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Projet de construction d'une installation de liquéfaction de gaz naturel à Bécancour

6211-19-021

(S&T)² Consultants Inc.

SNC·LAVALIN

Report Version 03

Comparative Life Cycle Assessment for Greenhouse Gases (GHG)

SLNGaz Project

Stolt LNGaz Inc.

SNC-LAVALIN INC.

(S&T)² Consultants Inc.

February 2015

REPORT

Project n°617039-14_V-03_FINAL

(S&T)² Consultants Inc.

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LIST OF ACRONYMS

AR4	Fourth Assessment Report
CAC	Criteria Air Contaminants
CAPP	Canadian Association of Petroleum Producers
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EU	European Union
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
HHV	Higher Heating Value
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Analysis
LCIA	Life Cycle Impact Assessment
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NG	Natural Gas
OPGEE	Oil Production Greenhouse gas Emissions Estimator
PADD	Petroleum Administration for Defense Districts
SAR	Second Assessment Report
SLNGaz	Stolt LNGaz Inc.

UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USA	United States of America

CHEMICAL SYMBOL

CO_2	Carbon dioxide
CH_4	Methane
HFC	Hydrofluorocarbon
N_2O	Nitrous oxide

1 INTRODUCTION

Stolt LNGaz (hereinafter SLNGaz) is in the approvals phase of its liquefied natural gas (LNG) liquefaction plant planned to be in operation in 2017 in Bécancour, Québec. SLNGaz' objective is to provide natural gas to industrial clients who are not currently connected to the Quebec distribution network of natural gas with any surplus being shipped to European and other markets. The Project represents an interesting opportunity for these potential clients to improve both their economic competitiveness and their environmental performance.

SNC-Lavalin Inc.'s Environment & Water business unit (hereinafter SNC-Lavalin) and $(S\&T)^2$ Consultants Inc. (hereinafter $(S\&T)^2$) were commissioned by SLNGaz to prepare a comparative Life Cycle Assessment (LCA) for several scenarios to include the future scenario of providing LNG to industrial clients and the status quo i.e. the reference scenario where diesel and/or heavy fuel oil (HFO) or liquefied petroleum gas (LPG) are used in the absence of access to natural gas. The LCA is conducted in accordance with the requirements of the International Organization for Standardization (ISO) standards 14040[1] and 14044[2].

1.1 LNG Process Description

Liquefaction of natural gas to LNG is achieved through well-known and proven technologies, by cooling natural gas down to temperatures reaching -162°C (methane boiling point at storage pressure). The SLNGaz plant will be powered by electricity. LNG production will proceed according to the following main steps:

- Natural gas metering;
- Pressure and temperature adjustment;
- Mercury removal;
- Acid gases removal (carbon dioxide and hydrogen sulfide);
- Water removal (dehydration / drying);
- Natural gas liquefaction;
- LNG storage (at atmospheric pressure and cryogenic temperatures);
- LNG ship and truck loading.

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[1] ISO 14040:2006, Environmental management – Life cycle assessment – Principles and framework.

[2] ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

Natural gas delivered from the Trans Québec & Maritimes Pipeline (TQM Pipeline) system will be metered and conditioned prior to being liquefied in a cryogenic state. The LNG is stored on site in a full containment storage tank and transported by LNG ships or trucks.

The plant will also have systems for handling boil-off and flash gases, heating and cooling systems, flares and utility systems such as demineralized water, nitrogen and compressed air production.

An LNG plant's liquefaction system is called a *train*. Although the environmental impact assessment[3] for the LNG plant was performed for the scenario of two trains for an output of 2,800 tonnes per day, the present assessment is based on 1 train in operation, that is an output of 1,400 tonnes per day, which corresponds to the market conditions for 2017 following a detailed market analysis performed for SLNGaz.

1.2 Life Cycle Assessment (LCA) Method

The life cycle assessment evaluates the environmental performance of a product or activity over its entire life cycle. It is thus a holistic approach that takes into account the extraction and processing of raw materials, manufacturing processes, transportation and distribution, use and management of the product end of life. In addition to the quantification of the different greenhouse gases, the life cycle assessment monitors other environmental impacts, making it a preferred method for the comparison of alternative scenarios.

Upon defining the system boundaries, the material and energy inputs and outputs for each stage of a product's life within the boundaries are quantified and the impacts evaluated. The results of an LCA can be used by companies and regulators for strategic and/or environmental purposes. The LCA only addresses the environmental impacts of a product system, whereas economic and social impacts are typically not within its scope. The LCA is a rigorous approach and is defined in the ISO standards in four distinct steps as illustrated in Figure 1-1.

[3] Environmental Impact Assessment Study Submitted to the Ministry of Sustainable Development, Environment and Fight against Climate Change, SNC-Lavalin Inc., October 2014.

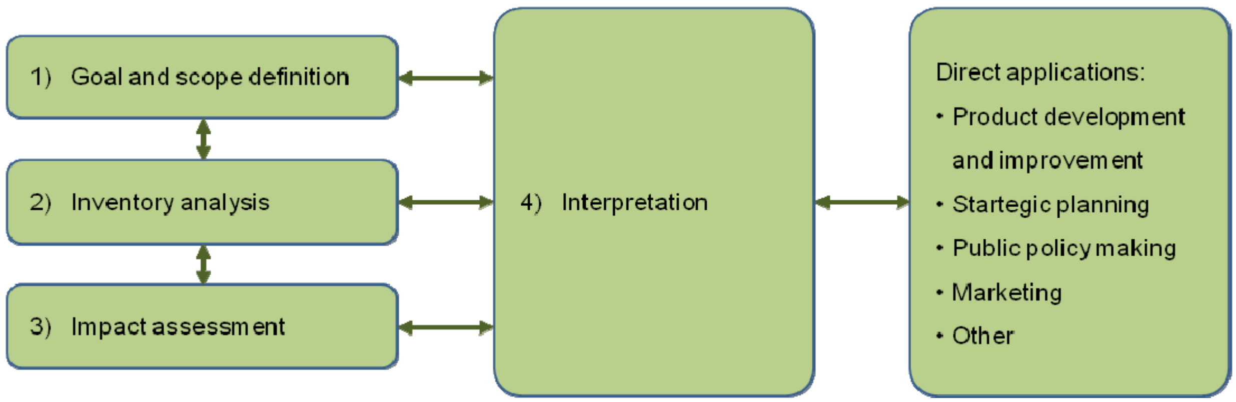

Figure 1-1: Stages of an LCA (source: adapted from Figure 1 of ISO 14040:2006)

The four stages of an LCA are briefly defined as follows:

1) Goal and scope definition: includes the definition of the intended application, the objective of the study, the intended audience, the functional unit and the definition of the system boundaries, among others.
2) Inventory analysis: the energy and material inputs are quantified and the flows for each process are related by the chosen functional unit.
3) Impact assessment: environmental impact categories are selected (e.g. Climate change) and the results of the inventory analysis are used for the calculation of category indicator results.
4) Interpretation: the results of the inventory analysis and impact assessment are used to identify any issues and are used to form conclusions, limitations and recommendations.

2 GOAL AND SCOPE DEFINITION

The following sections define in detail the goal and scope of the LCA to which all the other LCA phases must conform.

2.1 Goal of the Study

The production of LNG in Bécancour will provide an energy alternative to industries in order to reduce their energy costs and to assist them in reducing atmospheric emissions of greenhouse gas (GHGs). The goal and intended application of the study is to provide a consistent comparison of the environmental impacts related to the supply of LNG to remote areas, areas not connected to the natural gas network or areas with limited pipeline capacity against the reference scenario: the use of diesel and/or HFO and/or of liquefied petroleum gas (LPG) and/or heating oil. Global warming due to GHG emissions is the environmental impact assessed in this comparative LCA. All other environmental impacts are excluded from this study.

The study results and conclusions are intended to be disclosed to the public in the efforts to present the expected environmental benefits of the use of LNG instead of diesel and/or HFO and/or LPG and/or heating oil.

2.2 Scope of the Study

This comparative study includes two product systems to be considered:

- the project: use of LNG;
- the reference scenario: use of a mix of other fuels: diesel, LPG, HFO, and heating oil.

The principal function of the systems is to provide energy using different equipments: stationary combustion, stationary power and mobile equipment. There are no additional/secondary functions to fuels considered in this study.

The inventory of this comparative LCA will cover cradle-to-grave, from well head to fuel use.

Tables 2-1 and 2-2 below succinctly present the two product systems that are compared, the principal function, functional unit, reference flows, and key parameter.

Table 2-1: Product systems and principal function

Scenario	Product	Principal function
Project	LNG	Provide energy to the end user of the fuel (before combustion)
Reference	Mix of other fuels including : Diesel, HFO, LPG and heating oil	

Table 2-2: Functional unit, reference flows and key parameter

Scenario	Product	Functional unit	Reference flows	Key parameter
Project	LNG	GJ delivered in 2017 to: Quebec (62%), Sweden (15%), Caribbean (20%) and NE USA (3%)	In 2017: 500,000 tonnes of LNG	GJ delivered to end user (before combustion)
Reference	Mix of fuels: Diesel, HFO, LPG and heating oil		In 2017: 227,217 kl of diesel + 365,407 kl of HFO + 84,396 kl of LPG + 21,586 kl of heating oil	

All energy is expressed on a higher heating value (HHV) basis in this report since it is a measure used for the majority of commercial transactions in North America and it is the basis used for the reference to energy in the Quebec air emission reporting regulation[4].

[4] *Règlement sur la déclaration obligatoire de certaines émissions de contaminants dans l'atmosphère*, site web:http://www2.publicationsduquebec.gouv.qc.ca/dynamicSearch/telecharge.php?type=3&file=/Q_2/Q2R15.HTM.

The reference flow of 500,000 tonnes of LNG delivers 27,195,000 GJ to the end users (before combustion). To deliver this amount of energy, the reference flows were established for both scenarios as shown in Table 2-2. The HHV referenced in the Quebec air emission reporting regulation for diesel (also used for heating oil), HFO and LPG was used for the estimate of the volume of each fuel for the reference scenario.

The reference scenario considers the percentages of usage per fuel according to Figure 2-1.

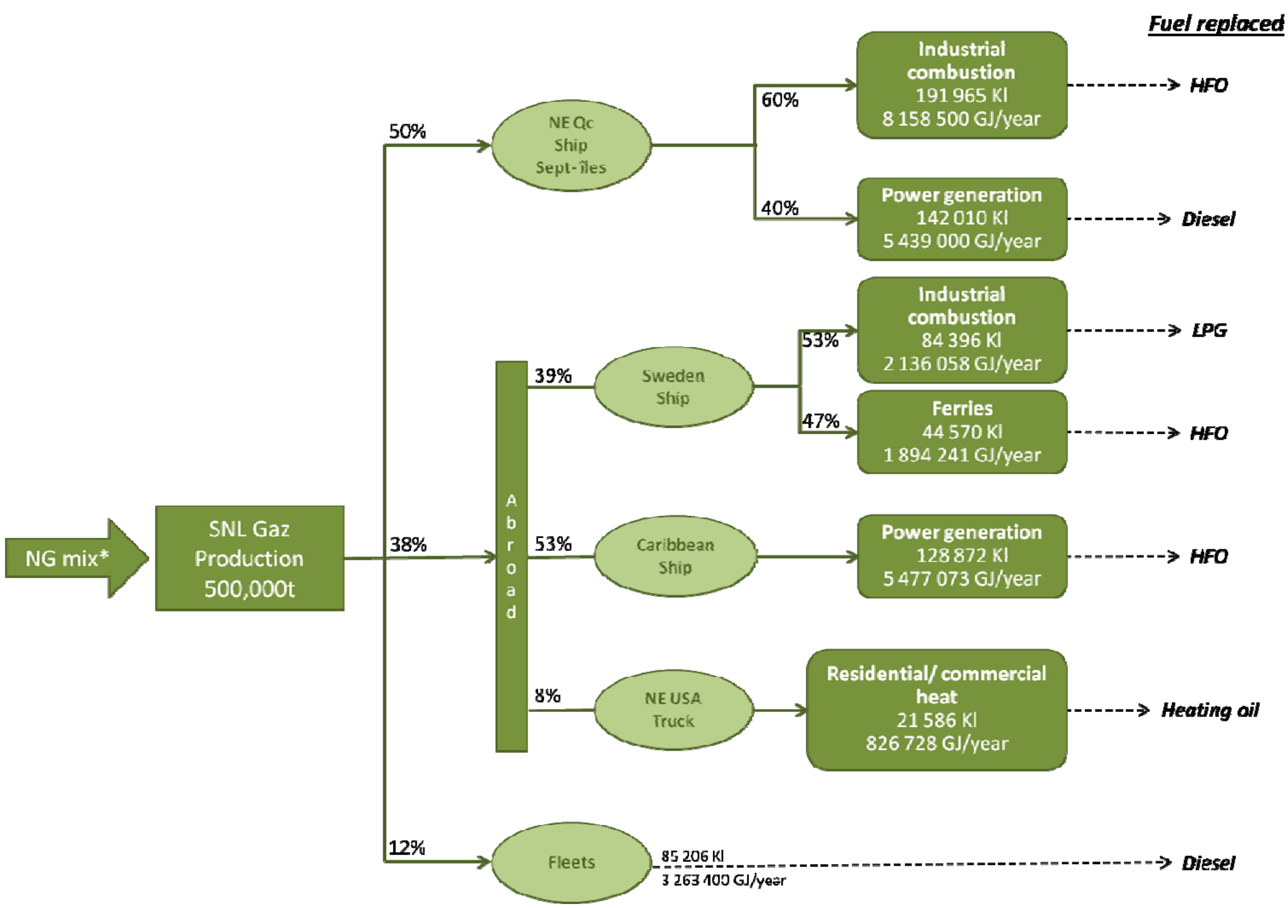

Figure 2-1: Project scenario

Figure 2-1 shows the potential future usage of LNG from the SLNGaz facility and what other fossil fuels it will potentially replace i.e. the project scenario. An attributional LCA has been performed. That is, the project scenario assumes that the fuels being replaced will no longer be produced if there isn't a demand for it.

The selection of the locations, equipment use and fuels to be replaced is based on an extensive market analysis as well as an independent market study. This work was mandated by SLNGaz and includes information of sensitive nature therefore the precise users and locations cannot be disclosed.

However, based on publicly available information, the selected locations and current usage of fuels in these locations can be corroborated as discussed below.

As shown in Figure 2-1, 50% of the LNG produced will be sent to North-East Quebec. Currently, no natural gas is available in the region. The industrial, residential and commercial and institutional sectors need to rely on the hydroelectric power or fossil fuel to fulfill their energy requirements. This information can be corroborated in the study: "État de l'Énergie au Québec[5]" elaborated by the management chair of the energy sector of HEC Montreal. For the industrial processes and/or certain mine developments, diesel or HFO are used for energy purposes. The Province of Quebec has implemented a carbon cap-and-trade system to attain its GHG emission reduction objectives. The cap-and-trade system covers industrial facilities emitting more than 25,000 tCO_2e since 2013 and fossil fuel distributors since 2015. Facilities have to comply either by reducing emissions in their facilities or buy emission units in the market. In this context, facilities are looking for less carbon intensive energy alternatives to reduce the cost of this new system. The use of LNG can contribute to attaining these objectives. Furthermore, Gaz Métro's extension of their natural gas distribution network has been put on hold for an undetermined period.Twelve percent of the LNG produced is planned to supply truck fleets in the surrounding areas of central and south-east Quebec. Currently, some transportation companies use natural gas as a fuel for their fleets. In the context of the Quebec Climate Change Action Plan 2013-2020[6], the demand for natural gas use by trucking fleets is expected to grow.

The remaining 38% of the LNG production will be exported to international markets namely Sweden, the Caribbean and North East USA.

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[5] État de l'Énergie au Québec 2015, HEC Montréal, Chaire de Gestion Secteur de L'Énergie, Automne 2014

[6] Plan d'Action sur les Changements Climatiques 2013-2020

In Sweden, two markets are targeted. The first being remote areas in northern Sweden that are not connected to the natural gas network. As referenced in the International Energy Agency report on "Oil&Gas Security Emergency Response of IEA Countries – Sweden 2012[7]," the use of natural gas in Sweden is low and is concentrated predominantly in the south and western areas of Sweden. Additionally, Sweden is moving forward to a low-carbon economy and needs to map a strategy to reach this goal for each industry sector. The transportation sector is a key contributor to the use of traditional fossil fuels and Sweden is looking at clean technologies, using natural gas for the ships being an alternative.

The Caribbean region, with the exception of Trinidad and Tobago, is a net importer of energy predominantly of diesel and heavy fuel oil. One of the key markets envisioned by S LNGaz is entering Bermuda. The government of Bermuda plans to liberalize the electric generation of electricity production. According to Bermuda's Online article "Bermuda's costs of electricity, imported cooking gas, gasoline and oil[8]" 82% of electric power generation is originated with HFO. In this same article, it is stated that LNG is being considered by the power producer Belco.

Finally, the smallest export market considered is North East USA. This market already has access to natural gas however as demand increases and some coal fired power plants cease to exist, pipeline capacity is limited. The LNG sent to this market can fulfill the increase in demand.

With the operations of the LNG facility in Bécancour expected to begin in 2017, the reference year for the study is 2017. The quantification of the GHG emissions are based on the output of 1,400 tonnes per day (1 train in operation) of LNG produced at the Bécancour facility[9]. Therefore, all inputs and outputs for the fuel mix in the reference scenario (diesel, HFO, LPG and heating oil) are based on the energy delivered to the end user (shown for each path in GJ/year) for each of the end uses for the LNG system, as presented in Figure 2-1.

When establishing the reference flows for each scenario, the following assumptions were made:

- The end users are not going to replace existing equipment when changing their fuel to natural gas.
- The efficiency of the equipment remains the same when changing fuels.

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[7] Oil & Gas Security Emergency Response of IEA Countrirs – Sweden 2012, International Energy Agency

[8] Bermuda's Cost of Electricity, imported cooking gas, gasoline and oil, Lack of economies of scale and huge import duties make them very costly compared to North America, Keith Archibald Forbes

[9] Environmental Impact Assessment Study Submitted to the Ministry of Sustainable Development, Environment and Fight against Climate Change, SNC-Lavalin Inc., October 2014.

These assumptions consider that the end users are not going to update and take advantage of newer and better performing equipment but rather spend the minimum required to convert the existing equipment to natural gas use since it is generally more economical. Also, it is very unlikely that efficiencies would be very different in changing the equipment for use with natural gas as is communicated in the Wartsila Technical Journal regarding power plants[10]. We can consider this to be true for industrial combustion as well since there is no difference between power production and industrial combustion: one produces heat for steam that is used in a turbine and the other produces heat or steam for direct use. The combustion efficiency is the same. In the case of mobile combustion devices, the assumption made was that the LNG would be used in Westport HPDI type engines where the performance and fuel economy is equivalent to that of diesel fuel engines[11].

This is considered a conservative approach since the combustion devices currently in use would not be replaced to achieve higher efficiencies. As such, energy conversion efficiencies were considered the same between the project and reference scenarios.

In the cases of mobile combustion devices, the different efficiencies expected from the engines were considered since the use of natural gas in engines can result in lower efficiencies.

However, since the functional unit is based on the energy delivered to the user, before combustion, and that the energy delivered is equivalent between fuels given the conservative approach considered as described above, the conversion efficiencies selected for the equipment and engines have no effect on the global results of the assessment.

The study parameters include:

- GHG: CO_2, CH_4, N_2O, HFC

The functional unit used in this study to relate the performance of the product systems is defined as a gigajoule (GJ) of energy delivered to the end user (before combustion) for the generation of heat, electricity production or transportation in Quebec, the NE USA, Sweden and the Caribbean in 2017. Therefore, the GHG emissions are presented on an intensity basis where, for example, CO_2 is quantified as kg CO_2 per GJ of energy delivered.

The model used for the assessment of emission factors for the parameters included in the assessment is the Canadian LCA model GHGenius. The model is described in Section 3.1.

[10] Gas-diesel conversions for power plant applications – Wartsila Technical Journal. Web: *www.wartsila.com/*

[11] Westport HPDI 2.0. Web: http://www.westport.com/is/core-technologies/hpdi-2.

2.2.1 System Boundary

The boundaries of the systems must be clearly defined in order to determine which unit processes are included in the study. In order to respond to the function of the systems defined in Section 2.2, all flows and processes from the extraction of the fuel to the combustion by the end users are included for each system.

When conducting an LCA, it is not necessary to quantify inputs and outputs that will only have a small impact on the broad conclusions of the study. Therefore, in keeping with the guidelines set out by the SETAC (1997) and ISO 14044 (2006), the initial identification and selection of processes in the system studied is generally based on the significance of the input and/or output to the study.

The exclusions deemed insignificant include:

- The construction of the LNG facility in Bécancour and facilities of reference scenarios
- Infrastructure manufacturing in both reference and project scenarios
- Site preparation, site closure and remediation
- All other substances since the goal of the study is to compare GHG emissions.

The electricity grids used in the assessment for Quebec, NE USA and central USA are shown in Appendix B.

Inland transportation, where equivalent in terms of distance and points of origin and destination in both the project and the reference scenario, have also been excluded. Although the energy density differs between the LNG and other fuels, LNG has a higher energy density and thus the assessment provides conservative results. Figure 2-2 presents the activities and processes included for each of the systems.

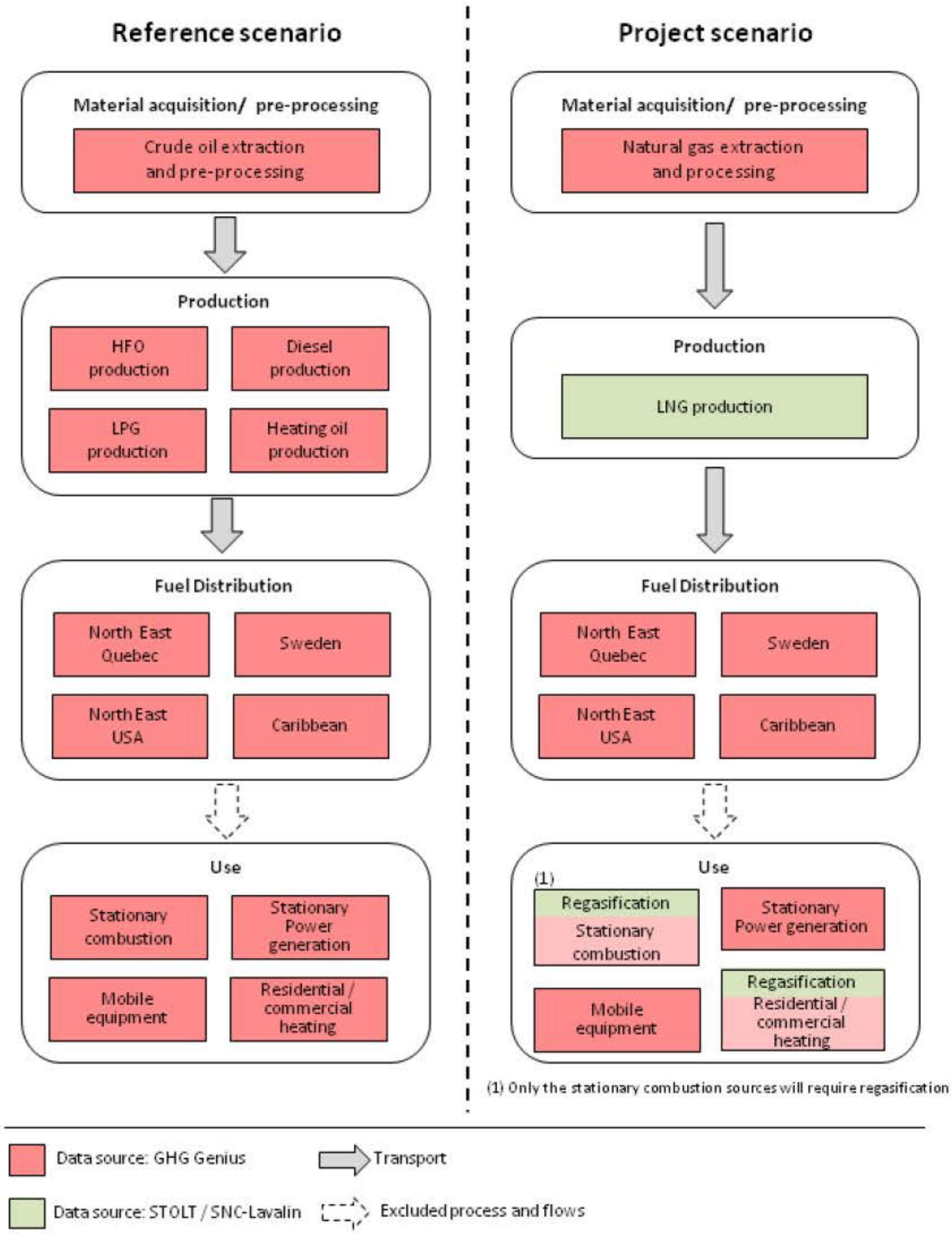

Figure 2-2: System boundary – Activities and processes

Table 2-3 provides an overview of the processes included within the system boundaries. Their emissions, although not specified in the table, are also included in the system boundaries.

Table 2-3: Processes included in the comparative LCA

Stages	Sub-stages	Description
Material acquisition and pre-processing	Natural gas extraction and processing	Data was not available as to the projected origins of the supply of natural gas to the Bécancour LNG plant. The project considers that 100% of the natural gas comes from western Canada. This has historically been the case for natural gas supply into Quebec, however recently some US natural gas has been supplied to this market. A sensitivity analysis was performed to show that the origin whether it be from Canada, the US or a combination, has little effect on the emissions, as shown in Section 5.2.1. Extraction and processing includes all major energy and electricity flows: process emissions, combustion emissions for process heat/steam, electricity generation, fugitive emissions, emissions from the life cycle of chemicals used and fugitive emissions from storage, handling, upstream processing prior to transmission and mining. Infrastructure manufacturing is not included in this activity since it is deemed negligible and/or comparable to the reference scenario.
	Natural gas transport and distribution	Following processing, the natural gas is transported by pipelines to the SNLGaz facility.

Stages	Sub-stages	Description
	Crude oil extraction and pre-processing	The crude oil for usage in Quebec is composed mainly of Canadian crude oil. The forecast for 2017 is presented in Appendix A. The crude oil for usage in Europe is mainly from North Africa, North Europe and the Persian Gulf. The crude oil for usage in the Caribbean comes mainly from the US (50%), Canada (17%), Mexico (8%), Venezuela (5%) and other smaller sources. The crude oil source data is from the US Energy Information Administration (EIA) and is for the year 2011. The crude oil for usage in NE USA comes from Africa (47%), Canada (23%), the US (8%) and other smaller sources. The crude oil source data is from the US EIA and is for the year 2011. Extraction and processing includes all major energy and electricity flows: process emissions, combustion emissions for process heat/steam, electricity generation, fugitive emissions, emissions from the life cycle of chemicals used and fugitive emissions from storage, handling, upstream processing prior to transmission and mining. Infrastructure manufacturing is not included in this activity since it is deemed negligible and/or comparable to the project scenario.
	Crude oil transport and distribution	Crude oil is transported and distributed through pipelines, ships, trucks and rail.
Production	Liquefaction of natural gas	The LNG plant emissions are based on the SNC-Lavalin impact study [12]. Emissions from the construction of the facility are excluded since these are considered negligible.

[12] Environmental Impact Assessment Study Submitted to the Ministry of Sustainable Development, Environment and Fight against Climate Change, SNC-Lavalin Inc., October 2014.

Stages	Sub-stages	Description
	Oil refining	Includes all major energy and electricity flows included in this activity with the exception of infrastructure manufacturing/construction which is deemed negligible. The data for Canadian energy refining use is from Statistics Canada, for US refining it is from the US EIA. The European energy use has been calibrated so that the model returns lifecycle emissions close to the values presented by the European Union (EU) in the Fuel Quality Directive.[13] The refinery energy use was adjusted to the EU Renewable Energy Directive (RED) values.
Distribution and storage	LNG transport to end user *	The LNG will be mainly distributed by ships and some ground transportation will be by trucks. Trucking for the US market is considered.
	Diesel transport to end user *	The diesel is also distributed by ship and some ground transportation by trucks and pipelines.
	HFO transport to end user *	HFO is also distributed by ship and some ground transportation by trucks and pipelines.
	LPG transport to end user *	LPG is distributed by ship.
	Heating oil transport to end user	Heating oil is distributed by rail, ship and pipelines.
Use (end of life)	Stationary combustion	This use considers a regasification unit for the project scenario and combustion of fuel (for both scenarios).

[13] COM (2014) 617 Annexes. http://ec.europa.eu/clima/policies/transport/fuel/docs/com_2014_617_annexes_en.pdf

Stages	Sub-stages	Description
	Stationary power generation	Combustion of fuel (for both scenarios). In this case, since power plants have a low efficiency and generate a considerable amount of waste heat, no regasification energy is considered for the project scenario since residual heat of the power plant will be used rather than use natural gas to supply this energy.
	Mobile equipment (local fleets and ferries)	Combustion of fuel (for both scenarios). It was assumed that the same emission reduction efficiency that is found in NG truck engines compared to diesel engines applies to ferries.
	Residential/commercial heating	This use considers a regasification unit for the project scenario and combustion of fuel for both scenarios.

*In-land transportation when deemed equivalent for both the project and reference scenarios were excluded.

2.2.2 Temporal Boundaries

The temporal boundaries of an LCA pertain to:

- The period defined by the functional unit, which takes into account the production, distribution, use (service life) and end-of-life management of products;
- The period over which the substances in the inventory have an effect.

In the present study, the functional unit refers to a time period of one year. Since the reference year is 2017, the study therefore constitutes a static LCA based on hypotheses of future fuel production.

2.2.3 Allocation Approach

For an LCA, allocation approaches are used to partition the input and output flows of a system where co-products exist. In the case of the product systems of the current study, co-products exist when crude oil is refined to produce gasoline, diesel fuel and heating oils and in the cases where synthetic crude oil is to any degree a component of the feedstock to the production of diesel and HFO.

The synthetic crude oil co-products are produced during the upgrading process of bitumen from Canadian oil sands, and can include products such as, LPG, petroleum coke, and electricity (although on an industry wide basis there is a net consumption of electricity). On an energy basis, LPG and marketed petroleum coke account for only 4% of the production from upgraders.

As described in Section 3.1.2, an adapted version of the *GHGenius lifecycle assessment of transportation fuels model - version 4.03* has been used by this study for emissions estimations. The model uses different allocation systems for different fuels and products consistent with the typical practices with fuel LCA's in North America.

For oil sand upgrading, the allocation method considered by the model is that of system expansion where the co-products (coke and LPG) are accounted for by estimating the emissions associated with a substitute product (ex. coal to be displaced by petroleum coke) and results in a credit that is subtracted from the total emissions of the system. The co-products are very small streams and allocation by mass or energy content would have insignificant impact on the results.

For oil refining the emissions associated with each product are allocated based on the estimated process energy used to produce each product. The allocation based on process energy used is based on the energy consumption in the refinery by stage and considers the amount processed. The relative energy use for gasoline and diesel fuel is 1.2, for chemicals it is 1.0, for high sulphur distillates it is 0.8, and for LPG and residual fuels it is 0.25. The allocation by process energy is the most widely used method for allocation of refinery emissions in fuel specific LCA models and in the regulatory environment in North America and Europe.

Allocation based on mass or energy is not process based but takes the total emissions and allocates them against the total energy produced. Allocation by mass or energy would reduce the emissions for diesel fuel but increase the emissions for HFO and LPG. System expansion would provide different results in different regions as the heavy fuel oil displaces natural gas in some regions and coal in other regions, similarly LPG might displace natural gas in some regions and diesel fuel in other regions. System expansion is rarely applied at the refinery level in LCA work. The impact of allocation of the refining emissions by energy content for Quebec is shown in the following table.

Table 2-4 Alternative Refinery Emission Allocation

	Base Case Allocation	Allocation by energy
	kg CO_2eq/GJ	
Diesel Fuel	21.4	19.4
Heavy Fuel Oil	13.6	19.1
LPG	13.2	18.7

The variation in the emissions range from -2.0 to 6.5 kg CO_2e/GJ. The impact of the allocation approach at the project level will depend on the ultimate mix of end users but it is expected to be very small since the emissions increase for one petroleum fuel and decrease for others.

2.2.4 Land-use Change Impacts

Land-use change impacts are integrated to the GHGenius model and have been considered in this study for oil sands crude oil production. The land use change is from deforestation and soil carbon loss from disturbing the peat soils. These emissions are very small representing at most 0.1 kg/GJ depending on the region.

2.2.5 Life Cycle Assessment Impacts

Only one impact category is evaluated in this study. The main focus of this study is GHG emissions having an impact on global warming. It does not assess other potential social, economic and environmental impacts arising from the provision of the fuels considered in this study.

For GHG accounting, a time horizon of 100 years is usually used, as suggested during the Framework Convention on Climate Change held in Kyoto in 1997 (United Nations, 1998). The factors are periodically revised within the scope of the IPCC Assessment Report. The factors used in this study are discussed in Section 3.1.4 Impact Categories.

There is international acceptance of the use of these indicators and they are used in national inventories. The IPCC findings are the results of studies completed by a wide range of scientific and technical experts which assures the validity and relevance of the global warming impact category.

2.2.6 Limitations

The results of this study cannot be applied to other LNG projects. The study scope considers end-users based on a market study performed by a specialized firm. The reality of the market in 2017 may be different from the current market study.

Also, the planned liquefaction facility will be built in a jurisdiction where the electricity mix is predominately hydro-based. Therefore applying these results in another jurisdiction that does not have the same electricity grid mix would be erroneous.

Also, the supply of the fossil fuels (natural gas, crude, oil, etc.) is established on a jurisdictional basis and may not be comparable to similar projects elsewhere.

The main limitations of the conclusions of this study are:

- The study was limited to the impact on global warming.
- The study assumes that the current combustion equipment is not changed for newer and more efficient equipment. As such, efficiency differences between natural gas systems and diesel / HFO systems are assumed to be identical.
- The completeness and validity of the inventory data :
    - The system was based on prospective estimations, forecasts and not on an existing LNG plant and for which inputs and outputs can be measured. Therefore, hypotheses had to be made, and some may vary in the future. For example, the study is based on a forecast of the supply of petroleum products which may be different from what may ultimately happen in 2017.
    - The relatively uneven representativeness of the temporal, geographic and technological generic data used to represent specific processes taking place Western Canada, USA, Quebec, Sweden and the Caribbean is also considered to be a limitation in the interpretation of results.
- The impacts assessed come from a simplified model, and hence provide insight into how the real environment may react and be impacted on. The Life Cycle Impact Assessment (LCIA) results do not predict the effects on exceeded thresholds, safety margins or risks. These results should therefore not constitute the only basis for comparison or public affirmations. Additional information is required in order to remedy certain limitations of the LCIA itself.

3 LIFE CYCLE INVENTORY ANALYSIS (LCI)

3.1 LIFE CYCLE INVENTORY (LCI) DATA

This sub-section provides an overview of the data sources that were used and of the data quality requirements that were implemented.

3.1.1 GHGenius model

The GHGenius model developed for Natural Resources Canada was used for the assessment of the emission factors for the parameters included in the assessment.

GHGenius is a widely used, publicly available LCA model focussing on fuels for transportation and other applications. It is specified in Government regulations in British Columbia, Alberta, and Ontario. Federally, it is used to support regulations in the fuel sector including Regulatory Impact Assessment Statements appearing in the Canada Gazette. It includes all of the products that are of interest for this study. The model includes regional data for Canada and the United States. The data is mostly derived from Government sources. For Canadian data the data sources include Statistics Canada, the National Energy Board, and Environment Canada. The US data in the model is mostly sourced from the US Energy Information Administration (EIA).

The model provides significant flexibility to the users to allow for regionalization, temporal adjustments, and alternative scenarios. The alternative scenarios can include allocation methods, feedstock and fuel supply and distribution scenarios, sensitivity runs and other adjustments.

The base case scenario involved modelling the Central region of Canada (Ontario and Quebec) for the anticipated crude oil slate in the year 2017. The model uses grid electricity for the specific region of activity (Quebec in the base case).

GHGenius can also model the US East region (Petroleum Administration for Defense District (PADD) 1) which include the US Northeast and the US Central region (PADD's 2 and 3) which includes the US Gulf Coast refineries.

The model is currently being expanded to include European data, however for this work the model was calibrated to produce results that are comparable to the carbon intensities of diesel fuel and LPG that have been published by the European Commission.

The model is fully documented ((S&T)^2 Consultants 2013a, 2013b). The version of GHGenius that was used for this study was published early in 2013. GHGenius generally uses time series of data for information on crude oil production, natural gas production and processing, and electric power production.

The last year of actual data in the model was generally 2011, although some data series, that take longer to update, end earlier. For the well-established industries, and crude oil production, refining, gas production and processing, and electric power production are in this category the changes from year to year are small. In many cases the data series are extrapolated from the last year of real data to provide an estimate of the values for the current year, or are based on official forecasts.

3.1.2 Data Sources

All of the data sources with the exception of the LNG facility and the regasification unit are from GHGenius (modified for this project as explained in Section 3.2.3). The LNG facility and the regasification unit are based on the SNC-Lavalin impact study[14]. Table 3-1 below summarizes the type of data source, the activity data and the emission factor sources.

Table 3-1: Data sources, activity data and emission factors

Life cycle activity	Data source	Activity data[1]	Emission factors
Natural gas extraction and processing	Secondary	Industry data compiled in GHGenius based on: US EPA. US DOE. Alberta Energy Regulator, Statistics Canada, Environment Canada, CAPP, BC Ministry of Energy and Mines.	GHGenius. EPA AP-42 and calculated from activity data.
Natural gas transport and distribution	Secondary	Industry data compiled in GHGenius - 3,700 km of pipeline obtained from Statistics Canada	GHGenius. EPA AP-42 and calculated from activity data.
Crude oil extraction and pre-processing	Secondary	Industry data compiled in GHGenius based on: Alberta Energy Regulator, CAPP, US Census, International Oil and Gas Producers Association, US National Energy Technology Laboratory, OPGEE.	GHGenius. EPA AP-42 and calculated from activity data.

[14] Environmental Impact Assessment Study Submitted to the Ministry of Sustainable Development, Environment and Fight against Climate Change, SNC-Lavalin Inc., October 2014.

Life cycle activity	Data source	Activity data[1]	Emission factors
Crude oil transport and distribution	Secondary	Industry data compiled in GHGenius that was derived from International Maritime Organization data.	GHGenius. EPA AP-42 and calculated from activity data.
Liquefaction of natural gas	Primary	Production of 500,000 tonnes of LNG per year (1 train in operation) . Based on the SLNGaz EIA performed by SNC-Lavalin.	Quebec emissions reporting regulations, GHGenius, EPA AP-42 and calculated from activity data. [15]
Oil refining	Secondary	Industry data compiled in GHGenius based on Statistics Canada and Environment Canada.	GHGenius. Environment Canada, EPA AP-42, and calculated from activity data.
Liquefaction of petroleum gas	Secondary	Industry data compiled in GHGenius based on Alberta Energy Regulator, US EIA.	GHGenius. EPA AP-42 and calculated from activity data.
LNG transport to end user*	Primary[16]	• 665 km by ship from Bécancour to Sept-îles • 150 km by LNG fueled trucks from Bécancour for local use in fleets • 550 km by LNG fueled truck from Bécancour to NE USA • 7,120 km by ship from Bécancour to Sweden • 3,280 km by ship from Bécancour to the Caribbean	GHGenius, Mobile 6.2C and International Maritime Organization (IMO).

[15] Based on results from the Environmental Impact Assessment Study Submitted to the Ministry of Sustainable Development, Environment and Fight against Climate Change, SNC-Lavalin Inc., October 2014.

[16] Distances by ship estimated using the tool provided on the following website: http://ports.com/sea-route/; distances by truck were estimated using the following website: https://maps.google.ca.

Life cycle activity	Data source	Activity data[1]	Emission factors
Diesel transport to end user*	Primary[17]	• Average of 730 km by ship from the Quebec refineries to Sept-îles; 15 km by truck and pipeline were also considered for the transfer of the diesel to the port • Average of 125 km from Quebec refineries for local use in fleets	GHGenius, Mobile 6.2C and IMO.
HFO transport to end user*	Primary[18]	• Average of 730 km by ship from the Quebec refineries to Sept-îles; 15 km by truck and pipeline were also considered for the transfer of the diesel to the port • 500 km by ship from a Swedish refinery to the point of use in Sweden. • 4,270 km by ship from Houston to the Caribbean.	GHGenius, Mobile 6.2C and IMO.
LPG transport to end user*	Primary	• Estimate of 500 km by ship from a Swedish refinery to the point of use in Sweden.	GHGenius, Mobile 6.2C and IMO.
Heating oil transport to end user	Secondary	Industry data compiled in GHGenius	GHGenius, Mobile 6.2C and IMO.

[17] Distances by ship estimated using the tool provided on the following website: http://ports.com/sea-route/; distances by truck were estimated using the following website: https://maps.google.ca.

[18] Distances by ship estimated using the tool provided on the following website: http://ports.com/sea-route/; distances by truck were estimated using the following website: https://maps.google.ca.

Life cycle activity	Data source	Activity data[1]	Emission factors
Stationary combustion	Primary for regasification Secondary for fuel combustion	189,273 tonnes of LNG will be regasified which includes the LNG distributed for industrial combustion in the project scenario presented in Figure 2-1. Industry data compiled in GHGenius based on US AP-42.	GHGenius and EPA AP-42.
Stationary power generation	Secondary	Industry data compiled in GHGenius based on US AP-42, Statistics Canada and Environment Canada.	GHGenius and EPA AP-42.
Mobile equipment	Secondary	Industry data compiled in GHGenius based on Environment Canada Mobile6.2C and industry compliance tests.	GHGenius and Mobile 6.2C.
Residential/ commercial heating	Primary for the regasification Secondary for fuel combustion	15,200 tonnes of LNG will be regasified which includes the LNG distributed for residential/commercial heating in the project scenario presented in Figure 2-1.	GHGenius and EPA AP-42.

[1] Data sources from GHGenius can be found in chapters 43 and 46 of Volume 2 of the GHGenius manual.

In the GHGenius model, CO_2 emissions are a function of the carbon content of the fuels. The carbon contents for the fuels used in this study are the following:

Diesel fuel and heating oil	0.858 g C/g fuel; 18,718 g C/GJ
HFO	0.858 g C/g fuel; 19,423 g C/GJ
LPG	0.818 g C/g fuel; 16,266 g C/GJ
Natural Gas	0.720 g C/g fuel; 13,726 g C/GJ

3.1.3 Data Quality Requirements and Data Improvement

The data used in GHGenius is generally the most recent data that was available for the year 2011. In some cases the data is extrapolated to the year 2017. The data is nationally and regionally specific to the processes studied and it generally includes the full coverage of the technologies employed in the industry as the reported data is industry wide.

Reliability of LCA results and conclusions depends on the quality of inventory data that are used. It is therefore important to ensure that the data meet specific requirements with regards to the LCA objectives.

As such, a modified version of GHGenius 4.03a has been used for this project. The model is identified as GHGenius 4.03 SLNGaz.xls. It is based on a development version of the model that will eventually be released to the public. The improvements made to this version include:

1. Since this project will not be in operation until 2017 it was important that the reference system in 2017 be reflective of the expected petroleum supply at that time. The normal way that GHGenius forecasts the future performance is to either utilize a government forecast, usually from the National Energy Board in Canada, or to extrapolate the past performance. Neither of these approaches is ideal when there are step changes expected in the system. Such a step change is expected between now and 2017 with respect to the source of crude oil that is refined in the Central Canada region of the model. The Enbridge Line 9 crude oil pipeline is in the process of being reversed. Once the project is completed in early 2015, crude oil from Western Canada will flow to Montreal to service all of the refineries in Ontario and the Suncor refinery in Montreal. In addition crude oil is expected to be shipped by barge or rail from Montreal to Lévis to supply the Valero refinery. It is therefore expected that this region will refine almost exclusively western Canadian crude oil.

   The type of crude oil refined in Central Canada in the model has been aligned with the 2014 forecast supplied by CAPP[19].

2. The data source for the US natural gas emissions in GHGenius is the US Inventory of U.S. Greenhouse Gas Emissions and Sinks that the US EPA publishes annually to meet their reporting requirements under the UNFCCC. The report published in April 2013 and which covers the period from 1990 to 2011 was used to determine the emission factors used in this version of GHGenius. This data was updated in GHGenius and resulted in a reduction of emissions for producing natural gas in the United States.

[19] 2014 Crude Oil Forecast, Markets and Transportation, http://www.capp.ca/forecast/Pages/default.aspx

3. Some of the data series have been updated to include 2013 data. These include foreign crude oil delivered to Canada, quantity of Canadian crude oil refined in Central Canada, crude oil types exported from Canada to the United States, and crop yields.

4. With the pipeline supply of crude oil for Central Canada being extended to Montreal, the pipeline distance for the crude oil delivered to Montreal was changed to be 500 km greater than Ontario.

5. Since the GHGenius model has not yet been programmed and updated to directly model emissions from the Caribbean, the HFO that is used in the reference case for the Caribbean is assumed to be produced at US Gulf Coast refineries and shipped from Houston to Bermuda. The GHGenius model has been set to the US Central region, the year is 2017, to be consistent with the other cases and the heavy product transportation distance has been set to 4,269 km.

6. One of the major developments underway with GHGenius is the addition of three regions in Europe. To model emissions from Sweden, the model has been set to Northern Europe, a region that encompasses the UK, Denmark, Ireland, Sweden, and Finland. It has been assumed that the crude oil refined in this region is light sweet crude oil.

   The model has been calibrated to produce lifecycle emissions for diesel fuel that is similar to the emissions for diesel published by the European Commission in 2014. The refinery energy use was adjusted to the EU Renewable Energy Directive (RED) values.

   The resulting GHG emissions from GHGenius are compared to the latest results for all of Europe as published by the European Commission in their latest proposals with respect to their Fuel Quality Directive. These are the most recent estimates available for Europe. The comparison is shown in the following table. These are done with the 2007 GWPs.

Table 3-2: Comparison of GHG emissions from Fuel Quality EU Directive[20] and GHGenius

	Fuel Quality Directive	GHGenius
	kg CO_2eq/GJ (HHV)	
Gasoline	87.4	85.7
Diesel Fuel	88.8	85.5
LPG	69.8	72.3

The GHGenius values are conservative (will underestimate the GHG benefits from LNG) for gasoline and diesel fuel and are slightly higher for LPG, which reflects different allocation assumptions made between the two modeling frameworks.

Although the assessment has been undertaken with the SAR (1996) GWP and that Table 3-2 presents emissions based on the AR4 (2007) GWP since these were the only ones available, a sensitivity analysis presented in Section 5.1 shows that the use of either set of GWP has little effect on the emissions.

A qualitative data quality assessment is presented for GHGenius in Table 3-3.

Table 3-3: Qualitative data assessment for GHGenius

Parameter	Evaluation
Reliability	Good (mostly government data sources)
Completeness	Good
Temporal Representativeness	Very Good (mostly time series of data used)
Geographic Representativeness	Very Good (regional data, Provincial level for some parameters)
Technological Representativeness	Good (most government data sets have high activity coverage and include all major technologies employed in the sector)

These modifications improve the representative and reliability of the data.

[20] COM (2014) 617 Annexes.
http://ec.europa.eu/clima/policies/transport/fuel/docs/com_2014_617_annexes_en.pdf

3.1.4 Impact Categories

In this comparative LCA, the study compares the GHG emissions between both scenarios.

For GHG accounting, a time horizon of 100 years is usually used, as suggested during the *Framework Convention on Climate Change held in Kyoto* in 1997 (United Nations, 1998). The factors are periodically revised within the scope of the IPCC Assessment Report. For this study, the Global Warming impact category was assessed using the Second Assessment Report (SAR) (IPCC,1996) values since they were included into the Kyoto Protocol and are those currently used in the Province of Quebec. A sensitivity analysis was done in order to measure the influence of the global warming potential (GWP_{100}) choice (see Section 5.1) in comparison to the IPCC Fourth Assessment Report (AR4). **Table 3-4** presents GWP_{100} values for the tree main GHGs according to both versions of the IPCC report.

Table 3-4: Global warming potential (GWP100) of the three main GHG for the fourth (AR4) and second (SAR) Assessment Report of IPCC.

GHG	AR4 (2007) (kg CO_2e)	SAR (1996) – used in assessment (kg CO_2e)
Carbon dioxide (CO_2)	1	**1**
Methane (CH_4)	25	**21**
Nitrous oxide (N_2O)	298	**310**

Note: The values used for the current assessment are in bold.

Carbon monoxide and unburned hydrocarbons are assumed to be converted to CO_2 for the purpose of calculating the GWP in accordance with IPCC practice.

3.1.5 Calculation Method

When all of the required data has been obtained and the associated flows have been standardised in relation to the functional unit that was selected, it is possible to model the product system using commercial LCA software. The GHGenius software (Version 4.03) with the improvements detailed in Section 3.1.3, developed by $(S\&T)^2$ Consultants Inc., was used to calculate the inventory and assess the potential environmental impacts associated with the inventoried emissions.

The inventory does not include weighting factors for delayed emissions, offsets and avoided emissions.

4 RESULTS

This section will provide the results of the inventory of both the project and reference scenarios according to the reference flows presented in Section 2 of this report and the final use.

Table 4-1 below presents the global inventory results per substance studied. The unit of analysis being one (1) GJ of energy delivered.

Table 4-1: Global inventory results – Cradle-to-grave (well head to fuel use)

Substance	LNG Project	Reference scenario	Δ
kg of CO_2e / GJ	64	88	- 27%
kg of CO_2 / GJ	61	85	- 28%
kg of CH_4 / GJ	0.13	0.14	- 7%
kg of N_2O / GJ	0.0020	0.0016	25 %
kg of HFC-134a / GJ	0.000011	0.000010	10 %

The emissions are lower in the LNG project scenario than the reference scenario. The fact that the liquefaction plant can use electricity from the Quebec electricity grid which has very low GHG emissions contributes to the lower intensity of the LNG project.

Tables 4-2 and 4-3 present the results per life cycle stage for the LNG scenario and the reference scenario respectively.

Table 4-2: Results by life cycle stage – LNG Project Scenario

Stage	GHG emissions	
	kg of CO_2e/GJ	Share
Material acquisition and pre-processing	7.3	11%
Production (gate-to-gate)	0.63	1%
Distribution	4.4	7%
Use	52	81%
Total	64	100%

Table 4-3: Results by life cycle stage – Reference Scenario

Stage	GHG emissions	
	kg of CO_2e/GJ	Share
Material acquisition and pre-processing	11	12%
Production (gate-to-gate)	5.3	6%
Distribution	2.3	3%
Use	70	79%
Total	88	100%

The share of GHG emissions according to the main life cycle stages for both scenarios are similar, i.e. the majority of GHG emissions occur in the *use* stage (approximately 80%).

Table 4-4 shows the inventory results at each destination of use along with the variation between both scenarios.

In analysing this table, the location with the greatest environmental gain of using the LNG is the Caribbean followed by the local fleets in Quebec, NE USA and NE Quebec. The location with the least environmental gain is Sweden.

Table 4-4: Emissions contribution comparison per location

Location	GHG emissions (kg of CO_2e/GJ) (1)		
	LNG	Ref	Δ(2)
NE Quebec	32	44	-27%
Sweden	9.6	11	-15%
Caribbean	13	19	-31%
NE USA	2.0	2.8	-28%
Local fleets	7.9	11	-28%
Total	64	88	-27%

(1) Emissions per region divided by total energy delivered.
(2) Δ is the difference between the reference scenario and the project.

Since the LNG would be used for various sources we have also compiled results per source to compare the gains per equipment type in Table 4-5.

Table 4-5 : Emissions contribution comparison per source type

Source type	GHG emissions (kg of CO_2e/GJ) (1)		
	LNG	Ref	Δ(2)
Stationary combustion	24	31	-21%
Stationary power generation	26	37	-31%
Mobile equipment	12	17	-27%
Heating	2.0	2.8	-28%
Total	64	88	-27%

(1) Emissions per source type divided by total energy delivered.
(2) Δ is the difference between the reference scenario and the project.

Since it isn't necessarily the same fuel that is being substituted in the different source types, the environmental gains cannot be directly attributable to the equipment itself.

5 UNCERTAINTY

Inventory uncertainty can be divided in three categories: parameter uncertainty, scenario uncertainty and model uncertainty. All three categories of uncertainty will be addressed in this section.

As previously stated, the results of this study cannot be applied to other LNG projects. The study scope considers end-users based on a market study performed by a specialized firm. The reality of the market in 2017 may be different from the current market study. It also is based on future projections of fuel supply and not necessarily based on current supply.

5.1 PARAMETER UNCERTAINTY

Parameter uncertainty is the uncertainty regarding the values used in the inventory representation of the process in the product's life cycle. Parameter uncertainty can cover data relating to the direct emission, the activity data, emission factors and global warming potential factors. As shown in Section 3, the data quality used for the activity data and emission factors present no real issues.

A sensitivity analysis was performed for the GWP factors since the province of Quebec still uses the GWP of the Second Assessment Report (1996). Results of the sensitivity analysis in presented in Table 5-1.

Table 5-1: Sensitivity analysis on the GWP factors – AR4 in comparison to SAR

	SAR (1996) (kg CO_2e /GJ)	AR4 (2007) (kg CO_2e /GJ)	% Increase
LNG Project	**64.4**	64.9	0.84%
Reference scenario	**88.0**	88.5	0.59%
Difference	23.6 (31%)	23.6 (31%)	

Note: The values used for the current assessment are in bold.

The analysis shows that the GWP factors have very minor impact on the study results.

5.2 SCENARIO UNCERTAINTY

The second uncertainty category is related to methodological choices made in the study. Three sensitivity analyses have been performed on assumptions pertaining to the methane emission controls versus non control of the ferries in Sweden, the natural gas supply and the crude oil origin.

The principal contributing process is the use of the fuel, therefore the sensitivity analysis regarding the methane emission controls in the ferries are necessary. The second contributor, of lesser contribution, is material acquisition and pre-processing phase. Even though its contribution is lower, sensitivity analyses were performed on the origin of the fuels.

5.2.1 Methane Emissions Control in Ferries

Some LNG fueled ferries can be equipped with emission control equipment whereas others may not. In the LNG project scenario, it was established that the ferries would be equipped with emissions control equipment. A sensitivity analysis was undertaken to see the impacts if the ships do not have these controls. Emissions from the ferries are part of the use stage of the life cycle. The results of the analysis are presented for the full life cycle of the LNG being supplied to Sweden in Table 5-2.

Table 5-2: Sensitivity analysis – methane emissions controls in ferries over all stages

	Contaminant emissions in kg/ GJ
Scenario	CO_2e
Emissions control	**64.8**
Hi methane slip	76.2

Note: The scenario used for the current assessment is in bold.

Emissions from ferries using LNG without methane emission controls still remain below the emissions from the reference scenario of 86 kg CO2e/ GJ. The differences between having the controls or not on the ferries does not change the global results of the study.

5.2.2 Natural gas supply

A sensitivity analysis was performed since an estimate of the break-up of the natural gas supply to Bécancour in 2017 is not known.

In GHGenius 4.03 it is assumed that the natural gas burned in Canada is sourced in Canada and thus the supply of natural gas was considered to be 100% from Western Canada. However, new data is available from Statistics Canada[21] that shows that this is no longer the case. The percentage of US gas consumed in Ontario and Quebec is shown in the following figure.

[21] Statistics Canada, CANSIM, website: http://www5.statcan.gc.ca/cansim/home-accueil?lang=eng, (Cansim Table 129-0004)

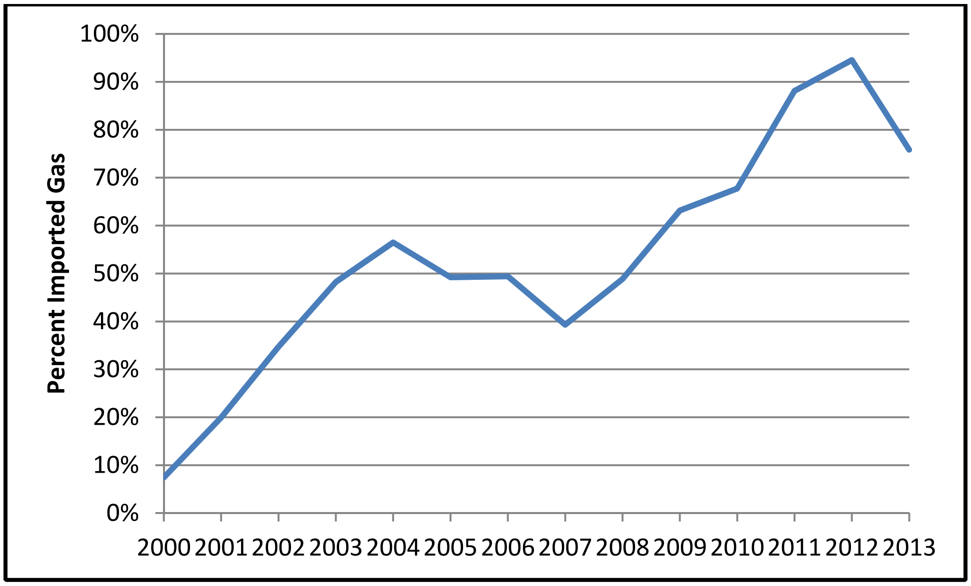

Figure 5-1: Percentage of US gas consumed in Ontario and Quebec

Since the facility will begin operating in 2017 and that the gas origin isn't yet known, a sensitivity analysis was performed considering a supply 100% from the US and another scenario where the supply would be 50% from Western Canada and 50% from the US. The results of this analysis are presented in Table 5-3.

Table 5-3: Sensitivity analysis on natural gas supply – includes all stages except *use*

NG feed	CO_2e (kg/GJ)
100% from Western Canada	**12.9**
100% from the US	13.4
50% from Western Canada/ 50% from the US	13.1

Note: The natural gas supply used for the current assessment is in bold.

The percent increase of GHG emissions if half or 100% of the supply would come from the US is 2% and 4% respectively, which is not a significant increase and would not change the global results of the study.

5.2.3 Natural Gas Leaks

The *material acquisition and pre-processing* stage represents 11 % or 7.3 kg of CO_2e/GJ of the emissions for the project scenario. This value is below other estimates that can be found in literature. A sensitivity analysis was performed by doubling the gas leaks from processing and recovery. Table 5-4 presents the results of the analysis which was performed on the NE USA pathway.

Table 5-4: Sensitivity analysis on natural gas leaks – material acquisition and pre-processing stage

Scenario	CO_2e (kg/GJ)
Base case project scenario (considers natural gas supply from Western Canada)	**7.2**
Project scenario considering 100% natural gas supply from the US	8.9
Project scenario considering 100% natural gas supply from the US with doubled gas leaks	10.9

Note: The scenario for the current assessment is in bold.

The results from Table 5-4 show that the *material acquisition and pre-processing* stage increases by 3.7 kg/GJ if the natural gas supply is considered from the US with natural gas leaks doubled in the GHGenius model. Since the project provides 24 kg/GJ of emissions reductions, the project still provides significant GHG emissions reductions if gas leaks are doubled.

5.2.4 Crude Oil Supply

A sensitivity analysis was performed for the crude oil origin. Currently, the model considers that Enbridge Line 9 reversal will be in operation in 2017, thereby considering that the crude oil originates mainly from Western Canada. For the sensitivity run, the GHGenius model was set to 2014, where the significant shift to the use of Canadian crude oil is not yet in the forecast. The crude oil forecast for both the 2014 and 2017 years is presented in Appendix A. Table 5-5 presents the results of the analysis.

Table 5-5: Sensitivity analysis on crude oil supply – includes all stages except *use*

Input year	CO_2e (kg/GJ)	
	Ref – HFO	Ref - diesel
2014 – Before Enbridge Line 9 reversal	13.70	21.21
2017 – After Enbridge Line 9 reversal	**14.34**	**22.12**

Note: The crude oil supply used for the current assessment is in bold.

The results in Table 5-4 present the emissions for the NE Quebec pathway which includes all stages of the life cycle including the regasification of the LNG, but without the combustion component.

In examining the results, emissions for the reference scenarios for HFO and diesel are greater in 2017, that is of 5 % and 4 % respectively, which is not a significant increase and would not change the global results of the study.

5.3 Model Uncertainty

The use of one model for the analysis of the complete two systems reduces bias through the use of consistent data sets and approaches. The data sets used in GHGenius are recent, geographically specific, and comprehensive. The GHGenius model has been assessed against other models and found to be more comprehensive than most models[22]. It is the only publicly available LCA model for fuel systems with Canadian data. The petroleum and natural gas pathways in the model were also assessed against the GREET model and modelling work undertaken by the US EPA and no major issues with respect to data quality, system boundaries, and methodology were identified[23].

[22] Cheminfo Systems, 2008

[23] ((S&T)² Consultants, 2013).

6 CRITICAL REVIEW

A critical review is a process used to verify whether the LCA satisfies the international standards. Critical reviews of LCA are generally optional, except in the case of LCA used to support comparative assertions that are made public. Such LCA requires special attention given the risks associated with the incorrect interpretations of the results by the various stakeholders. The critical review also enhances the credibility of the assessment. Ernst & Young was mandated to perform the critical review.

The critical review was performed according to the following steps:

1. Selection of an external independent expert by the commissioner of the original LCA study to act as a chairperson of the review panel on 25 November 2014.
2. Selection of other independent qualified reviewers to take part in the critical review panel between 26 November 2014 and 16 December 2014.
3. Communication of the carbon footprint report to the chairperson on 16 December 2014.
4. Communication of the review note to SNC-Lavalin and (S&T)^2 on 12 January 2015, including all comments and recommendations to the LCA practionner.
5. Communication of the updated carbon footprint report and response to comments and recommendations to the critical review panel on 29 January 2015.
6. Communication of the second review note to SNC-Lavalin and (S&T)^2 on 3 February 2015, including all comments and recommendations to the LCA practionner.
7. Communication of the final version of the carbon footprint report and response to comments and recommendations to the critical review panel on 9 February 2015.
8. Communication of the critical review report, including the critical review statement, to the LCA practitioner on 9 February 2015.

The review panel is composed of the following three experts:

Chairperson :
Bruno Gagnon, Eng., Ph.D.
Senior Consultant, Ernst & Young

External Reviewers:
Pierre-Olivier Roy, B.Eng., Ph.D.
Environmental consultant, CIRAIG

Devin O'Grady, B.Eng., M.Eng.
Technical Advisor, Natural Resources Canada

The review note is presented in Appendix C.

7 REFERENCES

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(S&T)[2] Consultants Inc.

SNC·LAVALIN

APPENDIX A

Crude Oil Supply for 2014 and 2017

The origin of crude oil for Central Canada is presented below for the 2014 and 2017 forecast.

	2014 Volume m^3	2017 Volume m^3
U. S.	74,964	49,410
Canada	25,664,703	39,943,726
Mexico	1,254,687	1,195,477
Nigeria	320,852	294,639
Algeria	4,500,000	82,810
Norway	1,295,614	79,799
Angola	792,240	768,710
United Kingdom	633,823	350,506
Other	5,463,587	0
TOTAL	**40,000,470**	**42,765,077**

Source: Statistics Canada. Cansim Table 134-0001

APPENDIX B

Electricity Grids

The GHGenius electric supply from the grid is regionalized and the power supply in the three North American consuming regions is shown in the following table. Activities (e.g. crude oil production) that occur in specific regions outside of the consuming region use the power supply from the producing region and not the consuming region. The liquefaction process is dependent on electric power but the reference pathways have only minor contributions from electricity.

	Quebec	NE USA	Central USA
	Fraction supplied[24]		
Coal	0.000	0.436	0.511
Oil	0.004	0.002	0.002
Gas Boiler	0.006	0.131	0.116
Gas Turbine	0.000	0.115	0.102
Nuclear	0.017	0.182	0.185
Wind	0.046	0.051	0.052
Other Carbon	0.000	0.000	0.000
Biomass	0.012	0.008	0.006
Hydro	0.914	0.075	0.026
Other	0.000	0.000	0.000
Delivered Carbon Intensity	47.9 g CO_2e/kWh	655 CO_2e/kWh	722 CO_2e/kWh

[24] Canadian data from NEB Canada's Energy Future: Energy Supply and Demand Projections to 2035. http://www.neb-one.gc.ca/nrg/ntgrtd/ftr/archive/2011/index-eng.html

US data is from US DOE Energy Information Administration (EIA), Annual Energy Review 2011, and Annual Energy Outlook 2013. http://www.eia.gov/totalenergy/data/annual/archive/038411.pdf and http://www.eia.gov/forecasts/archive/aeo13/

APPENDIX C

Critical Review Report

Ernst & Young s.r.l./S.E.N.C.R.L.
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9 February 2015

Subject: Critical review report of the comparative carbon footprint for the SLNGaz Project

Dear Ms. Vieira:

Find attached the critical review report on the comparative carbon footprint of liquefied natural gas (LNG) and other fossil fuels performed by SNC-Lavalin for Stolt LNGaz. The content of the critical review report is based on the carbon footprint report provided to the review panel by SNC-Lavalin on 9 February 2015.

The critical review was performed in accordance with the ISO 14044 standard and the ISO 14071 technical specification, as the results were intended to be used to support publicly disclosed comparative assertions. This process was followed to decrease the likelihood of misunderstandings or negative effects on external interested parties.

The main objective of the critical review process is to ensure that the study performed and the report prepared are consistent with the ISO 14044 standard. The critical review panel considers the modifications made to the original report as satisfactory, and that the final version of the report meets the requirements set forth in the ISO 14044 standard.

The fact that a critical review has been conducted implies in no way an endorsement of any comparative assertion that is based on an LCA study by the critical review panel. The limitations stated in the carbon footprint report must also be taken into account in the interpretation and use of the results.

Yours sincerely,

Ernst & Young LLP

Thibaut Millet
Associate Partner, Climate Change and Sustainability Services

Bruno Gagnon

Bruno Gagnon, Eng., PhD
Chairperson of the critical review panel

Critical review of the comparative carbon footprint for the SLNGaz Project

Critical review report

9 February 2015

Table of contents

NOTE: This report has been prepared to assist SNC-Lavalin. Our report has not considered issues relevant to third parties. Any use a third party may choose to make of this report is entirely at its own risk.

1. Context

This report was prepared for SNC-Lavalin as part of the critical review of the comparative carbon footprint report on liquefied natural gas (LNG) and other fossil fuels, which is itself carried as part of the SLNGaz Project environmental impact assessment.

As stated in the ISO 14044 standard (Environmental management - Life cycle assessment - Requirements and guidelines), a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public, in order to decrease the likelihood of misunderstandings or negative effects on external interested parties.

1.1 Review panel

The critical review panel consists of:

Review committee chairperson	Bruno Gagnon, Eng., PhD Senior Consultant, EY
External reviewers	Devin O'Grady, B.Eng., M.Eng. Technical Advisor, Natural Resources Canada
	Pierre-Olivier Roy, B.Eng., PhD Environmental consultant, CIRAIG

Bruno Gagnon
A senior advisor in EY's Climate Change & Sustainability practice, Bruno has experience in life cycle assessment (LCA) and product carbon footprints serving clients in various industry sectors. His experience also includes greenhouse gas (GHG) verification and performance audit in municipalities on environmental issues. Over the past few years, Bruno has served as a part-time lecturer and master's thesis advisor at the Université de Sherbrooke. Before joining EY, Bruno worked in consulting and also completed a PhD in environmental engineering. His scientific research focused on the integration of sustainable development principles in engineering design projects as well as wastewater management technologies, namely through the use of LCA.

Devin O'Grady
Devin holds a bachelor's degree in chemical engineering from the University of Ottawa (2005) and a master's degree in chemical engineering from McGill University (2007). Devin joined Environment Canada's Oil and Gas division in 2010 working on GHG regulatory development elements related to the oil and gas sector. This included reviewing crude oil LCA studies and managing contracts involving the Canadian lifecycle model GHGenius. Devin moved to Natural Resources Canada in 2013 with a focus on refining and transport fuel technical issues. His work involves LCA related activities, serving as a voting member for the Canadian General Standards Board (CGSB) Petroleum Committees, and participating as a workshop organizer for the 2015 Coordinating Research Council's Transport Fuel LCA Workshop.

Pierre-Olivier Roy
A chemical engineering graduate from École Polytechnique de Montréal in 2006, Pierre-Olivier Roy has completed both a Masters (2009) and a PhD (2012) at the International Reference Centre for the Life Cycle of Products, Processes and Services (CIRAIG). His thesis, entitled *Worldwide regional environmental modeling of terrestrial and aquatic acidification for a life cycle analysis context* allowed him to develop expertise related to the regional and global scale modeling of the consequences of terrestrial and aquatic acidification. He now works for CIRAIG as an environmental consultant. He has since worked on several projects such as the shale gas strategic environmental assessment for the Québec government, a confidential energy-related project for Total and the carbon footprint pilot project for the Québec government.

1.2 Objectives

As stated in ISO 14044, section 6.1, the critical review process shall ensure that:

- the methods used to carry out the carbon footprint are consistent with the ISO 14044 standard;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study;
- the study report is transparent and consistent.

Due to the nature of the study, relevant requirements put forward in the ISO 14067 Technical Specification (Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication) are also considered during the review.

1.3 Critical review process

The critical review was performed by a panel of three external experts at the end of the carbon footprint study, following the ISO 14071 Technical Specification (Environmental management - Life cycle assessment - Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006).

The critical review covers all aspects of an LCA, including data appropriateness and reasonability, calculation procedures, life cycle inventory (LCI) analysis, impact assessment methodologies, characterization factors, calculated LCI and life cycle inventory analysis (LCIA) results, and interpretation.

The critical review was performed according to the following steps:

1. Selection of an external independent expert (EY – Bruno Gagnon) by the commissioner of the original LCA study to act as a chairperson of the review panel on 25 November 2014.
2. Selection of two other independent qualified reviewers (Devin O’Grady and Pierre-Olivier Roy) to take part in the critical review panel between 26 November 2014 and 16 December 2014.
3. Communication of the carbon footprint report to the review panel on 16 December 2014.

4. Communication of the first review note to SNC-Lavalin on 12 January 2015, including all comments and recommendations to the LCA practitioner.
5. Communication of the second version of the carbon footprint report and response to comments and recommendations to the critical review panel on 29 January 2015.
6. Communication of the second review note to SNC-Lavalin on 3 February 2015, including all comments and recommendations to the LCA practitioner.
7. Communication of the final version of the carbon footprint report and response to comments and recommendations to the critical review panel on 9 February 2015.
8. Communication of the critical review report, including the critical review statement, to the LCA practitioner on 9 February 2015.

The selection of the external experts was based on their knowledge of, and proficiency in: (i) the ISO 14040 and ISO 14044 standards; (ii) the ISO 14067 technical specification; (iii) the LCA methodology and current practice; (iv) critical review practice; (v) the scientific disciplines relevant to the important impact categories of the study; (vi) environmental, technical and other relevant performance aspects of the product system(s) assessed; (vii) the language used for the study.

The comments were provided to the LCA practitioner in written form, after being discussed among the members of the review panel. Clarifications on the comments were provided to the LCA practitioner during a conference call and through e-mail exchanges. Answers to the review panel were provided by the LCA practitioner in written form, after modifications were done in the carbon footprint report.

The review of the carbon footprint was performed in reference to the ISO 14044 standard and ISO 14067 technical specification, with the support of the checklist presented in Section 3.

The review excludes an assessment of the life cycle inventory (LCI) model and the assessment of individual data sets (at the inventory level).

1.4 Review statement

The critical review statement belongs to version 3 (dated 9 February 2014) of the comparative carbon footprint report.

The critical review panel considers the modifications made to the original report as satisfactory. The final version of the report meets the requirements set forth in the ISO 14044 standard.

The fact that a critical review has been conducted implies in no way an endorsement of any comparative assertion that is based on an LCA study by the critical review panel.

The procedures we performed do not constitute an audit, examination or a review in accordance with generally accepted auditing standards or attestation standards. We have not audited or otherwise verified the information supplied to us in connection with this engagement.

2. Comments on the carbon footprint report

Legend:

Reviewer	
BG	Bruno Gagnon
DO	Devin O'Grady
PR	Pierre-Olivier Roy

Review panel comment	
● (yellow)	A correction, modification or justification is **required**. This item has an impact on consistency with the ISO 14044 standard and the ISO 14067 technical specification and/or the results.
● (grey)	A correction, modification or justification is **recommended**. This item could be adjusted to improve readability of the report and the quality of the results.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
1	BG	Title page	Life cycle assessment should be used instead of life cycle analysis.	● (grey)	Modified as recommended.	Satisfactory.
2	BG	Notice to reader	The disclaimer stating that the report has been undertaken for the exclusive use of Stolt LNGaz Inc. is inconsistent with the fact that the results and conclusions are intended to be disclosed to the public (section Goal of the study).	● (yellow)	Modified to fit with the goal of the study.	Satisfactory.
3	PR	List of Tables	Page numbers are erroneous.	● (yellow)	Corrected.	Satisfactory.
4	PR	List of Figures	Page numbers are erroneous.	● (yellow)	Corrected.	Satisfactory.
5	PR, BG	2.1, 2.2	The definition of the reference scenario should be better documented, namely to address these questions: • On what basis were the alternative fuels selected? • Why should LNG be expected to replace these fuels in the given location? Do the current infrastructure and equipment support the planned substitution?	● (yellow)	The selection of the locations, equipment use and fuels to be replaced is based on an extensive market analysis as well as an independent market study by a reputable consulting firm in Canada. This work was mandated by SLNGaz and includes information of sensitive nature for which the projected users and therefore precise locations cannot be	Satisfactory. This section is now much more transparent and understandable. The authors could mention an independent market study was performed without stating it was prepared by a "reputable consulting firm in Canada" as this portion of the statement is too vague to provide additional context.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			• Is it economically relevant for users to switch from diesel, HFO or LPG to LNG? Explanations must be provided for the choices of alternative fuels, the planned destinations and the market shares between the different uses. Could a different set of alternative fuels be assessed in a sensitivity analysis?		disclosed. However, the choices in the locations and fuel replacement can be backed by publicly available information which we have included in the report. An explanation for each location is now included in the report in section 2.2.	
6	DO	2.1	Under the goal of the study authors refer to "*supply LNG to remote areas or areas not connected to NG network*." How do Sweden, North East US and the Caribbean fit under this categorization?	● (grey)	This point is covered in the response to question number 5.	Satisfactory.
7	DO	2.1	"*Carbon and CAC emissions are the environmental impacts.*" Replace "Carbon" with "GHG".	● (yellow)	Modified as recommended.	Satisfactory.
8	DO	2.2	Figure 2-1 is not introduced in prior text and requires better explanation.	● (yellow)	Figure 2-1 is now introduced and described.	Satisfactory.
9	PR	2.2	The scenarios should be better detailed in relation with Figure 2-1. The readers have difficulty to follow the reference scenario for each of the geographical contexts. Authors should provide background information for each geographical context (Quebec, USA, Sweden and Caribbean).	● (yellow)	Has been addressed as per question number 5.	Satisfactory.
10	PR	2.2: Figure 2-1	The defined system assumes that the LNG will replace different types of energy sources but doesn't evaluate what will happen to these replaced energy sources. Therefore, the authors inherently assume an ideal case scenario in which the displaced energy	● (yellow)	An attributional LCA has been performed, which assumes that the fuels being replaced will no longer be produced if there is no a demand for it. This is now stated in the report.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			sources will no longer be exploited afterwards. This should at least be 1) validated and 2) clearly mentioned in the report.			
11	DO	2.2	Define HHV. Throughout the report, define abbreviations when mentioned for the first time.	○ (yellow)	The acronyms in the report are now defined when first mentioned as well as in a Table of acronyms.	Satisfactory.
12	PR, BG	2.2	The authors must define "criteria air contaminants" (CAC). Furthermore, they should explain why they only evaluated the NOx, SOx and PM emissions since the Canadian government also considers the NH_3, VOC, CO and O_3 emissions in their CAC assessment. Evaluating a limited number of CAC emissions could be misleading if the omitted CACs contribute significantly to the impacts of the studied systems. The fact that these substances are being analyzed at the inventory level and not the impact level must also be addressed (see comment 49).	○ (yellow)	Due to time constraints, this part of the CAC component of the study was removed.	Satisfactory.
13	DO	2.2	Last paragraph of 2.2 – "environmental exchanges" – what is meant by exchanges? Suggest replacing exchanges. "Elementary flows" appears a more appropriate term.	● (grey)	The sentence has been re-worded to remove the term.	Satisfactory.
14	PR	2.2: Functional unit	Functional unit should explicitly state: (1) the quantification of the function; (2) the geographical context and (3) the timeframe. Points 2 and 3 are lacking in the functional unit	○ (yellow)	The definition in the report has been updated as follows: The functional unit used in this study to relate the performance of the product systems is defined as a gigajoule (GJ) of energy delivered to the end user (before combustion) for the generation of heat,	Satisfactory. The functional unit could be stated before Figure 2-1 instead of at the end the section.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
					electricity production or transportation in Quebec, the NE USA, Sweden and the Caribbean in 2017.	
15	PR	2.2: Functional unit	As presently formulated, the functional unit doesn't seem to consider the use phase. As it stands, we interpret the term "energy delivered" as the energy content delivered to the gate of the energy production system. It could also potentially mean that it is the energy delivered to an energy production system (heat or electricity generation). In either case, the functional unit should be better formulated. For example, it could be formulated as "the production of 1 GJ of energy and its use for the generation of heat, electricity production or transportation in either *[list of geographical context]* in 2017.	○	Yes, it is defined as the energy content delivered to the gate of the energy production system (before end use). The functional unit is defined in question no. 14 above.	Satisfactory.
16	PR, BG	2.2: Reference flow	Did the authors consider the efficiency of the different technologies for fuel combustion? For example, burners, engines or turbines using different fuels might not provide the same useful output (heat, electricity, power) with a given energy input. It should be specified whether or not this aspect was taken into account, and if not, justification should be provided. If yes, a discussion about the influence of varying technology efficiency on the results should be discussed in the report.	○	We have assumed the same efficiency for stationary combustion. The mobile combustion devices do take into account different efficiencies expected from the fuel/engine. This is now mentioned in the report. However, since the functional unit is based on the energy delivered to the user, before combustion, the efficiencies of the equipment and engines have no effect on the global results of the assessment. A sensitivity analysis was performed and presented in section 5.2.	Unsatisfactory. Energy conversion efficiencies should be presented as assumptions should be better referenced and should be the subject of a sensitivity analysis. Refer to the follow-up comment 63 for further details.

No.	Reviewer	Section	Panel comment	Authors answer	Panel answer
17	PR	2.2: Reference flow	The energy content of each fuel should be reported. Explain the rationale for using high heating value (HHV) and not the low heating value (LHV)?	Added to the report: • The HHV referenced in the Quebec air emission reporting regulation for diesel (also used for heating oil), HFO and LPG was used for the estimate of the volume of each fuel for the reference scenario. • All energy is expressed on a higher heating value (HHV) basis in this report since it is a measure used for the majority of commercial transactions in North America and it is the basis used for the reference to energy in the Quebec air emission reporting regulation	Satisfactory.
18	PR	2.2: Reference flow	The reference flows are misleading as they pertain to the entire system and not the different geographical context. The reader has no idea what fuel is being replaced in a certain scenario or how much of this fuel is being replaced with these reference flows. For example, the authors could provide the breakdown at Figure 2-1 both in percentages and volumes. Furthermore, comment 17 relating to efficiency and energy content should be taken into account when defining the reference flows, because 1GJ of LNG could not be equivalent to 1GJ of HFO, diesel, LPG or heating oil.	Volumes of the fuel distributed have been added to Figure 2-1. As mentioned in the answer to question no. 17, we have assumed the same efficiency for stationary combustion. The mobile combustion devices do take into account different efficiencies expected from the fuel/engine. Since the functional unit is based on the energy delivered to the end user, before combustion, the definitions of the reference flows are exact.	Satisfactory. Refer to the comment 63 for issues specific to energy conversion efficiencies.
19	PR	2.2: Reference	The authors should define ULSD (ultra low sulfur diesel).	All references to ULSD have been replaced with heating oil in the report.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
		flow	Why is ULSD not included as a product in Table 2-2? Why is ULSD not reported elsewhere in the report? Is it in fact the "*heating oil production*"?		Heating oil has been added to Table 2-2.	
20	DO	2.2.1	Last sentence before figure. Replace Figure 2-1 – with Figure 2-2	○	This correction has been made in the report.	Satisfactory.
21	PR	2.2.1	"*where equivalent*" should be corrected to "*were equivalent*"	○	The correct term is 'where equivalent' since these are not equivalent for all scenarios. For instance, the inland distances are not the same for the delivery of LNG to NE USA and heating oil to NE USA.	Satisfactory. We suggest that commas be added for clarity: *"inland transportation, where equivalent […], have also been excluded".*
22	BG	2.2.1	*"Emissions from the construction of infrastructure, exploration, site preparation, site closure, and remediation are excluded".* Does this apply to natural gas production? It has been documented that those life cycle stages can have significant impacts for shale gas production. For example, refer to "Methane Leaks from North American Natural Gas Systems" by Brandt *et al.* in *Science* (vol. 343). Clarify to which processes in the product system this exclusion applies.	○	Emissions from the construction of infrastructure, exploration, site preparation, site closure, and remediation are excluded for both scenarios. Methane leaks from well drilling are included since this is part of the US EPA inventory.	Satisfactory. Refer to the follow-up comment 77 for the uncertainty around methane emissions from natural gas extraction and processing.
23	PR, BG	2.2.1	*"Inland transportation where equivalent in both the project and the reference scenario has also been excluded".* This hypothesis is erroneous as it could only be right if: (1) the distances; and (2) the transported fuels weighted the same; and (3) both origin and destinations are exactly the same. An unlikely outcome	○	Inland transportation is considered equivalent in the assessment for those paths where the distance travelled and points of origin and destination in both the project and the reference scenario are identical. Although the energy density differs	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			considering the differences in the nature of the fuels (and therefore their density). In comparative assessments, only flows which are exactly identical from one product system to another can be excluded. The model should include inland transportation, unless flows can be proven to be exactly identical.		between the LNG and other fuels, LNG has a higher energy density and thus the assessment provides conservative results.	
24	PR	2.2.1	The authors should provide a rationale for the selection of the geographical context referred to in Figure 2-2 (also see comments 5 and 19). As the report lacks information, the readers do not know if this geographical context is relevant.	●	The selection of the locations, equipment use and fuels to be replaced is based on an extensive market analysis as well as an independent market study by a reputable consulting firm in Canada. This work was mandated by SLNGaz and includes information of sensitive nature; therefore, the precise users and locations cannot be disclosed. However, the report now includes a rationale based on publicly available information.	Satisfactory.
25	PR	2.2.1	The authors included the "*heating oil production*" in the system boundaries (Figure 2-2)? Why is it not mentioned in most places where alternative fuels are enumerated (e.g. section 2.2 and Table 2-2)? The description of alternative fuels should be consistent throughout the report.	●	The heating oil used is designated as ULSD. This section has been updated to be more consistent.	Satisfactory.
26	PR, DO	2.2.1	Do emissions in the "end of life" stage correspond to combustion emissions? These emissions should actually be considered in the "*use phase*". While the authors state that their study is "cradle to grave", it is erroneous as no end of life processes (e.g. disposition of	●	Emissions for the combustion stage are included in the USE stage. The study is cradle-to-grave, from well head to fuel use. The product end of life being the usage of the fuel.	Satisfactory.

No.	Reviewer	Section	Panel comment	Authors answer	Panel answer
			residues from crude oil refining, dismantling of equipment used for fuel combustion at the end of their service life) are considered. It is more of a cradle to end of pipe assessment, as the last life cycle stage included in the assessment is the combustion of fuels.		
27	DO	2.2.1	Major energy inputs and co-products could be included at each stage in the Figure 2-2.	Energy inputs are added to Figure 2-2.	Satisfactory.
28	BG	2.2.1	As mentioned further in the report by the authors, US shale gas already represents a significant fraction of natural gas imported in Quebec and this fraction is expected to increase in the future. The authors should justify in the report why they consider in their most plausible scenario that 100% of the natural gas comes from Western Canada.	Data were not available as to the projected origins of the supply of natural gas to the Bécancour LNG plant. The project considers that 100% of the natural gas comes from Western Canada. This has historically been the case for natural gas supply into Quebec; however, recently some US natural gas has been supplied to this market. A sensitivity analysis was performed to show that the origin whether it be from Canada, the US or a combination, has little effect on the emissions, as shown in section 5.2.1.	Satisfactory. The review panel is still not comfortable with the definition of a default scenario for 2017 where 100% of the natural gas comes from Western Canada. However, as the sensitivity analysis performed in section 5.2.1 shows that the natural gas origin has a small influence on the results, no further action is required.
29	BG	2.2.1	References must be provided to support the different values presented in Table 2-3.	References will be added.	Satisfactory. Specify whether or not there are still references missing in the current version of the report, as the answer is not clear.
30	DO	2.2.1	Table 2-3 – Under Description it states that "*Extraction and processing includes all major energy and electricity flows.*" Identifying and defining these processes	Additional details were provided.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			and flows would help the reader to better understand which processes are specifically included.			
31	DO	2.2.1	Table 2-3 – Under Crude oil extraction, based on IEA data, Russia should be forecasted to supply Europe with crude. Also, for NE USA, the US should be forecasted to supply more crude than 8%. Authors should provide the data sources used for these breakdowns and explain (when relevant) how historical data was adjusted for future projections.		For Europe the model was calibrated to provide results similar to the results of the European Commission. Data sources have been included in the report.	Unsatisfactory. Additional details should be provided for crude oil origin in Europe and the calibration of the GHGenius model for this region. Assumptions around projected 2017 crude oil origin should also be stated. Refer to the follow-up comment 66 for further details.
32	PR	2.2.3	The authors use the expression "*Western Canadian tar sands*". However, the expression "oil sands" would be more appropriate.		The expression has been modified as recommended.	Satisfactory.
33	PR	2.2.3	We do not see how the oil sands can generate electricity as a co-product. Please clarify. This could occur if the oil sands operators are using cogeneration units. But this should be specified if this is indeed the case.		Co-generation units are used in the oil sands. However, the primary co-products are LPG and petroleum coke.	Satisfactory.
34	PR, BG	2.2.3	"*The allocation method considered by the model is that of displacement*". This term is not aligned with the ISO 14044 standard. Did the authors mean system expansion? In any case, the "allocation approach" section should describe in much more details what was actually done. For example, the list of co-products, the relative proportion in which they are		System expansion is the ISO 14044 term for displacement. Displacement has been modified to expansion in the report. The "allocation approach" section has been expanded in the report.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			produced and the substituted product for each co-product.			
35	PR, DO	2.2.3	What is the authors' approach considering the allocation of impacts from the crude oil refining process and the LNG process, as these processes generate several co-products? This should be described in the "Allocation approach" section.		The "allocation approach" section has been expanded in the report.	Satisfactory. The difference between allocation based on estimated process energy used and allocation based on the energy content of fuels should be explained.
36	BG	2.2.3	A sensitivity analysis should be performed on the procedures chosen to allocate impacts from upgrading bitumen from oil sands and refining crude oil, namely to include allocation based on the energy content of co-products.		LPG and marketed petroleum coke account for only 4% of the production from upgraders. Alternative allocation approaches will have minimal impacts on the results. Alternative refinery allocation approaches are investigated in the report.	Satisfactory. Authors should mention in the report that LPG and marketed petroleum coke account for only 4% of the production from upgraders and specify whether this is expressed on a mass or energy basis.
37	DO	2.2.4	2nd sentence – requires further explanation. The land use change associated with which process results in "*soil carbon loss from peat soils disturbance*". 3rd sentence – Unnecessary or requires further explanation to be relevant. 4th sentence – How do land use change and co-product emission credit offset each other? We do not see how these two elements are related. The authors should justify this offset.		2nd sentence: Deforestation and removal of the overburden. 3rd sentence has been removed. One is a positive impact and one is a negative impact. The emissions are small and are not material.	Satisfactory. Authors should provide the magnitude of emissions from land use change ($kgCO_2/GJ$) so that the reader can understand that they represent a small contribution to the overall results.
38	PR, BG	3.1.1: Table 3-1	The authors rely heavily on the GHGenius model. However, the authors do not describe this model, the databases that it uses or its validity, credibility and accuracy.		A new section 3.1.1 dedicated to describing the model has been added to the report.	Satisfactory. However, the following sentence in section 2.2 is not accurate: "the GHGenius model from Natural

No.	Reviewer	Section	Panel comment	Authors answer	Panel answer
			The data sources on which GHGenius relies must be specified, as they can be of different quality for different fuels and geographical context even for the same life cycle stage. For primary data, sources should also be provided. For example, how were emissions from the projected liquefaction plant in Bécancour evaluated and how do they compare to other plants?	Emissions from the Bécancour LNG plant were obtained from the EIA study that was mandated by SLNGaz to SNC-Lavalin.	Resources Canada." Natural Resources Canada does not own GHGenius. Authors could rather refer to the "Canadian LCA model, GHGenius."
39	BG, DO	3.1.2	The improvements made on data quality should be clearly related to the product systems under study or the processes contributing most to environmental impacts. For example, much of the first half of this section describes data improvements and model updates that seem to have no implications on this study. All model changes that do not impact the current study should be removed: • Point 2 in the first list on GWP factors • Second list (points 1 – 4) referring to changes to the model that have no impact on pathway results. Those comments do not relate directly to the study nor help the reader understand the current goal of study.	This section has been updated to include only the relevant information.	Satisfactory.
40	BG, DO	3.1.2	Different crude receipt scenarios at the refinery should be taken into account. Quebec refineries currently import significant quantities of U.S. crude oil. This should be reflected in the sources of	The assessment is based on 2017. Enbridge Line 9 will be in operation by then.	Satisfactory.

No.	Reviewer	Section	Panel comment	Authors answer	Panel answer
			crude oil, as the start-up of the Enbridge Line 9 pipeline has been delayed.		
41	DO	3.1.2	Figure 3-1 is not clear. Is it supposed to represent the total refining capacity for Central Canada? (approx. 800,000 bbl/d). Authors could provide additional explanations on the content of Figure 3-1.	This figure is not very clear and has been removed.	Satisfactory.
42	BG, DO	3.1.2: Figure 3-2	Figure 3-2 is in fact a Table. Furthermore, the reference should be provided for values appearing in the Table. For example, in 2011, according to the IEA, Sweden imported 50% of its crude oil from Russia.	"Figure" has been modified for "Table". The model has been calibrated for the latest EU estimates.	Satisfactory.
43	DO	3.1.2	Figure 3-3 should be labeled as a Table.	Corrected in report.	Satisfactory.
44	PR	3.1.3: Table 3.2	Why not also report the most recent GWP from the 5th IPCC report whose values are also included in the GHGenius model as mentioned previously in the report?	For this study, the Global Warming impact category was assessed using the Second Assessment Report (SAR) (IPCC,1996) values included into the Kyoto Protocol and are those currently in use in the Province of Quebec. A sensitivity study was done in order to measure the influence of the global warming potential (GWP100) choice (see Section 5.1) in comparison to the IPCC Fourth Assessment Report (AR4). The GWP values presented in the 5th IPCC report are not commonly used yet.	Satisfactory. Table 3-3 is referred to as Table 3-2 in the text beforehand. Change for Table 3-3.
45	PR	3.1.3	The authors state that the "*Sensitivity study was done in order to measure the influence of the global warming potential (GWP100) choice*". The authors should clearly state which GWP were used in their sensitivity study.	Now more clearly defined in the report.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
46	DO	3 (General)	For those unfamiliar with GHGenius, this section may be difficult to follow as the reader is left to make assumptions regarding details of the model. For example, which provinces does the Central Canada include? Which PADD does the US Central region represent? Some definitions, explanations and background should be provided to help the reader better understand GHGenius.	● (yellow)	A new section 3.1.1 dedicated to describing the model has been added to the report.	Satisfactory.
47	DO	4 (General)	Some graphs could be useful for displaying the results versus tables.	● (grey)	Graphs are no longer necessary with the reduction in scope of the study.	Satisfactory.
48	PR	4: Table 4.1	The results are presented according to a GJ of energy delivered. According to the ISO 14044 standard, results should be presented according to the functional unit (which should be redefined following comments 14 and 15).	● (yellow)	Results are presented according to the functional unit of 1 GJ energy delivered (before combustion).	Satisfactory.
49	PR, BG	4: Table 4.1	The authors provide the inventory results of GHG and CAC emissions. While the impacts of GHG emissions are in fact evaluated at the midpoint level, SOx, NOx and PM emissions are truly presented and discussed as an inventory result. However, according to the ISO 14044 standard (section 4.2.3.7) “A life cycle impact assessment shall be performed for studies intended to be used in comparative assertions intended to be disclosed to the public”. Hence, the authors cannot only present the results from a life cycle inventory but should also provide an evaluation of the potential impacts related to this inventory	● (yellow)	Due to time constraints, this part of the CAC component of the study was removed.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			on relevant impact categories (e.g. respiratory effects, acidification and eutrophication). The authors should either perform an impact evaluation or remove the CAC "evaluation" from their report.			
50	DO	4 (General)	What contribution do methane emissions have for the LNG pathway throughout the life cycle stages for GHG emissions? Are venting emissions significant in this pathway?	● (grey)	Methane emissions for the project have been added to Table 4-1.	Satisfactory.
51	PR, DO, BG	4 (General)	Interpretation of results is lacking from the report. There is no analysis of the contribution of the different processes and no explanation of the results, the authors preferring the use of generic sentences such as: *"For the CACs, the contribution of each stage varies significantly"* Authors should provide a more complete interpretation of results and include elements listed in ISO 14044, section 4.5.1.1, such as the identification of significant contribution by life cycle stages. For example, the breakdown of the GHG emissions for the Acquisition and Production stages could be provided for the different pathways.	● (yellow)	The CACs have been removed from the report. The results are presented per life cycle stage in Tables 4-2 and 4-3.	Satisfactory.
52	PR	4: after Table 4.3	"*the majority of carbon emissions occur in the use stage*". However, according to your system boundaries (in which the emissions from the combustion occurs in	● (yellow)	The USE stage is where combustion occurs. The study is cradle-to-grave, from well head to fuel use. The product end of life being the usage of the fuel.	Satisfactory. However, a word seems to be missing from the last sentence following Table

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			the end of life), one should actually expect that most GHG emissions occur at the “end of life” phase. Furthermore, there is no end of life stage listed in the provided results. Authors should present life cycle stages in a coherent manner throughout the report.		Clarifications were added to the report.	4-5.
53	PR, DO, BG	5.1	The authors state that “As shown in Section 3, the data quality used for the activity data and emission factors present no real issues”. The authors should be careful in their formulation as no content provided in Section 3 which allows readers to come to this conclusion. Data quality for top contributing processes is not assessed against criteria suggested in the ISO 14044 standard (e.g. time, geographical coverage, technology coverage, precision, completeness, consistency). Secondly, this is surprising considering that the study heavily relies on the GHGenius model which compiles industry data. Therefore, there should, at the very least, be some sort of variability pertaining to the specific activities of the compiled data; a variability which should become apparent once you make a Monte Carlo analysis. However, there is a lack of evidence that such an analysis was performed in the report. Authors should perform the required data		We have added a description of the GHG model in section 3. Data sources and characteristics against the criteria have been added to the report.	Unsatisfactory In addition to high level discussions on the entire GHGenius model, data quality should be discussed for top contributing processes. Refer to the follow-up comment 75 for further details.

No.	Reviewer	Section	Panel comment	Authors answer	Panel answer
			quality assessment and checks suggested in the ISO 14044 standard and report their findings in the report to justify their conclusions on data quality.		
54	PR, DO, BG	5.2	As the report does not provide a contribution analysis, the reader doesn't know whether the scenario analysis performed are relevant and focus on top contributing processes or key parameters. Authors should explain on what basis the 2 sensitivity analyses included in the report were defined and selected. While varying the natural gas supply appears relevant, the selection of this control case seems random. Were other cases considered, such as a different crude oil slate? Knowing that the combustion phase is where most of the GHG emissions occur, scenarios analysis should also target the processes in this phase. It may have been more appropriate to consider, as an alternative scenario, varying combustion efficiency rates.	We have expanded on the reasons for the choices of the sensitivity analyses in section 5.2. The NG analyses were performed since an estimate of the break-up of the supply to Bécancour for 2017 is not known. The analysis with respect to emissions control in ferries was chosen since the assessment was made under the assumption that ferries were equipped with emissions controls and we want to show that there is little impact on the results should the ferries have no emissions control. Since the functional unit is based on the energy delivered to the user, before combustion, the efficiencies of the equipment and engines have no effect on the global results of the assessment.	Unsatisfactory. Sensitivity analysis is still lacking for the top contributing process (combustion of fuels) and uncertain processes (e.g. methane emissions associated with natural gas extraction). Refer to the follow-up comment 77 for further details.
55	PR	5.2	The authors use a scenario in which gas supply comes from 100% US shale gas; an unlikely scenario as the US main gas production still comes from conventional wells. While shale gas' proportion is	Any reference to shale gas has been removed from the report.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			currently around 17% of the total US natural gas production and that this percentage will increase in the coming years, this hypothesis does not seem appropriate considering the study's timeframe. Furthermore, how can the authors be sure that the distribution will only provide natural gas from shale gas? Once in the distribution network, it is impossible to distinguish conventional from unconventional natural gas. Authors should provide the rationale supporting the selection of the natural gas supply scenarios.			
56	DO	5.2.1	Table 5-2 and analysis of results from this Table – The results presented in the Table show a decrease in GHG emissions, not an increase as stated. The 2% and 4% numbers are incorrect. Also, the results represent which stage of the life cycle?		There was a typo in the GHG emissions for 100% Western Canada. Now the information is consistent.	Satisfactory. The values in Table 5-2 appear to be provided in kg/GJ and not in g/GJ. Correct the units if necessary.
57	DO	5.2.2	How were methane emission controls in ferries modeled in GHGenius? Also, specify to which life cycle stage those emissions contribute.		It was assumed that the same emission reduction efficiency that is found in NG truck engines compared to diesel engines applies to ferries. These emissions contribute to the USE phase.	Unsatisfactory. Refer to comment 63 for the additional content to be provided for energy conversion efficiencies.
58	PR, DO	5.3	This section is over-simplified. The model itself has a certain degree of uncertainty. Authors only state that *"The use of one model for the analysis of the complete two systems reduces bias through the use of consistent data sets*		This section has been expanded in the report.	Discussion on the overall credibility of the GHGenius model is satisfactory. However, refer to comment 75 for the additional content to be provided on process specific data quality

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			and approaches." This claim does not appear justified as good input data or approaches provided to an inadequate model are not likely to provide high-quality results. As there is no evaluation of the credibility of the GHGenius in the report, the uninformed reader is not able to evaluate the quality of the model.			assessment.
59	PR, BG	6	The review panel needs to be listed in the final report.	● (yellow)	Listed in final report.	Satisfactory.
60	PR, DO, BG	References	A reference section needs to be added at the end of the report and appropriate citations need to be added throughout the text.	● (yellow)	A reference section has been added.	Satisfactory.
61	PR, BG	General	Use of the formulation "environmental parameter" should be modified to be aligned with the ISO 14044 standard. For example by using "substance", "emission" or "impact category". This would better reflect the fact that different substances or emissions can contribute to the same impact category and that multiple impact categories can be taken into account.	● (grey)	The tern 'environmental parameter' has been revised as recommended.	Satisfactory.
62	BG	2.2	Provide additional context on the context of Quebec's cap-and-trade (e.g. the fact that it came into effect in 2013 for industrial sites exceeding emissions of 25ktCO_2e per year, that free allowances from the government will decrease progressively, etc.)	● (grey)	We have added some context as recommended.	Satisfactory.
63	PR, BG	2.2	Authors state that the efficiency doesn't change between systems, which is an	● (yellow)	We have taken a conservative approach in assuming that the equipment will not	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			assumption and should be presented as such. As different efficiencies could be taken into account, it shouldn't be stated that they have no effect on the results, but rather that the influence is considered small. The magnitude of the impact this assumption has on the result should be documented through a sensitivity analysis, namely because fuel combustion is the top contributing process (see comment 77). The authors should also indicate the value used for conversion efficiency used for each technology and provide references supporting their assumptions.		be replaced with newer and more efficient equipment upon changing fuels. It is unlikely that the efficiency of equipment will be reduced with the change of fuel to LNG. It should be noted that since we assumed that the efficiencies of the equipment remained the same and therefore the energy delivered to the user (pre-combustion) is identical between fuels, the results in kg/GJ **delivered** is not affected by the efficiency selected for the equipment. Precisions to the assumptions made have been added to section 2.2 of the report.	
64	BG	2.2	Explain what is a "train" and under what circumstances would one train or two trains be in operation. A short description and a figure describing the liquefaction process could be taken from the environmental impact assessment report to increase understandability.	●	A description has been added to a new section 1.1.	Satisfactory.
65	PR	2.2.1: Figure 2-2	The color-coded figure's legend should clearly state that it applies to the data source (i.e. data comes from either/or GHGenius and SNC or its client).	●	The legend has been modified as recommended.	Satisfactory.
66	BG, PR	2.2.1: Table 2-3	Since relative shares and references for crude oil origin were provided for Canada, the Caribbean and NE USA, they should also be provided for Europe.	●	The source of crude oil is not relevant for Europe as the model was calibrated to provide emissions similar to the EU Fuel Quality Directive.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			Explicitly state that the projected 2017 crude oil sourcing in Europe, the Caribbean and NE USA is expected to be similar as sourcing in 2011. Discuss why this assumption is realistic and, if relevant, explain the influence of this assumption on the results. Finally, provide further details on how the GHGenius model was calibrated to provide values similar to those found in the EU Fuel Quality Directive.		The GHGenius model was calibrated by adjusting parameters to output emissions similar to the EU Fuel Quality Directive.	
67	BG	2.2.1: Table 2-3	Further explain the sentence "no regasification energy considered for the project since residual heat of the power plant will be used."		Power plants have a low efficiency and generate considerable amount of waste heat which is used for regasification rather than burn some NG to supply this energy**.** This description has been added in Table 2-3.	Satisfactory.
68	BG	2.2.6	Define LCIA.		The term has been defined and added to the table of acronyms.	Satisfactory.
69	PR	2.2.6	While already mentioned at several occasions, it should be mentioned again in section 2.2.6 that environmental assessment is limited to GHG emissions		It has been added to section 2.2.6.	Satisfactory.
70	BG	3.1.1	Define PADD.		The term has been defined in the text.	Satisfactory.
71	BG	3.1.2	Emission factors for inputs, combustion or industrial processes are likely taken from sources rather than being directly measured for the GHGenius model. Provide additional detail on those sources, for example in the case the same sources apply for activity data and emissions factors.		Additional detail has been added to Table 3-1.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
72	BG	3.1.2: Table 3-1	References mentioned in the Table are not found in the references section. Either add the references or indicate where they can be found in the GHGenius documentation.	○ (yellow)	Most of the emission factors can be found in chapters 43 and 46 of Volume 2 of the GHGenius manual. This indication has been added to the report.	Satisfactory.
73	PR	Table 3-2	Table 3-2 states the results are in LHV while it was mentioned that the study uses HHV for all calculations. Values should be converted to HHV to help the reader compare them with the other results in the report.	● (grey)	The values have been converted.	Satisfactory.
74	PR	Table 5-1	It is probably a rounding issue, but 88 minus 65 doesn't equal 24. Authors could present the values under a different format (add a decimal).	○ (yellow)	A decimal has been added.	Satisfactory.
75	PR, DO, BG	5.1	The information provided in section 3.1.3 does not constitute an explicit data quality assessment for top contributing processes against criteria commonly used (e.g. time, geographical coverage, technology coverage, precision, completeness, consistency). Hence, it is currently difficult to evaluate if data quality for those processes is satisfactory for all criteria and to what extent it varies from one system to another. A qualitative data quality assessment for top contributing processes should be performed, for example following the guidelines in the *GHG Protocol Product Standard* which include 5 data quality indicators evaluated on a 4 level scale).	○ (yellow)	A qualitative data analysis has been added to section 3.1.3.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
76	PR	Section 5.1 Parameter uncertainty	The new parameter uncertainty section doesn't include a Monte Carlo analysis related to GHGenius data inherent variability. In the event such an assessment cannot be performed for the current study, reasons should be mentioned.		We have chosen to undertake sensitivity analysis on several items individually rather than looking at them in combination (Monte Carlo). We think that this provides more useful information.	Satisfactory. However, the review committee would have considered it preferable to perform a Monte Carlo analysis, since the GHGenius model has this functionality. This would have provided insight on the overall level of uncertainty for both scenarios, in addition to the sensitivity analysis provided.
77	PR, DO, BG	5.2	Stating that the systems have the same efficiencies, in a baseline scenario, is acceptable to the extent the assumption can be supported by references. However, it is impossible to understand the influence of this parameter on the results and conclusions. Hence, as fuel combustion is the top contribution process for both systems, the initial assumptions on energy conversion efficiencies should be tested in a sensitivity analysis. For the same reason, there should also be a sensitivity analysis on combustion emissions factors, as they can vary from one source to another (Quebec MDDELCC, USEPA, EU) or one technology to another (e.g. boiler, steam generator). Natural gas extraction and processing is also one of the top contributing process		We are not expecting the users to change their devices. The effect of equipment efficiencies has been discussed in comment # 63. Any variation in emission factors for the final combustion from one source to another has a very minor impact on the results. A sensitivity analysis has been done for NG leaks and is presented in section 5.2.3.	Satisfactory.

No.	Reviewer	Section	Panel comment		Authors answer	Panel answer
			for which emissions are uncertain. Authors should discuss how the value found in GHGenius (7.3 $kgCO_2/GJ$), compares to other estimates in the literature, for example in Skone et al. (2011) (between 8 and 11 $kgCO_2e/GJ$). A sensitivity analysis should be performed on this parameter. This is justified by the fact that the emission factor from the USEPA appears to understate total emissions for natural gas systems, as discussed in Brandt et al. (2014).			
78	DO	Appendix A	Total numbers in 2014 and 2017 columns do not add up properly. Also make sure that all values are presented under the same format.		The numbers have been corrected.	Satisfactory.
79	BG	Appendix B	Provide the references consulted for the calculation of regional grid mixes.		References have been provided.	Satisfactory.
80	BG	Appendix C	Appendix C could simply be titled “Critical review report”.		Modified as recommended.	Satisfactory.

3. Consistency with ISO 14044 standard and ISO 14067 technical specification

Legend : ☒ Requirement met ⧅ Requirement partially met ☐ Unmet requirement ⬚ Requirement not applicable

Notes: The initial assessment is provided in the requirement column. The final assessment, taking into account the authors answers, is provided in the column Panel answer. Requirements from the ISO 14044 standard, except those in *italic*, taken from the ISO 14067 technical specification.

Requirement		Section	Panel comment	Authors answer	Panel answer	
General aspects						
☒	LCA commissioner, practitioner of LCA (internal or external)					
☒	Date of report					
☒	Statement that the study has been conducted according to the requirements of relevant standards	Introduction				
☒	Reasons for carrying out the study	2.1				
☒	Its intended applications	2.1				
☒	The target audiences	2.1				
☒	Statement as to whether the study intends to support comparative assertions intended to be disclosed to the public	2.1				
Scope of the study						
⧅	Function, including: • statement of performance characteristics • any omission of additional functions in comparisons	Section 2.2	The primary function was stated. Additional functions or lack thereof are not reported.	Added to section 2.2 of the report.	☒	Satisfactory.
⧅	Functional unit, including: • consistency with goal and scope • definition	Section 2.2	The functional unit needs to be reviewed. See comments 14-15.	The definition in the report has been updated as follows: The functional unit used in this	☒	Satisfactory.

Requirement	Section	Panel comment	Authors answer	Panel answer
• result of performance measurement			study to relate the performance of the product systems is defined as a gigajoule (GJ) of energy delivered to the end user (before combustion) for the generation of heat, electricity production or transportation in Quebec, the NE USA, Sweden and the Caribbean in 2017.	
☒ System boundary, including: • omissions of life cycle stages, processes or data needs. • quantification of energy and material inputs and outputs. • assumptions about electricity production.	2.2, 2.2.1	Scenario description lacks clarity; • Omissions about certain life cycle stage or processes need clarification in most cases and/or correction since omission is based on erroneous assumptions. • The assumption about electricity production is lacking. Specify if the grid mix has been adjusted to the geographical context. For Quebec, report the grid mix used.	Clarifications have been added to section 2.2.1 of the report.	☒ Satisfactory.
☐ Cut-off criteria for initial inclusion of inputs and output, including: • description of cut-off criteria and assumptions • effect of selection on results • inclusion of mass, energy and environmental cut-off criteria		This aspect is lacking from the report.	Added to section 2.2.1 of the report.	☒ Satisfactory.

Requirement		Section	Panel comment	Authors answer	Panel answer	
Life cycle inventory analysis						
☐	Data collection procedures		Authors state that the inventory data comes from the model but give no information about how the model's data was gathered.	A description of the model and its data sources has been included in the report.	☒	Satisfactory.
☒	Qualitative and quantitative description of unit processes		The qualitative description of unit processes should be refined (see comments 29 to 31). No quantitative description of unit processes (inputs and outputs) is provided.	See table 2-3 and figure 2-1, both have been revised.	☒	Satisfactory.
☐	Sources of published literature		Multiple comments in the previous section point out the fact that data sources need to be provided. • Most data sources are secondary sources – GHGenius and the Impact Study. Provide primary data sources within these secondary sources to show greater transparency. For example, GHGenius uses data from CAPP, Alberta Energy Regulator, etc. • Nowhere is it mentioned why GHGenius is selected as the LCA model. Authors should provide a reason for choice of model as many other LCA models exist.	Data sources have been added to the report and the GHGenius model has been described. Since the study was to compare fuels and GHGenius is based on North American data, GHGenius was the appropriate model to use.	☒	Satisfactory.

Requirement		Section	Panel comment	Authors answer	Panel answer	
☒	Calculation procedures	3.1.4	This section lacks details. Greater detail on how GHGenius computes the data would be beneficial. One cannot discern from the explanation provided if GHGenius accurately estimates GHG emissions for the fuel pathways selected. Furthermore, as the results are not presented according to the functional unit, it would seem that the authors did not do what they intended to do.	Detail has been added on the GHG model. There was some confusion as to the definition of the functional unit. This has been redefined in the report.	☒	Satisfactory.
☐	Validation of data, including • data quality assessment • treatment of missing data	3.1.2	Almost absent. The changes performed to the GHGenius model appear irrelevant for the current study (see comment 39). Overall, the precision, completeness and representativeness of the data and underlying model are not detailed (see comments 38 and 53). For example, indicate the age of the data (if data is outdated this could impact results).	We have added a description of the GHG model in section 3. Data sources and characteristics against the criteria have been added to the report.	☒	Satisfactory.
☐	Sensitivity analysis for refining the system boundary		Performed sensitivity analysis aren't clearly defined and the reader doesn't know if these sensitivity analysis are relevant (see comment 54).	The NG analyses were performed since an estimate of the break-up of the supply to Bécancour for 2017 is not known. The analysis with respect to	☒	Satisfactory.

Requirement		Section	Panel comment	Authors answer	Panel answer	
				emissions control in ferries was chosen since the assessment made the hypothesis that ferries were equipped with emissions controls and we want to show that there is little impact on the results should the ferries have no emissions control. The sensitivity analysis now also includes modeling the 2014 crude oil mix.		
☐	Allocation principles and procedures, including • documentation and justification of allocation procedures • uniform application of allocation procedures	2.2.3	Allocation principles and procedures should be detailed, documented and justified (see comment 35). Furthermore, the application of the allocation procedures isn't clearly described. For example, users do have the option of changing the allocation method within GHGenius however this point is not discussed. The choice of allocation method can have significant impact on results as has been shown in other LCA studies. More discussion should be included and justification as to why the system expansion method was selected versus allocation by energy, mass or economic.	Allocation approaches for refining emissions have been discussed in the model. Alternative approaches are investigated. Allocation is generally not required in the natural gas system.	☒	Satisfactory.

	Requirement	Section	Panel comment	Authors answer		Panel answer
Life cycle impact assessment						
⍁	The LCIA procedures, calculations and results of the study, including: • *GHG emissions and removals by life cycle stage (absolute and relative contribution;* • *Fossil GHG emissions and removals;* • *Biogenic GHG emissions and removals;* • *Land use change GHG emissions, if quantified;* • *GHG emissions from aircraft transportation, if significant;*	4	Results for GHGs should be presented according to the breakdown required in the ISO 14067 Technical Specification.	Results for GHGs have been added to Table 4-1. The absolute and relative contributions of GHG emissions by life cycle stage are presented in Table 4-2. Biogenic and land use change GHG emissions are considered insignificant. There is no aircraft transportation in the study scenarios.	☒	Satisfactory.
☐	Limitations of the LCIA results relative to the defined goal and scope of the LCA		Absent	More details have been added to section 2.2.6.	☒	Satisfactory.
⍁	The relationship of LCIA results to the defined goal and scope	Section 3.1.3 Section 4	Results are not presented in relation to the functional unit (see comment 48).	The functional unit has been more clearly defined. The definition in the report has been updated as follows: The functional unit used in this study to relate the performance of the product systems is defined as a gigajoule (GJ) of energy delivered to the end user (before combustion) for the generation of heat, electricity production or transportation in Quebec, the NE USA, Sweden and the Caribbean in 2017.	☒	Satisfactory.

Requirement		Section	Panel comment	Authors answer	Panel answer	
⧅	The relationship of the LCIA results to the LCI results	Section 3.1.3 Section 4	Results are not presented in relation to the functional unit (see comment 48).	Same as above.	☒	Satisfactory.
⧅	Impact categories and category indicators considered, including a rationale for their selection and a reference to their source	3.1.3	Only impacts on global warming are clearly linked to an impact category (see comment 49).	A life cycle assessment impact section (2.2.5) has been added to the report. Due to time constraints, this part of the CAC component of the study was removed.	☒	Satisfactory.
⧅	Descriptions of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations	3.1.3	Only impacts on global warming are clearly linked to an impact category (see comment 49).	Due to time constraints, this part of the CAC component of the study was removed.	☒	Satisfactory.
☐	Descriptions of or reference to all value-choices used in relation to impact categories		Absent.	The choice of the IPCC GWP selected for the assessment is defined in section 3.1.4. Section 2.2.5 on impact categories was added.	☒	Satisfactory.
☐	A statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks		Absent.	Added in section 2.2.6	☒	Satisfactory.
☐	*A statement that the carbon footprint only addresses the single impact category of climate change and does not assess other potential social, economic and environmental impacts arising from the provision of a product.*		Absent. Include if the assessment is in fact a carbon footprint (limited to the climate change impact category).	Added to section 2.2.5	☒	Satisfactory.

Requirement		Section	Panel comment	Authors answer	Panel answer	
Life cycle interpretation						
⧄	The results	Section 4	Only impacts on global warming are clearly linked to an impact category (see comment 49).	Due to time constraints, this part of the CAC component of the study was removed.	☒	Satisfactory.
☐	Assumptions and limitations associated with the interpretation of results, both methodology and data related	Section 4	Mostly absent (see comments made for Section 4 of the report).	The comments addressing section 4 of the report have been reviewed as documented in response to the comments.	☒	Satisfactory.
☐	Data quality assessment	Section 4	Mostly absent (see comment 53).	We have added a description of the GHG model in section 3. Data sources and characteristics against the criteria have been added to the report.	☒	Satisfactory.
☐	Full transparency in terms of value-choices, rationales and expert judgements	Section 4	Transparency is an issue throughout the report.	The report has been reviewed and descriptions and explanations to the choices made have been added.	☒	Satisfactory.
Critical review						
⬚	Name and affiliation of reviewers		Not applicable for the preliminary report. Needs to be added to the final report.	Added to revised report.	☒	Satisfactory.
⬚	Critical review reports		Not applicable for the preliminary report. Needs to be added to the final report.	Added to final report.	☒	Satisfactory.
⬚	Responses to recommendations		Not applicable for the preliminary report. Needs to be added to the final report.	Added to final report.	☒	Satisfactory.
Further reporting requirements for comparative assertion intended to be disclosed to the public						
☐	Analysis of material and energy flows to justify their inclusion or exclusion		Absent (see comments 22 and 23).	Clarifications have been added to the report in response to	☒	Satisfactory.

Requirement		Section	Panel comment	Authors answer	Panel answer	
				comments 22 and 23.		
☐	Assessment of the precision, completeness and representativeness of data used		Absent (see comment 53).	A discussion has been included in response to comment 53.	☒	Satisfactory.
☐	Description of the equivalence of the systems being compared in accordance with 4.2.3.7		Absent. The efficiency of the different systems should be discussed and taken into account if needed (see comment 17).	A description has been added. Since the functional unit is based on the energy delivered to the user, before combustion, the efficiencies of the equipment and engines have no effect on the global results of the assessment.	☒	Satisfactory. Limitations associated with the assumptions made regarding efficiency of natural gas and diesel or HFO systems have been acknowledged by the authors.
☒	Description of the critical review process	Section 6	Could be improved to include a description of the different steps and their timing.	A description of the different steps and timing has been added.	☒	Satisfactory.
☐	An evaluation of the completeness of the LCIA		Absent.	Clarity provided in section 2.2.6	☒	Satisfactory.
☐	A statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use		Absent.	Added in section 2.2.5	☒	Satisfactory.
☐	An explanation for the scientific and technical validity and environmental relevance of the category		Absent.	Added to section 2.2.5	☒	Satisfactory.
☒	Indicators used in the study	Section 3.1.3	Present but should have been better defined as isn't clear which GWPs have been used for the default scenario (IPCC, 1996 or IPCC, 2007). Furthermore, section 3.1.3 isn't coherent with the fact that GHGenius includes	The identification of the GWPs used was defined in section 3.1.4 (previously 3.1.3) in the following sentence: *The factors are periodically revised within the scope of the IPCC Assessment Report. For this*	☒	Satisfactory.

	Requirement	Section	Panel comment	Authors answer		Panel answer
			the most recent IPCC GWPs.	*study, the Global Warming impact category was assessed using the Second Assessment Report (SAR) (IPCC,1996) values since they were included into the Kyoto Protocol and are those currently used in the Province of Quebec.* In order to make it more obvious, the SAR 1996 has been identified as the GWP used in the assessment in Table 3-4.		
⧄	The results of the uncertainty and sensitivity analyses	Section 5.2	Uncertainty analysis is lacking. The relevance of the sensitivity analyses performed is not demonstrated (see comment 54).	The NG analyses were performed since an estimate of the break-up of the supply to Bécancour for 2017 is not known. The use phase is the most significant. Therefore, the sensitivity analysis for ferries is necessary. Please refer to section 5.2 for more details. An additional sensitivity analysis has been added to include crude oil supply.	☒	Satisfactory. However, the review committee would have considered it preferable to perform a Monte Carlo analysis, since the GHGenius has this functionality. This would have provided insight on the overall level of uncertainty for both scenarios, in addition to the sensitivity analysis provided.

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