hydrogen production from coal, wood and wood pellets is entered on the Input sheet in row 274, columns U to W. Select the type of electricity displaced in cell AV274. The default value is “Generic Power” which is the electricity mix for the region. The model also allows users to define a custom electricity mix for the displaced electricity, if applicable. To do this, first select 'User Input' in Cell AV274 on the Input sheet then provide the fractions of each type of electricity for the custom grid in cells AV287 to AV297. The displaced electricity mix is used to calculate avoided emissions for the electricity co-product. Note that to use a non-default electricity grid justification for using it needs to be included in the Technical Report.

4.3.1.2 Electricity from Natural Gas

For the natural gas to hydrogen pathway, excess electricity is input on the Coprods sheet in cell D107. The input units for coproduct electricity are kilowatt-hours per gigajoule of hydrogen produced (kWh/GJ_{H2}).

Use Cell AV274 on the Input sheet to select the type of electricity displaced. The default value is “Generic Power” which is the electricity mix for the region. The model also allows users to define a custom electricity mix for the displaced electricity, if applicable. To do this, first select 'User Input' in Cell AV274 on the Input sheet, then provide the fractions of each type of electricity for the custom grid in cells AV287 to AV297. The displaced electricity mix is used to calculate avoided emissions for the electricity co-product.

4.3.2 Steam

The quantity of coproduct steam is entered on the Coprods sheet in cell D146 (Steam). This steam is excess to the fuel production. Only ‘Displacement’ can be selected for the allocation method in cell B201. The units for the coproduct steam input are megajoules of steam per gigajoule of hydrogen produced (MJ_{Steam}/GJ_{H2}).

4.3.3 Oxygen

Oxygen is co-produced with hydrogen during electrolysis. If oxygen is captured and used or sold as a product separately, then it is a co-product. GHGenius is not specifically set up to model co-products from electrolysis, but a displacement credit can be calculated by entering negative oxygen consumption on the Alt Fuel Prod sheet in cell V59 (oxygen, kg). The input unit is kg of oxygen per gigajoule of hydrogen (kg_{Oxygen}/GJ_{H2}). Applicants claiming an oxygen displacement credit must submit evidence to the BC LCFS demonstrating that oxygen is captured at the rate (kg_{Oxygen}/GJ_{H2}) included in the LCA and sold or used internally.

Not all projects will capture the co-produced oxygen. If oxygen is not captured it is considered a waste stream and no emissions can be attributed to it.

4.4 Carbon Capture and Sequestration

Inputs for carbon capture and sequestration are entered on the Input sheet and the Sequestration sheet. To include carbon capture and sequestration, enter 1 into cell B69 (Carbon Sequestration for fuel production) on the Input sheet.

There are two user inputs on the Sequestration sheet (columns U to AC), the fraction of CO_2 that is sequestered (row 19) and the energy used for the sequestration process (rows 22 to 26). The energy required for carbon capture will vary between applications. Include both electricity and thermal energy requirements, where applicable. Note that the light blue cells (Row 24, Columns V to Z) indicate that a fuel other than natural gas should be entered. For example, methanol use should be entered in Cell V24 of the methanol Column (Column V).

Figure 4-1 illustrates the input locations in the Sequestration sheet (columns U to AC, rows 19 to 26).

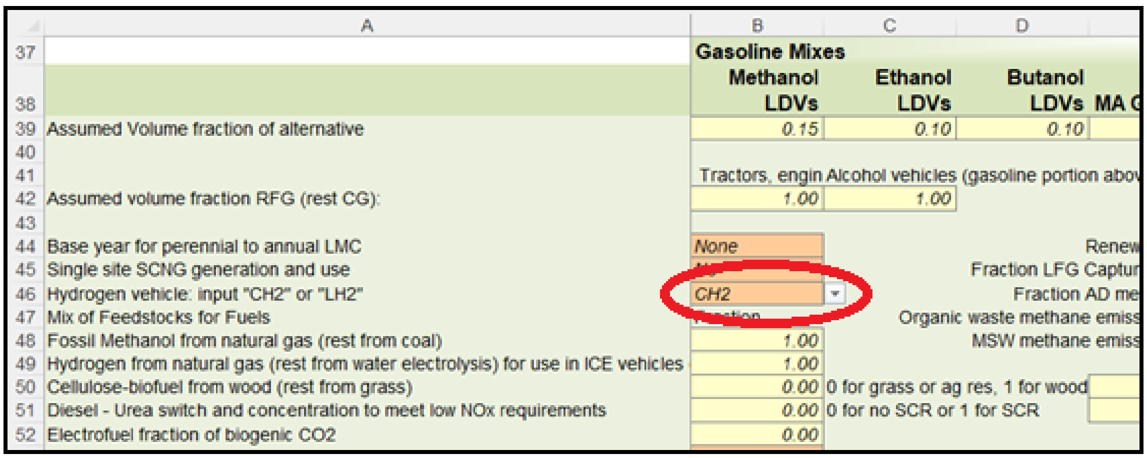
Figure 4-1 CO_2 Sequestration Inputs for Hydrogen Production

	A	U	V	W	X	Y	Z	AA	AB	AC
13										
14	**Fuels**									
15	**Fuel**	**H2**	**H2**	**H2**	**H2**	**H2**	**H2**	**H2**	**H2**	**H2**
16	**Feedstock**	**NG**	**Methanol**	**Gasoline**	**Ethanol**	**FT**	**LPG**	**Coal**	**Wood**	**Wood Pellets**
17	Inputs (below) per output	GJ	GJ	GJ	GJ	GJ	GJ	GJ	GJ	GJ
18										
19	Fraction emissions sequestered	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
20	Dollars per tonne sequestered	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
21										
22	Electricity (kWh)	12.00	14.20	16.00	15.00	15.40	14.00	21.00	23.00	23.00
23	Diesel (L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Natural gas (MJ)	110.97	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00
25	Coal (kg)	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	0.00
26	Wood (kg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.00	10.00
27			Blue indicates a fuel other than NG							
28										
29	kJ spent/GJ produced	154,174	151,120	157,600	154,000	155,440	150,400	517,658	302,800	282,800
30	g sequestered/GJ produced	63,334.3	65,641.8	109,426.7	96,260.4	104,210.7	96,845.0	155,709.8	147,136.7	142,535.7
31	GJ/Tonne CO2 Captured	2.4	2.3	1.4	1.6	1.5	1.6	3.3	2.1	2.0
32	Cents per litre* produced	44.9	46.5	77.6	68.2	73.9	68.6	110.4	104.3	101.0
33										

4.5 Hydrogen Compression/Liquefaction

GHGenius calculates the emissions for compression or liquefaction of hydrogen. Users select the applicable option on the Input sheet in cell B46 (Hydrogen vehicle: input CH2 (compression) or LH2 (liquefaction)). This input is required for all hydrogen pathways. The input location is shown below in Figure 4-2.

Figure 4-2 Compression/Liquefaction Drop Down



4.5.1 CH2 - Hydrogen Compression Parameters

For CH2 applications, users can set compression parameters using the Input sheet column C, rows 253 (assumed vehicle fuel tank storage pressure) and 254 (Inlet Pressure for compressor), as shown in Figure 4-3 below. The units are mega pascals (MPa). Rationale must be provided if a value other than the default is used for the fuel tank storage pressure.

Figure 4-3 Compression Modelling Inputs

	A	B	C	D
251	**ENERGY USE AND EMISSIONS AT SERVICE STATIONS, INCLUDING ENERGY TO COMPRESS OR LIQUEFY GASE**			
252		**CNG**	**CH2**	
253	Assumed vehicle fuel tank storage pressure (MPa) Defaults	*24.82*	*34.47*	
254	Inlet Pressure for compressor (MPa)	*0.45*	*0.69*	
255				
256	LNG Service Station NG (MJ/tonne)	*0.00*		
257	LNG Service Station Elec (kWh/tonne)	*500*		
258				
259				

4.5.2 LH2 - Hydrogen Liquification Parameters

For LH2 applications, the energy leakage and boil off inputs for liquefaction are specified on the Service Station sheet in column E, rows 7 to 13; see Figure 4-4 Liquefaction Modelling Inputs below. If these values are not available, users should retain the default values for the model.

The input parameters are:

- Joules of process energy per joule of fuel processed (E7)
- Fuel boil-off rate (E9)
- Number of fuel transfers (E10)
- Annual change in boil-off rate (E12)
- Fraction of fuel lost to boil-off that is reliquefied (E13)

Figure 4-4 Liquefaction Modelling Inputs

	A	B	C	D	E	F
1						
2	ENERGY USE AND EMISSIONS AT SERVICE STATIONS, INCLUDING ENERGY TO COMPRESS OR LIQUEFY GASEOUS FUELS					
3						
4	ENERGY USED TO COMPRESS OR LIQUEFY NATURAL GAS OR HYDROGEN: INPUT DATA					
5		CNG	LNG	CH2	LH2	
6	Vehicular storage pressure (kPa)	24,821		34,474		
7	J process energy per J fuel processed, at refuelling site	0.0	~~0.0~~	0.1	0.26	
8	Fraction of process energy from electricity	1.00	~~1.0~~	electricity only		
9	Fuel leakage or boil-off, per fuel transfer, in a base year (fraction of net output to consume	0.0	0.01	0.0	0.04	
10	Number of transfers, at refuelling site	1.00	3.00	1.00	3.00	
11	Base year of fuel-leakage or boil-off (BY)	1995	1995	1995	1995	
12	The annual change in leakage or boil-off (ΔFL)	-0.01	-0.05	-0.01	-0.07	
13	Of fuel boiled-off, the fraction reliquefied (FLR)	0.0	0.50	0.0	0.50	
14	Calculated dispensing process J per J fuel to vehicles,	0.02	~~0.00~~	0.06	0.26	
15	Calculated dispensing process kWh per kg fuel to vehicles,	0.10	~~0.00~~	0.42	1.73	
16	Calculated liquifaction process J per J fuel		~~0.03~~			
17	Boil off losses from vehicles themselves are supposed to be accounted for in the km/GJ measure. LPG treated as evaporating liquid.					

4.6 Hydrogen Transportation

Transportation of hydrogen (finished fuel) can be modelled as by truck, rail, pipeline and marine vessel. The input parameters are found on the Input sheet in columns BH and BI, rows 91 to 102 as shown in the following Figure 4-5.

Figure 4-5 Hydrogen Finished Fuel Transportation Inputs

	A	BF	BG	BH	BI
88	TRANSPORTATION OF FINISHED FUELS				
89		CNG	LNG	LH2	CH2
90	Average km shipped				
91	Include Transloading				
92	By Rail	0	0	644	0
93	Domestic water	0	0	0	0
94	International water	0	0	0	0
95	Pipeline, tram, conveyor	calculated	0	0	483
96	Truck Defaults	0	161	161	161
97	Tonnes-shipped/tonne-produced				
98	By Rail	0.00	0.00	0.05	0.00
99	Domestic water	0.00	0.00	0.00	0.00
100	International water	0.00	0.00	0.00	0.00
101	Pipeline, tram, conveyor	calculated	0.00	0.00	1.00
102	Truck	0.00	1.00	1.00	1.00

4.6.1 Transloading

Transloading refers to the process of transferring the product from one mode of transportation to another (e.g. from truck to rail or vice versa).

For hydrogen fuel pathways modelled in GHGenius 5.02b there is no transloading option. Transloading does not need to be considered.

5 Distribution, Dispensing, and Use in BC

Modelling of the fuel pathway must include the emissions associated with distribution, dispensing, and use within BC. To accurately reflect these emissions, the model region must be set to BC (see Section 2.3.1 above).

If fuel production occurs outside of BC, a separate modelling run must be completed to capture the BC distribution, dispensing, and use emissions.

If fuel production occurs within BC, the distribution, dispensing, and use emissions can be calculated at the same time as the fuel production emissions by inputting both the fuel production inputs and the finished fuel transportation values in the same run.

Enter the following information in the Input sheet column that represents the hydrogen feedstock (see Figure 4-5):

- Row 96 – Truck Distance: 80 km
- Row 102 – Truck Mode: 1.0

Row 96 may be set to an alternate distance only if the applicant has supporting data demonstrating the weighted average transportation distance within BC.

6 Material Balance Calculation

The material balance calculation requirements are detailed in RLCF-008. Hydrogen CI applications submitted under the BC LCFS must include a material balance calculation for the fuel production stage.

6.1 Electrolysis of Water

The electrolysis of water pathway does not require a material balance calculation.

6.2 Steam Methane Reforming Material Balance Example

Hydrogen from SMR is produced in a facility with the input data shown in Table 6-1. Only the natural gas which is used as feedstock should be entered. Natural gas used as energy source should not be entered into material balance table.

Table 6-1 SMR Material Balance Example Inputs

Input Stream	GHGenius Location	GHGenius Input	Input (g/kg H_2)	Function	Notes
Natural Gas (CH_4)	Input W245	921 MJ/GJ_{H2}	2,353	Feedstock	HHV_{CH4}= 55.5 MJ/kg HHV_{H2}= 141.8 MJ/kg
Steam (H_2O)	N/A	N/A	9,053	Feedstock	
		Total Input	**11,406**		

The output data for the facility is shown in Table 6-2. The mass of waste is calculated as the difference between the total input mass and the total of the other outputs' masses.

Table 6-2 SMR Material Balance Example Outputs

Output Stream	GHGenius Location	GHGenius Input	Output (g/kg H_2)	Function	Notes
Hydrogen (H_2)	N/A	N/A	1,000	Main product	
Waste gasses	N/A	N/A	10,406	Production Emissions	Unmetered waste stream. Calculated using material balance.
		Total Output	**10,406**		

6.3 Gasification of Wood Pellets Material Balance Example

Hydrogen from wood pellet gasification is produced in a facility with the input data shown in Table 6-3. Note that natural gas is not included as an input because it is an energy source and not a feedstock in this scenario.

Table 6-3 Gasification Material Balance Example Inputs

Input Stream	GHGenius Location	GHGenius Input	Input (g/kg H_2)	Function	Notes
Wood pellets	Input BY247	80.0 kg/GJ$_{H2}$	11,344	Renewable feedstock	HHV_{H2}= 141.8 MJ/kg
Steam (H_2O)	N/A	N/A	11,000	Feedstock	
		Total Input	**22,344**		

The output data for the facility is shown in Table 6-4. The mass of waste is calculated as the difference between the total input mass and the total of the other outputs' masses.

Table 6-4 Gasification Material Balance Example Outputs

<table>
<tr><th>Output Stream</th><th>GHGenius Location</th><th>GHGenius Input</th><th>Output (g/kg H_2)</th><th>Function</th><th>Notes</th></tr>
<tr><td>Hydrogen (H_2)</td><td>N/A</td><td>N/A</td><td>1,000</td><td>Main product</td><td></td></tr>
<tr><td>Waste gasses</td><td>N/A</td><td>N/A</td><td rowspan="2">21,344</td><td>Waste product</td><td rowspan="2">Unmetered waste streams. Calculated by material balance.</td></tr>
<tr><td>Solid Waste (ash)</td><td>N/A</td><td>N/A</td><td>Waste product</td></tr>
<tr><td colspan="3">Total Output</td><td>22,344</td><td></td><td></td></tr>
</table>

7 Appendices

7.1 Electrolysis of Water Example

An example of inputs for the electrolysis pathway is shown below in Table 7-1. In this case, a Polymer Electrolyte Membrane (PEM) system is modelled, and the facility is located in BC and uses grid electricity. The finished hydrogen gas is compressed and transported by truck to a fueling station.

Note: All electrolysis systems are modelled using the same pathway and input parameters, only the magnitude of the inputs will vary.

Table 7-1 Model Inputs for BC Hydrogen from Electrolysis

Sheet	Cell	Description	Value
Input	B4	Region	BC
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	CH2
Input	B34	Hydrogen electrolysis grid	Local Grid
Input	BI95	Pipeline distance (km)	0
Input	BI96	Truck distance (km)	80
Input	BI101	Pipeline fraction (tonne shipped/tonnes produced)	0
Input	BI102	Truck fraction (tonne shipped/tonnes produced)	1

Sheet	Cell	Description	Value
Input	V241	Year	2023
Input	V243	Electricity (kWh/GJ)	390
Input	V244	Diesel (L/GJ)	0.0
Input	V245	NG (MJ/GJ)	0.0
Input	V246	Coal (kg/GJ)	0.0
Input	V247	Feedstock (Wood etc.) (kg/GJ)	0.0
Input	V248	Feedstock (Corn etc.) (kg/GJ)	0.0
Input	C253	Outlet Pressure (MPa)	34.47
Input	C254	Inlet Pressure (MPa)	0.69

The results are shown in Table 7-2. These are from column CC on the BC LCFS sheet.

Table 7-2 Total Hydrogen Emissions

Stage	Total Emissions (g CO_2e/GJ (HHV))
Direct land use change	0
Feedstock production or cultivation	0
Feedstock upgrading	0
Feedstock transport	0
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	16,683
Fuel coproducts production	0
Fuel distribution and storage	855
Fuel dispensing	769
Vehicle or Vessel operation	12
Total	**18,319**
Total, g CO_2e/MJ	**18.32**

7.2 Natural Gas with CCS Example

In this example, hydrogen fuel is produced in Alberta via natural gas reforming with carbon capture and sequestration. The hydrogen is liquified in Alberta, no liquification parameters are available, and the liquified hydrogen is transported by truck to BC for use in transportation.

The example will demonstrate how to model a system where two model runs are required; one for emissions from production, CCS, and liquefaction in AB (with default liquification parameters), and the second for transportation and distribution in BC.

Note: in GHGenius SMR and ATR are modelled using the same pathway and input parameters, only the magnitude of the inputs will be different.

Inputs for the Alberta run are shown in Table 7-3.

Table 7-3 Model Inputs for Alberta Hydrogen from Natural Gas with CCS

Sheet	Cell	Description	Value
Input	B4	Region	Alberta
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	LH2
Input	B69	Sequestration (1 = Yes, 0 = No)	1
Input	BH92	Rail Distance (km)	0
Input	BH95	Pipeline distance (km)	0

Sheet	Cell	Description	Value
Input	BH96	Truck distance (km)	1000
Input	BH98	Rail fraction (tonne shipped/tonnes produced)	0
Input	BH101	Pipeline fraction (tonne shipped/tonnes produced)	0
Input	BH102	Truck fraction (tonne shipped/tonnes produced)	1
Input	W241	Base year for alternative production of H2 from NG	2023
Input	W243	Electricity (kWh/GJ)	3.0
Input	W244	Diesel (L/GJ)	0.0
Input	W245	NG (MJ/GJ)	1500
Input	W246	Coal (kg/GJ)	0.0
Input	W247	Feedstock (Wood etc.) (kg/GJ)	0.0
Input	W248	Feedstock (Corn etc.) (kg/GJ)	0.0
Sequestration	U19	Fraction CO2 captured (decimal)	0.90
Sequestration	U22	Sequestration Electricity (kWh/GJ)	12
Sequestration	U24	NG for Sequestration (MJ/GJ)	10

The results for the Alberta-based activities are shown in Table 7-4. These are found in column CE on the BC LCFS sheet.

Note: the headings for columns CC to CI change to match the value chosen on the Input sheet in cell B46 (Hydrogen vehicle: input "CH2" or "LH2").

Table 7-4 Alberta Hydrogen Emissions

Stage	Total Emissions (g CO_2e/GJ (HHV))
Direct land use change	0
Feedstock production or cultivation	5,831
Feedstock upgrading	5,427
Feedstock transport	1,801
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	16,307
Fuel coproducts production	0
Fuel distribution and storage	5,283
Fuel dispensing	39,317
Vehicle or Vessel operation	12 (omitted)
Total – omitting vehicle operation	**73,964**
Total, g CO_2e/MJ	**73.96**

The transportation distance for the BC model run is prescribed as 80 km for all applications where the finished fuel is transported to BC from any other region.

The liquefaction emissions are included in the Alberta run, so we do not include liquefaction emissions ('Fuel dispensing' emissions) in the BC model run. To model the BC emissions, the model region is set to BC on the Input sheet, BH96 is set to 80 km, and BH102 is set to 1.0. All other transport values in BH92-102 range are zeroed, as shown in Table 7-5 below.

Table 7-5 Model inputs for BC run

Sheet	Cell	Description	Value
Input	B4	Region	BC
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	LH2
Input	BH92	Rail distance (km)	0
Input	BH93	Domestic Water distance (km)	0
Input	BH94	International Water distance (km)	0
Input	BH95	Pipeline distance (km)	0
Input	BH96	Truck distance (km)	80
Input	BH98	Rail fraction (tonne shipped/tonnes produced)	0
Input	BH99	Domestic Water fraction (tonne shipped/tonnes produced)	0
Input	BH100	Internation Water fraction (tonne shipped/tonnes produced)	0
Input	BH101	Pipeline fraction (tonne shipped/tonnes produced)	0
Input	BH102	Truck fraction (tonne shipped/tonnes produced)	1

The results for the BC region model run are shown in Table 7-6. These are found in column CE, cells CE16 and CE18 for 'Fuel distribution and storage', and 'Vehicle operation' respectively on the BC LCFS sheet.

Table 7-6 BC Hydrogen Emissions

Stage	Total Emissions ($g\ CO_2e/GJ$ (HHV))
Direct land use change	0
Feedstock production or cultivation	5304 (omitted)
Feedstock upgrading	4939 (omitted)
Feedstock transport	2811 (omitted)
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	70,004 (omitted)
Fuel coproducts production	0
Fuel distribution and storage	703
Fuel dispensing	3131 (omitted)
Vehicle or Vessel operation	12
Total – Omitting all but the fuel distribution and storage and vehicle operation	**715**
Total, g CO_2e/MJ	**0.72**

The two sets of emissions are then combined in Table 7-7.

Table 7-7 Combined/Total Hydrogen Emissions

Stage	Alberta Emissions G CO_2e/GJ (HHV)	BC Emissions g CO_2e/GJ (HHV)	Total Emissions g CO_2e/GJ (HHV)
Direct land use change	0	0	0
Feedstock production or cultivation	5,831	0	5,831
Feedstock upgrading	5,427	0	5,427
Feedstock transport	1,801	0	1,801
Feedstock coproducts production	0	0	0
Avoided emissions	0	0	0
Fuel production	16,307	0	16,307
Fuel coproducts production	0	0	0
Fuel distribution and storage	5,283	703	5,986
Fuel dispensing	39,317	0	39,317
Vehicle or Vessel operation	0	11.5	11.5
Total	**73,964**	**715**	**74,681**
Total, g CO_2e/MJ	**73.96**	**0.72**	**74.68**

More than half of the emissions are from the liquefaction stage ('Fuel dispensing'). The model assumes the energy used for liquefaction comes from electricity. To model a scenario where the energy for liquefaction is provided by natural gas, the electricity required for liquefaction on the Service Stations sheet would be set to zero and the extra natural gas would be added to the natural gas input on the Input sheet (W245). The revised Alberta inputs for this scenario are shown in the following Table 7-8.

Table 7-8 Model Inputs for Alberta Run with NG for Liquefaction

Sheet	Cell	Description	Value
Input	B4	Region	Alberta
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	LH2
Input	B69	Sequestration (1 = yes, 0 = no)	1
Input	BH92	Rail distance (km)	0
Input	BH95	Pipeline distance (km)	0
Input	BH96	Truck distance (km)	1000
Input	BH98	Rail mode (tonne shipped/tonnes produced)	0
Input	BH102	Truck mode (tonne shipped/tonnes produced)	1
Input	W241	Base year for alternative production of H2 from NG	2023
Input	W243	Electricity (kWh/GJ)	3
Input	W244	Diesel (L/GJ)	0
Input	W245	NG (MJ/GJ)	2150
Input	W246	Coal (kg/GJ)	0

Sheet	Cell	Description	Value
Input	W247	Feedstock (Wood etc.) (kg/GJ)	0
Input	W248	Feedstock (Corn etc.) (kg/GJ)	0
Sequestration	U19	Fraction CO2 captured (decimal)	0.90
Sequestration	U22	Sequestration Electricity (kWh/GJ)	12
Sequestration	U24	NG for Sequestration (MJ/GJ)	10
Service Stations	E7	Process energy (electricity) for liquefaction (kWh/GJ)	0.0

The Alberta emissions results for the natural gas-powered liquefaction scenario are shown in Table 7-9. These are found in column CE on the BC LCFS sheet.

Table 7-9 Alberta Hydrogen Emissions with NG for Liquefaction

Stage	Total Emissions (g CO_2e/GJ (HHV))
Direct land use change	0
Feedstock production or cultivation	8,340
Feedstock upgrading	7,763
Feedstock transport	2,576
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	19,814
Fuel coproducts production	0

Stage	Total Emissions (g CO_2e/GJ (HHV))
Fuel distribution and storage	5,283
Fuel dispensing	0
Vehicle or Vessel operation	11.5 (omitted)
Total – omitting vehicle operation	**43,787**
Total, g CO_2e/MJ	**43.79**

The BC emissions stay the same (see Table 7-6 above) and the revised combined emissions (Alberta and BC) are shown in the following Table 7-10.

Table 7-10 Combined/Total Hydrogen Emissions – NG Liquefaction

Stage	AB Emissions g CO_2e/GJ (HHV)	BC Emissions g CO_2e/GJ (HHV)	Total g CO_2e/GJ (HHV)
Direct land use change	0	0	0
Feedstock production or cultivation	8,340	0	8,340
Feedstock upgrading	7,763	0	7,763
Feedstock transport	2,576	0	2,576
Feedstock coproducts production	0	0	0
Avoided emissions	0	0	0
Fuel production	19,814	0	19,814
Fuel coproducts production	0	0	0

Stage	AB Emissions g CO_2e/GJ (HHV)	BC Emissions g CO_2e/GJ (HHV)	Total g CO_2e/GJ (HHV)
Fuel distribution and storage	5,283	703	5,986
Fuel dispensing	0	0	0
Vehicle or Vessel operation	0	12	12
Total	**43,787**	**715**	**44,491**
Total, g CO_2e/MJ	**43.79**	**0.72**	**44.49**

7.3 Waste Hydrogen Capture and Upgrade Example

In this example, waste gas from a chlor-alkali production facility based in Quebec, Canada is captured and sent to an adjacent hydrogen plant. The gas is purified and the resulting hydrogen is liquefied using 170 kWh of grid supplied electricity per GJ of hydrogen. The liquefied hydrogen is transported to BC via truck where it is converted (vaporized) into compressed gas and supplied for use in fuel cell vehicles.

This scenario is modelled using the electrolysis (H2 - Water) pathway with the following three model runs:

- Run 1 – Region set to Quebec

  This run captures the emissions resulting from purification of the waste gas, liquefaction of the hydrogen in Quebec, and truck transport to BC.

- Run 2 – Region set to BC

  This run captures the emissions resulting from storage and vaporization of the liquified hydrogen into compressed hydrogen after it has arrived in BC.

- Run 3 – Region set to BC

  This run captures the emissions resulting from distribution and dispensing of the compressed hydrogen within BC.

For the first run, the liquefaction electricity needs to be entered into cell E7 of the Service Stations sheet. The resulting emissions are in the fuel dispensing row

(row 17) of the BCLFS Results sheet. This entry requires units of Joules electricity per Joule of liquified hydrogen ($J_{Electricity}/J_{H2}$) so the 170 kWh/GJ of electricity must be converted to J/J as follows:

$$170\left(\frac{kW \cdot Hr_{Electricity}}{GJ_{H2}}\right) \times 3.6\left(\frac{MJ_{Electricity}}{kW \cdot Hr_{Electricity}}\right) \times \left(\frac{GJ_{Electricity}}{1000\ MJ_{Electricity}}\right) = 0.612\,\frac{J_{Electricity}}{J_{H2}}$$

The electrolysis (H2 – Water) pathway in GHGenius does not support a zero-value entry for the electrical input in cell V243 of the Input sheet and liquefaction emissions are already captured in the Service Stations sheet as discussed above. A value of 0.0001 kWh/GJ must be entered in cell V243 to approximate the absence of electricity consumption in the fuel production stage.

There are no special considerations required to capture the transportation emissions of the liquefied hydrogen to BC; parameters are entered as outlined in Section 3.1. The resulting transportation emissions are in the fuel distribution and storage row (row 16) of the BCLCFS Results sheet.

The inputs for the fuel production and transportation (Quebec) model run are shown in Table 7-11.

Table 7-11 Model Inputs for Quebec Run

Sheet	Cell	Description	Value
Input	B4	Region	Quebec
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	LH2
Input	BH92	Rail distance (km)	0
Input	BH96	Truck distance (km)	4500
Input	BH98	Rail fraction (tonne shipped/tonnes produced)	0
Input	BH102	Truck fraction (tonne shipped/tonnes produced)	1
Input	V241	Base year for alternative production of H2 from water	2023
Input	V243	Electricity (kWh/GJ)	0.0001
Input	V244	Diesel (L/GJ)	0.0
Input	V245	NG (MJ/GJ)	0.0
Input	V246	Coal (kg/GJ)	0.0
Input	V247	Feedstock (Wood etc.) (kg/GJ)	0.0
Input	V248	Feedstock (Corn etc.)	0.0
Service Stations	E7	Process Energy required per Hydrogen Energy (J/J)	0.612

The results for the first run are shown in Table 7-12. The emissions shown for Fuel production result from the 0.0001 kWh/GJ entry in cell V243 of the Input sheet and may be ignored.

Table 7-12 Quebec Liquefaction and Transportation Emissions

Stage	Total Emissions ($g\ CO_2e/GJ$ (HHV))
Direct land use change	0
Feedstock production or cultivation	0
Feedstock upgrading	0
Feedstock transport	0
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	0.0029 (omitted)
Fuel coproducts production	0
Fuel distribution and storage	20,410
Fuel dispensing	5004
Vehicle or Vessel operation	11.5 (omitted)
Total – omitting fuel production and vehicle operation	**25,414**
Total, g CO_2e/MJ	**25.41**

The inputs for the storage and vaporization in the BC run are shown in Table 7-13 below. A small distance is included to account for transport via pipeline at this stage, and grid electricity use is 9.0 kWh per GJ of hydrogen (kWh/GJ). Users should input values according to their storage and vaporization systems.

Table 7-13 Model Inputs for BC Storage and Vaporization

Sheet	Cell	Description	Value
Input	B4	Region	BC
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	LH2
Input	BH92	Rail distance (km)	0
Input	BH95	Pipeline distance (km)	0.01
Input	BH96	Truck distance (km)	0
Input	BH98	Rail fraction (tonne shipped/tonnes produced)	0
Input	BH101	Pipeline fraction (tonne shipped/tonnes produced)	1
Input	BH102	Truck fraction (tonne shipped/tonnes produced)	0
Input	V241	Base year for alternative production of H2 from water	2023
Input	V243	Electricity (kWh/GJ)	9.0
Input	V244	Diesel (L/GJ)	0.0
Input	V245	NG (MJ/GJ)	0.0
Input	V246	Coal (kg/GJ)	0.0
Input	V247	Feedstock (Wood etc.) (kg/GJ)	0.0
Input	V248	Feedstock (Corn etc.) (kg/GJ)	0.0

The resulting emissions are shown in Table 7-14. These are found in column CC on the BC LCFS sheet.

Table 7-14 BC Hydrogen Storage and Vaporization Emissions

Stage	Total Emissions ($g\ CO_2e/GJ$ (HHV))
Direct land use change	0
Feedstock production or cultivation	0
Feedstock upgrading	0
Feedstock transport	0
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	387
Fuel coproducts production	0
Fuel distribution and storage	334
Fuel dispensing	3131 (omitted)
Vehicle or Vessel operation	11.5 (omitted)
Total – omitting fuel dispensing and vehicle operation	**722**
Total, g CO_2e/MJ	**0.72**

The inputs for the BC distribution and dispensing run are shown in Table 7-15 below. In this run, the fuel is no longer liquefied so the hydrogen vehicle input is set to “CH2” in cell B46 of the Input sheet. The vehicle tank pressure and the inlet pressure and the dispensing compressor inlet pressure are then entered into cells C253 and C254 of the Input sheet. For this scenario, these pressures are 70 MPa and 45 MPa, respectively.

As outlined in Section 5, applicants must assume 80 km of transportation by truck for the BC use and distribution run. Alternate distribution distances may be accepted if rationale is provided with the application package.

The model does not support zero values for electricity input in the electrolysis (H2 – Water) pathway. Applicants must enter 0.0001 kWh/GJ in cell V243 of the Input sheet to approximate no electricity use.

Table 7-15 Model Inputs for BC Distribution and Dispensing

Sheet	Cell	Description	Value
Input	B4	Region	BC
Input	B7	Year	2023
Input	B46	Hydrogen Vehicle input	CH2
Input	BI92	Rail distance (km)	0
Input	BI95	Pipeline distance (km)	0
Input	BI96	Truck distance (tonne shipped/tonnes produced)	80
Input	BI98	Rail fraction (tonne shipped/tonnes produced)	0
Input	BI101	Pipeline fraction (tonne shipped/tonnes produced)	0
Input	BI102	Truck fraction (tonne shipped/tonnes produced)	1
Input	V241	Base year for alternative production of H2 from water	2023
Input	V243	Electricity (kWh/GJ)	0.0001
Input	C253	Vehicle fuel tank pressure (MPa)	70
Input	C254	Inlet pressure (MPa)	45

The results for these BC emissions are shown in Table 7-16. These are found in column CC on the BC LCFS sheet. The emissions shown for Fuel production result from the 0.0001 kWh/GJ entry in cell V243 of the Input sheet and may be ignored.

Table 7-16 BC Hydrogen Distribution and Dispensing Emissions

Stage	Total Emissions (g CO_2e/GJ (HHV))
Direct land use change	0
Feedstock production or cultivation	0
Feedstock upgrading	0
Feedstock transport	0
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	0.00428 (omitted)
Fuel coproducts production	0
Fuel distribution and storage	1484
Fuel dispensing	50
Vehicle or Vessel operation	11.5
Total – omitting fuel production emissions	**1545**
Total, g CO_2e/MJ	**1.55**

The combined emissions for all runs are shown in Table 7-17 below.

Table 7-17 Combined/Total Hydrogen Emissions

Stage	Quebec Emissions g CO_2e/GJ (HHV)	BC Emissions g CO_2e/GJ (HHV)	BC Emissions g CO_2e/GJ (HHV)	Total Emissions g CO_2e/GJ (HHV)
Direct land use change	0	0	0	0
Feedstock production or cultivation	0	0	0	0
Feedstock upgrading	0	0	0	0
Feedstock transport	0	0	0	0
Feedstock coproducts production	0	0	0	0
Avoided emissions	0	0	0	0
Fuel production	0	387	0	387
Fuel coproducts production	0	0	0	0
Fuel distribution and storage	20,410	334	1484	22,238
Fuel dispensing	5004	0	50	5054
Vehicle or Vessel operation	0	0	11.5	11.5
Total	**25,414**	**722**	**1545**	**27,681**
Total, g CO_2e/MJ	**25.38**	**0.72**	**1.55**	**27.68**

7.4 Gasification of Wood Pellets Example

An example of inputs for the gasification of wood pellets pathway is shown below in Table 7-18. In this case, the wood pellets are sourced from BC and they are transported to the hydrogen production facility in BC via truck. The finished hydrogen gas is compressed and transported by truck to a fueling station for dispensing and use in BC.

Table 7-18 Model Inputs for BC Hydrogen from Gasification of Wood Pellets

Sheet	Cell	Description	Value
Input	B4	Region	BC
Input	B7	Year	2023
Input	B46	Hydrogen vehicle input	CH2
Input	AR76	Feedstock Rail distance (km)	0
Input	AR79	Feedstock Pipeline distance (km)	0
Input	AR80	Feedstock Truck distance (km)	200
Input	AR82	Feedstock Rail fraction (tonne shipped/tonnes produced)	0
Input	AR85	Feedstock Pipeline fraction (tonne shipped/tonnes produced)	0
Input	AR86	Feedstock Truck fraction (tonne shipped/tonnes produced)	1
Input	BI92	CH2 Rail distance (km)	0
Input	BI95	CH2 Pipeline distance (km)	0

Sheet	Cell	Description	Value
Input	BI96	CH2 Truck distance (km)	600
Input	BI98	CH2 Rail fraction (tonne shipped/tonnes produced)	0
Input	BI101	CH2 Pipeline fraction (tonne shipped/tonnes produced)	0
Input	BI102	CH2 Truck fraction (tonne shipped/tonnes produced)	1
Input	BY241	Base year for alternative production of H2 from Wood Pellets	2023
Input	BY243	Electricity (kWh/GJ)	1.0
Input	BY244	Diesel (L/GJ)	0.0
Input	BY245	NG (MJ/GJ)	5
Input	BY246	Coal (kg/GJ)	0.0
Input	BY247	Feedstock (Wood etc.) (kg/GJ)	80.0
Input	BY248	Feedstock (Corn etc.) (kg/GJ)	0.0
Input	C253	Outlet Pressure (MPa)	34.47
Input	C254	Inlet Pressure (MPa)	0.69

The results are shown in Table 7-19. These are from column CH on the BC LCFS sheet.

Table 7-19 BC Hydrogen Emissions

Stage	Total Emissions (g CO_2e/GJ (HHV))
Direct land use change	0
Feedstock production or cultivation	0
Feedstock upgrading	2,191
Feedstock transport	1,736
Feedstock coproducts production	0
Avoided emissions	0
Fuel production	2,039
Fuel coproducts production	0
Fuel distribution and storage	15,057
Fuel dispensing	768
Vehicle or Vessel operation	11.5
Total	**21,803**
Total, g CO_2e/MJ	**21.80**