15 GREENHOUSE GASES

15.1 Approach

Greenhouse gas (GHG) emissions (e.g., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and others) accumulate in the atmosphere and are believed to be a major factor in producing the greenhouse effect that may affect climate. The global GHG emissions resulting from human activities have been rising over the last century. Since about 1850, the atmospheric CO_2 concentration has risen approximately 35% (Houghton 2007). Global GHG emissions are estimated to be 44,000 Mt CO_2e (Netherlands Environmental Assessment Agency 2011; U.S. EPA 2011).

In 2010, the total GHG emissions in Canada were estimated to be 692 Mt CO_2e, of which 562 Mt CO_2e (81%) were attributed to the energy sector. Fossil fuel combustion accounted for 90% of energy sector emissions, contributing 503 Mt CO_2e. For these reasons, recent federal and provincial government policies and regulations are focused on the reduction of GHG emissions to the atmosphere.

The release of GHGs from the Project has been identified as a concern by regulatory agencies and Aboriginal groups. The GHGs from the Project must be considered in the environmental assessment (CEA Agency 2003) and greenhouse gases have been selected as a VC for the assessment. The VC greenhouse gases will be assessed as outlined in the Environmental Impact Statement Guidelines (EIS Guidelines) for the Project, and following the methods set forth in Volume 2 Section 10 Effects Assessment Methodology. Specific aspects of the methodology are highlighted here.

In this assessment, releases of CO_2, CH_4, and N_2O are estimated according to best practice methods suggested by the IPCC (2003). Three approaches are described by IPCC (referred to as “Tier 1”, “Tier 2”, and “Tier 3”). The details for Tier 1 and 2 are presented in the GHG report (Volume 2 Appendix S Greenhouse Gases Technical Report). In this assessment, the predictions/estimates from the more detailed modelling approach (“Tier 3”) are used and include a site-specific evaluation of ecosystem carbon cycling in the Local Assessment Area. Only the Tier 3 results are presented here, as these are based on the best model (and methods) for making the predictions. This specific carbon model was developed for the Project to simulate and estimate carbon flows over the lifecycle of the Project (Jacques Whitford Axys 2009), and has been updated for this assessment to reflect the current Project Description (Volume 1 Section 4).

15.1.1 Regulatory and Policy Setting

This assessment has been prepared in accordance with Section 8 and Section 14 of the Environmental Impact Statement Guidelines (EIS Guidelines) for the Project (BC Hydro 2012).

There are currently no provincial or federal standards or guidelines for GHG concentrations in ambient air, nor are there any emission limits with respect to GHG releases from individual sources or sectors in place for British Columbia at this time. As such, the scope of this Project does not contain any aspects that are currently regulated for GHG emissions provincially or federally.

The latest guidance from the CEA Agency (2003), Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners was followed for this environmental assessment. As summarized in the introduction of that document, GHGs as precursors to climate change constitute a global phenomenon rather than a local issue, and the science of this phenomenon is not yet developed to the stage where global environmental effects from a single project of this nature can be measured. Following CEA Agency guidance, “the environmental assessment process could not consider the bulk of GHG emitted from existing developments. Furthermore, unlike most project-related environmental effects, the contribution of an individual project to climate change cannot be measured” (CEA Agency 2003). This presents a technical boundary in that the specific contribution of the Project to global climate change ultimately cannot be established at this time under current guidance.

In light of this, CEA Agency (2003) recommends evaluation of the net changes in GHG emissions as a result of a project and consideration of detailed mitigation if GHG emissions are found to be medium or high (note that these terms are used but not clearly defined in the document). Based on descriptions of project activities in the CEA Agency document, it is logical to consider an industrial source, such as a fossil-fuelled electrical generating station or a petroleum refinery as a high GHG emitter, and a pipeline project or a hydroelectric facility as a low GHG emitter. The considerations of low, medium and high are related to the magnitudes of the releases of GHGs from the Project in comparison to those from the industrial profile, and the provincial and global totals. An additional consideration includes a comparison of emissions intensity with those for other modes of electrical generation.

Project-related GHG emissions “will be assessed and considered in the context of local, provincial, national and industry sector normals” (CEA Agency 2003) and significance of environmental effects will be based on the quantities of GHG emissions in those contexts. The assessment also considers mitigation and adaptive management strategies aimed at minimizing Project-related GHG emissions, and that the Project will be designed with adaptive management opportunities being taken into consideration to allow compliance with future regulations. This approach is consistent with the CEA Agency guidance (CEA Agency 2003), and is presented in additional detail throughout the remainder of Chapter 15.

15.1.2 Key Issues and Identification of Potential Effects

The consultation process identified key issues and concerns with the Project. For example, there are concerns amongst Aboriginal groups with respect to GHG emissions as they relate to climate change and associated Aboriginal interests, asserted or established Aboriginal rights, and existing Treaty 8 Rights. Generally speaking, there is concern that increased GHG emissions will bring about climate change and seasonal deviations in weather patterns. There is also public concern with the loss of the Project area as a potential carbon sink or displacing activities that are perceived to have a lower carbon footprint than a hydroelectric reservoir (e.g., agriculture). A summary of key issues is shown in Table 15.1.

Table 15.1 Key Issues: Greenhouse Gas Emissions

Key Issue	Approach to Addressing Key Issues
Aboriginal concerns that Project GHG emissions will change climate or seasonal weather.	The rationale for inclusion of GHG as a valued component is because of the link between GHG emissions and global climate change.
Concern that the current river valley and forest is a carbon sink that will be lost if the Project proceeds.	The GHG estimate approach includes an estimate of current GHG processes (both captures and releases) from the area proposed for the reservoir, and compares these to GHG emissions with the Project, and reports the difference as net emissions.
Interest in Project GHG emissions in context of B.C. GHG goals.	The assessment of Project GHG emissions is discussed in the context of provincial and national emission inventories.
Interest in assessing the valued component climate change and microclimate instead of greenhouse gas emissions.	Predicted Project-related changes to microclimate are included in Section 11.10 Microclimate, in Volume 2 Section 11 Environmental Background. The predictions for future climate change in northeastern B.C. are taken into account in the Project design, as well as in Agriculture. The Project GHG emissions are estimated and presented in this section of the EIS.
Interest in the estimated multi-year GHG emission profile associated with the reservoir.	This section of the EIS summarizes the estimated multi-year GHG emission profile, and Volume 2 Appendix S Greenhouse Gases Technical Report provides further information.
Interest in the comparison of the GHG profile of the Project with other electricity and demand-management supply options.	This assessment provides comparisons with other electricity supply options. BC Hydro's integrated resource planning process, including the resource options analysis, provides further technical, financial and environmental comparisons with electricity supply options and demand-side management (conservation) programs for BC Hydro customers.

The Project-environment interactions on each environmental effect were ranked for their potential to result in a change in GHG emissions, based on anticipated quantities of emissions, and using the methodology described in Volume 2 Section 10 Effects Assessment Methodology.

Potential Project interactions with the Greenhouse Gases VC are summarized in Volume 2 Appendix A Project Interactions Matrix, Table 2. Within the table, interactions for all identifiable Project activities are ranked as a "0", "1", or "2", based on their ability to affect the greenhouse gases VC. A ranking of "0" indicates that there is no potential interaction between the Project activity and the VC. Project activities with a "1" ranking. These activities are discussed in Section 15.3.1. A "2" ranking in Table 2 indicates that the effects of an interaction may not be fully avoided or mitigated through the application of standard mitigation measures, or are not well understood. Therefore, they require analysis and evaluation in the environmental assessment.

The potential interactions between the Project and greenhouse gases that were ranked as "2" (using the methodology described in Volume 2 Section 10 Effects Assessment Methodology) are discussed in more detail in the effects assessment below and are presented in Table 15.2.

Table 15.2 Interactions of the Project with Greenhouse Gases

Project Activities and Physical Works	Key Aspects
	Change in GHG emissions
Construction	
Dam, Generating Station, and Spillways, and Quarried and Excavated Materials	✓
Reservoir Clearing	✓
Transmission Line to Peace Canyon	✓
Construction Access	✓
Highway 29 Realignment	✓
Worker Accommodation	✓
Operations	
Spillways	✓
Reservoir	✓

NOTE:
Only Project interactions ranked as "2" in Volume 2 Appendix A Project Interaction Matrix, Table 2 are carried forward to this table. A ✓ indicates that a project component or activity is likely to interact with Greenhouse Gas Emissions.

15.1.3 Standard Mitigation Measures and Effects Addressed

A "1" ranking was given where an adverse effect may result from an interaction, but standard mitigation measures to avoid or minimize the potential effects are available and well understood to be effective, and any residual effect is negligible. These interactions were not carried forward through the effects assessment.

During operation, dam, and generating station activities (e.g., water management and monitoring and maintenance), the transmission line to Peace Canyon and the Highway 29 realignment are also likely to generate some emissions of GHG from fuel combustion of equipment operation. However based on past experience, and in light of the standard mitigation regarding fuel conservation, fleet management, and trip reduction planned for the Project, these emissions are expected to be nominal and are very unlikely to cause GHG emissions that are considered important on the regional or provincial scale. These interactions with a change in GHG emissions are therefore also ranked as 1.

The activities described above that are ranked as 1 are not expected to result in substantive emissions. Therefore, the potential environmental effects of the Project-related activities that were ranked as 1 for a change in GHG emissions during all phases of the Project are not considered further in the environmental assessment.

15.1.4 Selection of Key Indicators

The assessment of a change in GHG emissions in the atmosphere requires knowledge of the constituents comprising and present in the atmosphere, both in magnitude and as trends. The emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) were selected as key indicators of the greenhouse gases VC (Table 15.3), due to the potential for Project activities to result in the release of these types of GHG emissions. These key indicators receive considerable local, national, and international attention in terms of existing and proposed legislation, development of action plans, and

international agreements. The rationales for the key indicators used in the assessment of environmental effects are listed in Table 15.3.

Table 15.3 Key Indicators for Greenhouse Gases

Key Aspects	Key Indicators	Rationale for Selection of the Key Indicators [a]
Change in GHG Emissions	GHG emissions – CO_2, CH_4, and N_2O (in units of CO_2 equivalents or CO_2e)	• GHG emissions are identified as an important influence on climate change. • GHG emissions associated with the Project are an aspect of climate that must be considered in the environmental assessment (CEA Agency 2003; BC Hydro 2012). • Recent federal government policies and regulations are focused on GHG reduction [a, b] • The inventory and analysis of GHG emissions are widely recognized when assessing related environmental effects on climate (CEA Agency 2003)
	GHG emissions intensity in units of tonnes of CO_2e per year per (t CO_2e/year)	• To put the GHG emissions from the Project into context with respect to the industry profile, as recommended in CEA Agency (2003) guidance

NOTES:

[a] The Government of Canada has committed to reducing GHGs and improving the air quality nationally by taking action sector by sector. On September 1, 2010, Canada enacted the Renewable Fuels Regulations, which require gasoline and diesel fuels to contain an average renewable content of at least 5% and 2%, respectively. In October 2010, regulations to limit the GHGs from passenger vehicles and light duty trucks in model years 2011 to 2016 were released. Proposed regulations for GHG emission limits on for heavy-duty vehicles were released in April 2012. Regulations to reduce emissions from coal-fired electricity generators were released in September 2012. (Government of Canada 2012).

[b] The British Columbia Ministry of Environment (BCMOE) has prepared a Climate Action Plan (BCMOE 2008) in response to increasing concern for and awareness of these issues. The 2007 Greenhouse Gas Reduction Targets Act legislates three commitments, including a reduction of GHG emissions by 33% from 2007 emissions by 2020.

15.1.5 Spatial and Temporal Boundaries

The spatial and temporal boundaries for the assessment of potential environmental effects of the Project on greenhouse gases were determined by considering the activities with the potential to cause effects and by the potential zone of influence associated with Project activities, as well as the length of time expected for each of the Project phases.

15.1.5.1 Spatial Boundaries

The spatial boundaries for the assessment of potential environmental effects of the Project on Greenhouse Gases (Figure 15.1) are based on a combination of experience with similar projects and professional judgment. These are described in Table 15.4

The Local Assessment Area is the Project activity zone as the area within which GHG emissions from construction activities will occur, and as the area within which the reservoir will be formed, which enabled estimates of GHG emissions associated with land conversion.

In recognition of the global nature of the potential environmental effects of a change in GHG emissions on global climate, the assessment will compare Project-related GHG emissions to global, national, and provincial GHG emissions.

Table 15.4 Spatial Assessment Areas for Greenhouse Gases

Local Assessment Area (LAA)	Regional Assessment Area (RAA)
The LAA is defined as a 30 m buffer zone around the maximum reservoir elevation (to describe GHGs from land conversion) and the project activity zone to characterize emissions associated with construction activities	The RAA is defined as National

15.1.5.2 Temporal Boundaries

The temporal boundaries for greenhouse gases are the Project phases of construction (including reservoir filling, and reclamation) and operations.

The time period for construction is expected to be eight years, concluding with reservoir filling.

The time period for operation is at least 100 years; therefore, the carbon model has been established to cover 100 years of operation.

15.2 Baseline Conditions

15.2.1 Emission of GHGs from Existing Facilities

Greenhouse gases (GHG) of concern generally include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), among others. Provincial GHG emissions in 2010 were 56,100 kt of carbon dioxide equivalent (CO_2e), reported as part of the National Inventory Report (Environment Canada 2012).

Under the federal GHG reporting program, 68 facilities in British Columbia reported GHG emissions to Environment Canada for 2010 (Environment Canada 2010). The reporters with the four highest percentages of the total B.C.-reported GHG emissions included the Fort Nelson Gas Plant (9.5%), the Pine River Gas Plant (8.4%), the Kitimat Works facility (6.8%), and the Delta Cement Plant (5.3%) (Environment Canada 2010).

Canada's GHG emissions in 2010 were 692,000 kt CO_2e (Environment Canada 2012). British Columbia's contribution to the national total GHG emissions was 8.1%.

Canada's contribution to global GHG emissions is 1.6%, and British Columbia's contribution to global GHG emissions is approximately 0.13%, based on 2010 data.

15.2.2 Greenhouse Gas Emissions from Reservoirs

Land use changes, such as land clearing for agriculture, forestry, urbanization, or the development of large projects including dams, may change the balance of local or regional GHG storage or emissions. Critics of hydroelectric development (e.g., International Rivers Network) (IRN 2006) have argued that dams and their associated reservoirs are globally important sources of GHG emissions, including CO_2 and CH_4. Operational carbon emissions from hydroelectric developments are fundamentally different than carbon emissions from an electrical generating station that burns fossil fuels (i.e., coal, natural gas, oil, or peat). Whereas a fossil fuel burning generator emits CO_2 that was previously in some form of geological storage, the carbon emissions from a hydroelectric development represent carbon that is already engaged in the cycle between the atmosphere and green plants. A new hydroelectric reservoir is a

living system that integrates with the surrounding environment – the effects to carbon cycling and whether the system as a whole is a source or sink for carbon is dependent on a number of factors, which are evaluated and modelled in this assessment.

There is a consensus that N_2O emissions from reservoirs are typically very low, relative to CO_2 and CH_4 (IPCC 2006). For instance, measured diffusive emissions of CO_2 and CH_4 were 20,000 and 5,300 times greater than N_2O emissions from a tropical reservoir (Galy-Lacaux 1996). Similarly, diffusive CO_2 emissions were 60,000 times greater and CH_4 emissions 2,000 times greater than diffusive N_2O emissions from a boreal reservoir (Hellsten et al. 1996). Since N_2O emissions measured from freshwater reservoirs have been considered negligible, it has been suggested that N_2O emissions need not be included in reservoir-induced GHG research (UNESCO 2006). Although there are few published data on N_2O emissions from flooded lands, it is generally accepted that these emissions are typically low unless the area is under intense agricultural production (IPCC 2006). Since farming occurs along the Peace River valley, with potential for elevated nitrogen concentrations from the application of agricultural fertilizers, the estimation of N_2O was added to the Project GHG emission estimate to account for anthropogenic inputs from agriculture.

Land flooding results in many changes, ranging from the obvious (e.g., conversion of terrestrial habitat to aquatic habitat) to the subtle (e.g., the balance between the creation of new or larger sediment traps where carbon may be stored, and the formation in reservoir sediments of CH_4, which has a stronger potential as a GHG than an equivalent amount of CO_2). UNESCO (2006) considers CH_4 to be the most important GHG produced by a reservoir, due in part to the high CH_4 emissions measured from tropical reservoirs, and also to the relative potency of CH_4 in comparison with CO_2 as a GHG.

Many factors may influence the emissions of CO_2, CH_4, and N_2O from flooded land. Examples include the age of the reservoir, land use prior to inundation, climate, and management practices as well as pH, salinity, depth, altitude, available carbon, and the carbon:nitrogen ratio (IPCC 2006). It is widely understood, for example, that temperature is an important control on the overall magnitude of CH_4 and CO_2 emissions. This is demonstrated by higher GHG emissions from reservoirs situated in tropical climates than those in boreal and temperate climates (Duchemin et al. 2002; St. Louis et al. 2000). Tropical reservoirs are 40% of the total global reservoir surface area, but account for 70% and 94% of CO_2 and CH_4 emissions from reservoirs, respectively. Temperate and boreal reservoirs account for the remaining 60% of the surface area, but only 30% and 16% of CO_2 and CH_4 emissions from reservoirs respectively (Lima et al. 2007). Average fluxes of CO_2 and CH_4 from five tropical reservoirs were estimated to be 3,500 mg/m^2/d and 300 mg/m^2/d, respectively, whereas average fluxes from 17 temperate reservoirs were estimated to be 1,400 mg/m^2/d and 20 mg/m^2/d for CO_2 and CH_4, respectively (St. Louis et al. 2000). In a similar study, diffusive fluxes from tropical reservoirs averaged 3,625 mg/m^2/d and 31 mg mg/m^2/d for CO_2 and CH_4, respectively; with a mean bubble flux of 190 mg/m^2/d for CH_4 (Duchemin et al. 2002). In comparison, diffusive fluxes from boreal and temperate hydroelectric reservoirs averaged 1,430 mg/m^2/d and 16 mg mg/m^2/d for CO_2 and CH_4, respectively; with a mean bubble flux of 0.1 mg/m^2/d for CH_4 (Duchemin et al. 2002).

The CO_2 measured at reservoir surfaces largely represents a product of the natural carbon cycle. For a relatively short period of time following inundation, the decomposition of vegetation or near-surface soil carbon that was left in the flooded areas can result in high initial fluxes of CO_2 and CH_4. In the case of a newly formed

reservoir, there tends to be a peak in emissions during the first two to three years following inundation as flooded vegetation decomposes (UNESCO 2006). However, after a period of time, a reservoir can reach a steady state that is similar in bacterial abundance and biomass to that of surrounding natural water bodies (Soumis et al., 2005). According to Tremblay et al. (2004a), in boreal and semi-arid reservoirs greater than 10 years of age, GHG emissions are similar to those measured from natural lakes in the same area.

In British Columbia, mean values from one literature source for measured CO_2 emissions were approximately 250 (+/- 800) mg CO_2/m^2/day and 500 (+/- 650) mg CO_2/m^2/day, for old reservoirs and natural lakes, respectively (Tremblay et al. 2004a). Measured CO_2 emissions from another literature source ranged from -1,786 mg CO_2/m^2/day to 3,666 mg CO_2/m^2/day (mean of 198 mg CO_2/m^2/day) and -419 mg CO_2/m^2/day to 2,780 mg CO_2/m^2/day (mean of 706 mg CO_2/m^2/day) for reservoirs and natural lakes, respectively (Tremblay et al. 2005). Overall, the measured data for British Columbia reservoirs indicate less CO_2 emissions and slightly higher CH_4 emissions when compared to other boreal reservoirs in Canada of similar age (Tremblay et al. 2005).

15.2.3 Modelling of Baseline Conditions

One of the main objectives in the assessment is to determine the net GHG emissions (CO_2, CH_4, and N_2O) in the area of Site C, where “net” refers to the emissions from the area with the Project in place and operating minus the emissions from area prior to the Project being constructed (existing or baseline). Therefore, it is essential to determine the baseline emissions of the study area prior to inundation.

A carbon mass-balance model was constructed to represent the primary carbon stocks (e.g., atmosphere, soil, vegetation, water, etc.) as well as the flows of carbon between stocks (e.g., water-atmosphere, vegetation-soil, etc.), and to estimate emissions of CO_2 and CH_4 (the full model description is provided in EIS Volume 2 Appendix S Greenhouse Gases Technical Report).

Mass-balance models provide a detailed accounting system for the movement of an element in a system, such as carbon, that cannot be eliminated, only transferred. This method also allows for carbon to be converted from one form (e.g., organic C) to another form (e.g., CO_2) through various processes. The modelled study area included an area extending 30 m beyond the reservoir contour at maximum capacity. The mass of carbon in stocks under current conditions and the flux rates between stocks were estimates using land cover inventories as well as site-relevant published literature values on carbon mass in stocks and observed flux rates. The values most representative of Site C conditions were selected for the model stocks and fluxes, and assumed to be representative of this system. As values were drawn from various literature sources of representative systems, but were not measured in the same location and time, it was also necessary to calibrate the model to integrate the various fluxes into one system. As some stocks (lakes and rivers, terrestrial vegetation) are expected to maintain constant average carbon masses over large areas and in the short term (i.e., on an annual basis), key fluxes (water to atmosphere CO_2 and terrestrial vegetation to water) were adjusted to balance fluxes and produce constant stock values. A smaller separate N_2O model was also built to model the fluxes of this GHG from agricultural sources (livestock and agricultural inputs) within the landscape.

Once the carbon model was calibrated and the N_2O model constructed, it was possible to estimate the annual net GHG emissions of the system. Under current conditions, the Site C study area is a weak source of GHGs, at approximately 5,700 t/year CO_2e. The landscape on its own is a carbon sink. However, the agricultural activities in the area release GHGs that are greater in magnitude than those from the sequestration processes of the landscape. These agricultural releases arise from the methylation of biomass carbon into CH_4, largely through ruminants, and the anthropogenic emissions of N_2O (Volume 2 Appendix S Greenhouse Gases Technical Report).

15.2.4 Aboriginal Traditional and Community Knowledge

Aboriginal people and First Nation communities did not provide any information specific to the GHG assessment. Aboriginal interests in GHG emissions and climate change, as expressed to BC Hydro, are summarized in Section 15.1.2 Key Issues and Identification of Potential Effects.

15.3 Effects Assessment

There is a potential for Project-related GHG emissions to contribute to the global concentration of GHGs in the atmosphere. In the assessment, consideration was given to GHG emissions from vehicles and heavy equipment during construction and biological processes during operations, as well as any reduction or increase in carbon sequestration.

The release of GHG emissions as a result of the Project's land clearing and construction activities are important considerations in estimating the life cycle emissions of the Project.

The expected GHG emissions associated with construction activities of the Project will consist of CO_2, CH_4, and N_2O, mainly from fuel combustion associated with equipment operation. The construction emissions are assessed for the following Project activities:

- Dam and generating station, spillways, and quarried and excavated materials
- Reservoir clearing
- Transmission line to Peace Canyon Dam
- Access road and rail
- Highway 29 realignment
- Worker accommodation

In the calculation of construction emissions, the values of CO_2, N_2O, and CH_4 emissions were converted to carbon dioxide equivalent (CO_2e) using an emission factor specific to the GHG source activity. These emission factors are calculated using the individual Global Warming Potentials as prescribed by the IPCC. Further, the emission factors specific to Canadian fuel and electricity generation were used in the estimates.

Consumption estimates for fuel combustion and electricity use for each activity were provided by the BC Hydro Design Team and through experience with similar projects. The data are organized by overall construction activity (as indicated above) and converted to GHG emissions using the applicable emission factors. Two sources for emission factors were used for the construction emissions inventory. These include

publications from Western Climate Initiative (WCI) and Environment Canada. The references for the emission factors are provided in Table 15.5.

Table 15.5 Summary of Emission Factor Sources

GHG Emission Source	Emission Factor Reference
Fuel Combustion	Western Climate Initiative (WCI). Final Essential Requirements of Mandatory Reporting, 2011 Amendments for Harmonization of Reporting in Canadian Jurisdictions, December 2011, published in February 2012, Table 20.2.
Electricity Consumption	Environment Canada. National Inventory Report: (1990-2010) Greenhouse Gas Sources and Sinks in Canada, published in April 2012, Part 3: Annex 13.

The emission factors for fuel combustion from WCI are used to quantify GHG emissions associated with construction activities. It is noted that this referenced WCI publication is required to be used by industries reporting GHG emissions under the B.C. *Greenhouse Gas Reduction (Cap and Trade) Act*. The WCI publication does not provide separate emission factors for Stationary Diesel Combustion and Mobile Diesel Combustion. The emission factors in the units of grams CO_2e per litre are calculated from CO_2, CH_4, and N_2O emission factors and their respective Global Warming Potentials.

The Electricity Consumption Intensity (for B.C.) published by Environment Canada is used to quantify indirect GHG emissions from electricity consumption. It is noted that the WCI publication does not reference the Electricity Consumption Intensity, as emissions from electricity consumption are not regulated under the *Greenhouse Gas Reduction (Cap and Trade) Act*.

The most recent published emission factors are used in this study. A detailed spreadsheet including all calculations and emission factors is presented in the GHG Report (Volume 2 Appendix S Greenhouse Gases Technical Report).

For the operations phase of the Project, three separate methods of analysis were used to model and evaluate GHG emissions for the Project, following methods described by the Intergovernmental Panel on Climate Change (IPCC 2003). The first two IPCC methods are generic and use simple calculations to estimate emission rates from land flooding only (Tier 1) or from land flooding and degassing at turbines and spillways (Tier 2). The third method (Tier 3) involves developing a more detailed carbon model to account for the substantive carbon stocks, processes, and fluxes relevant to the Project (Volume 2 Appendix S Greenhouse Gases Technical Report).

The Tier 3 approach (IPCC 2006) provides guidelines for developing project-specific models that account for all major stocks, processes, and pathways (fluxes) of carbon within the watershed (Volume 2 Appendix S Greenhouse Gases Technical Report, Section 8.0). This approach provides the most precise estimate of the net emissions produced as a result of reservoir inundation and is therefore a more realistic and thus more applicable model.

For post-inundation, using Tier 3 methods, (after the dam is constructed and operating), the emissions of GHGs were estimated for two different scenarios: Firstly, a conservative (i.e., worst case) scenario with conservative default settings; and secondly, a likely scenario, which treated merchantable timber and buried biomass as stored carbon instead of emissions. While the likely scenario is the more probable of the two, both are modelled to ensure that a conservative approach is taken in the assessment.

On the use of cleared vegetation, the IPCC (2003) guidelines recommend including all cleared or flooded vegetation as a project carbon emission during calculations, though the guidelines recognize that carbon in the merchantable fraction of cleared vegetation may be permanently stored in various timber products.

Under the conservative emissions scenario, all cleared vegetation was included as an emission and treated as flooded biomass that undergoes decomposition, while in the likely emission scenario, it is assumed that the carbon in merchantable timber would be permanently stored and 30% of cleared non-merchantable timber would be buried in deep portions of the reservoir and permanently stored.

15.3.1 Effects Assessment – Construction

In the following sections, GHG emissions associated with various construction categories are described. Data sources and assumptions are provided in each section.

15.3.1.1 Dam and Generating Station, Spillways, and Quarried and Excavated Materials GHG Emissions

The GHG emissions associated with these project components arise from vehicle and equipment use (i.e., fuel combustion) during the following activities:

- Clearing of the areas associated with the dam, generating station, access roads, and transmission line
- Channelization (bridges, excavation, and cofferdam construction)
- Diversion (cofferdam construction, dam foundations, earthfill dam, spillway)
- Commissioning
- Site restoration (removal of temporary facilities and reclamation)

Greenhouse gas emissions from fuel combustion and electricity consumption are quantified using the emission factors published in Western Climate Initiative's Final Essential Requirements of Mandatory Reporting, December 2011 (WCI 2011) and Environment Canada's National Inventory Report (Environment Canada 2012) publications, respectively.

The total direct and indirect emissions of GHGs from the dam and generating station, spillway, and quarried and excavated material activity over the eight-year construction period are estimated to be 304,163 t CO_2e and 2,597 t CO_2e, respectively.

15.3.1.2 Reservoir Clearing GHG Emissions

The GHG emissions associated with the reservoir clearing activity are released from the fuel combusted during the harvesting of merchantable timber, and waste collection and disposal.

Greenhouse gas emissions from fuel combustion were calculated using the emission factors in Final Essential Requirements of Mandatory Reporting (WCI 2011).

The total direct GHG emissions from fuel combustion associated with Reservoir Clearing are 18,730 t CO_2e over the eight-year construction period.

15.3.1.3 Transmission Line to Peace Canyon GHG Emissions

The GHG emissions associated with the Transmission Line construction arise from vehicle and equipment use (i.e., fuel combustion) during the following activities:

- Distribution of components along the right-of-way
- Installation of foundations and guy anchors
- Assembly of towers and associated equipment
- Erection of towers
- Conductor pulling and tensioning equipment
- Installation of counterpoise
- Removal and reclamation of temporary access and cleanup and restoration of the right-of-way

Greenhouse gas emissions from fuel combustion associated with transmission line construction were calculated using the emission factors provided in Final Essential Requirements of Mandatory Reporting (WCI 2011).

The total direct GHG emissions from fuel combustion associated with the transmission line construction are 6,511 t CO_2e over the eight-year construction period.

15.3.1.4 Project Access Road and Rail GHG Emissions

The GHG emissions associated with the construction of the Project access road and rail (e.g., the building of a rail siding) are attributed to fuel combustion associated with construction equipment use. Greenhouse gas emissions from fuel combustion were calculated using the emission factors provided by in Final Essential Requirements of Mandatory Reporting (WCI 2011). Greenhouse gas emissions from electricity usage were calculated using the emission factors provided by the National Inventory Report, (Environment Canada 2012).

The total direct and indirect emissions of GHGs from fuel combustion and electricity use associated with Project access road and rail are 6,315 t CO_2e and 19.20 t CO_2e, respectively, over the eight-year construction period.

15.3.1.5 Highway 29 Realignment GHG Emissions

BC Hydro has estimated the fuel consumption associated with the Highway 29 realignment. The GHG emissions from combustion of fuel and consumption of electricity were quantified using the emission factors provided in the Final Essential Requirements of Mandatory Reporting (WCI 2011) and the National Inventory Report (Environment Canada 2012), respectively.

The total direct and indirect emissions of GHGs from fuel combustion and electricity use associated with the Highway 29 realignment are 26,910 t CO_2e and 34.14 t CO_2e, respectively, over the eight-year construction period.

15.3.1.6 Worker Accommodation GHG Emissions

There will be two worker accommodation camps available for workers. In addition to the construction of the accommodations, there will be electricity use associated with heating,

utilities, and domestic use. The estimated GHG emissions were calculated using consumption data provided by BC Hydro and emission factors from the National Inventory Report (Environment Canada 2012).

The total indirect GHG emissions from electricity consumption at the worker accommodations are 3,490 t CO_2e over the eight-year construction period.

15.3.1.7 Summary of Construction GHG Emissions

A summary of the estimated GHG emissions (direct and indirect) released from each construction activity described above is presented in Table 15.6. The percentages of GHG emissions that contribute to the total Direct and Indirect Construction Emissions are also provided for each type.

Table 15.6 Summary of Construction GHG Emissions

Activity	GHG Emissions (Tonnes of CO_2e)		Contribution to Total Emissions from Construction (%)	
	Direct	Indirect	Direct	Indirect
Dam and Generating Station, Spillways, and Quarried and Excavated Materials	304,163	2,597	84	42
Reservoir Clearing	18,730	0	5	0
Transmission Line to Peace Canyon	6,511	0	2	0
Access Road and Rail	6,315	19.20	2	0
Highway 29 Realignment	26,910	34.14	7	1
Worker Accommodation	0	3,490	0	57
Total	**362,629**	**6,141**	**100**	**100**

Based on these estimates (Table 15.6), it is clear that dam and generating station construction activities represent the major GHG sources during construction activities. This is primarily due to the fuel combustion associated with construction equipment for dam and generating station construction.

Over the eight-year construction period, the total direct GHG emissions from construction are 362,629 t CO_2e. Assuming a 15% contingency is applied to address some uncertainty in the estimates, the direct emissions would be 417,023 t CO_2e. The total indirect GHG emissions from construction are 6,141 t CO_2e. The indirect emissions would be 7,062 t CO_2e with a 15% contingency.

The emissions may also be presented over the time for construction on an annual basis. These data are based on the expected activity levels for each year. The releases of GHGs by year (with contingency) are provided in Table 15.7.

Table 15.7 Construction GHG Emissions – by Year (Tonnes CO2e/Year)

Parameter (tonnes CO_2e per year)	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Total
Direct Emissions – Low	8,449	34,797	49,017	52,432	41,696	76,090	64,752	31,049	4,347	362,629
Direct Emissions – High	9,716	40,016	56,369	60,296	47,951	87,504	74,465	35,706	4,999	417,023
Indirect Emissions – Low	126.66	403.17	444.19	477.06	591.07	1,544.61	1,495.17	937.09	122.27	6,141
Indirect Emissions – High	145.65	463.64	510.82	548.61	679.73	1,776.30	1,719.44	1,077.65	140.61	7,062

15.3.1.8 GHG Emissions from Construction Materials based on Life Cycle Assessment (LCA)

An analysis of the GHG emissions associated with the materials used in the construction of the Project was also undertaken. These emissions were quantified based on emission factors associated with the production of concrete, fly ash, steel, stainless steel, aluminum, and copper. The emission factors and the related references, used for this LCA, are presented in the GHG report (Volume 2 Appendix S Greenhouse Gases Technical Report).

The low range quantity of materials (tonnes) to be used in the construction (over the eight-year period) was estimated based on best available information and professional experience with similar projects. The high range quantity of materials to be used was calculated based on the percentage contingency (15% contingency for steel, aluminum, cement, and flyash; 25% contingency for stainless steel; and 50% contingency for copper). In order to estimate the GHG emissions (tonnes of CO_2e) from the construction materials, the low range and high range quantity of materials (tonnes) were subsequently applied to the low and high emission factors (tonnes CO_2 per tonne of material), respectively. Additional detail is provided in Volume 2 Appendix S Greenhouse Gases Technical Report.

The total life cycle GHG emissions for materials to be used in the construction are estimated to range from 628,455 to 1,059,622 t CO_2e.

15.3.2 Effects Assessment – Operations

In order to estimate the net environmental effect of the Project on carbon storage and fluxes, three different scenarios were evaluated, one representing the carbon exchanges of the assessment area under current conditions (pre-flooding) and two scenarios under the post-inundation conditions. The Site C carbon model was developed to consider all major carbon stocks, processes, and fluxes, including land conversion to the reservoir and the removal of trees and vegetation for Project construction. Models representing each of the following scenarios, were programmed to run for a model period of 100 years to compare GHG emission estimates:

- Current conditions (summary of results provided in Section 15.2.3)

- Post-inundation with conservative model parameters (conservative scenario)
- Post-inundation with likely model parameters (likely scenario)

The specific description on how vegetation, land areas, and carbon and nitrogen inventories were estimated for the Project is provided in Volume 2 Appendix S Greenhouse Gases Technical Report. In this report, the terms used in the Project carbon cycle and nitrogen cycle models with regards to the current and post-inundation conditions for the Project are described and quantified.

The Site C carbon model for the Peace River post-inundation scenarios suggest that, initially, the net emissions for the assessment area would be increased due to flooded organic matter decomposition. Emissions from the Site C reservoir are initially much higher than current levels, and decline back to current conditions by approximately Year 20 (Figure s 15.2 and 15.3). While this duration is longer than the typical extent before emissions return to near pre-inundation level (~10 years) (Tremblay et al. 2004b), it is not unreasonable given that several conservative assumptions were made, such as little biomass burial, conservatively low sedimentation estimates, and emissions include all releases from flooded biomass regardless of when and where gases are released. Furthermore, this difference may also be due to a slower modelled decomposition rate than typically occurs in reservoirs, which would partially explain why the modelled time to return to current conditions emissions estimates are higher than typically observed elsewhere, and would not be accounted for in emission estimates of reservoirs based solely on field measurements (Tremblay et al. 2004b; Teodoru et al. 2012).

The average annual net project emissions for the Project (using the Tier 3 model) are approximately 58,200 t CO_2e/year, and 43,400 t CO_2e/year, for the conservative and likely scenarios, not considering emissions from construction. The Tier 3 year values are initially high due to the initial pulse of GHG emissions, but by Year 20, these emissions are substantively reduced. These results are consistent with the observations of Bastien et al. (2007) that the GHG fluxes in Smallwood reservoir 30 years post-inundation are similar to those of natural lakes in the region.

This model indicated that initially, inundation removes 950,000 t of carbon from the soil, vegetation, and wetland stocks within Site C due to flooding, and an additional 323,000 t of carbon are removed from land cleared for new roads and transmission lines. This value does not change with respect to timber harvesting, as it represents the loss of terrestrial carbon stocks in the conservative scenario. Under the assumption that all harvested timber would be stored in long-term forest products and that 30% of non-merchantable vegetation would be permanently buried in the reservoir, there would be a 27% reduction in net emissions over the 100-year lifespan.

The estimated emission intensities for Site C under the conservative and likely scenarios decreased substantially over time (Figure 15.4). The estimated values during the time period immediately after inundation are expected to be relatively high due to the large flux of GHGs from biomass decomposition. The range in emission intensity between the maximum conservative and minimum likely scenario estimates, based on sensitivity analyses conducted for three key model parameters (i.e., livestock estimates, biomass burial rates, and sedimentation rates) was initially less than two-fold; this decreased over time, indicating that the model was relatively insensitive to these model parameters. Beyond Year 20, the emission intensity estimates stabilized at values between one and two orders of magnitude lower than in Year 1, were very similar among scenarios, and

were well below emission intensities of any fossil fuel generating facility of similar capacity. Additional information on the sensitivity analysis is provided in the GHG report (Volume 2 Appendix S Greenhouse Gases Technical Report).

These model estimates were also comparable to observed emission intensity trends observed for Eastmain-1, a boreal hydroelectric reservoir in Québec (Teodoru et al. 2012).

15.3.3 Summary of Project GHG Emissions

A summary of estimated GHG emissions from Construction and Operation using Tier 3 and the associated GHG emission intensities are provided in Table 15.8.

Table 15.8 GHG Emissions Estimates - Site C Clean Energy Project

Activity/Method	GHG Emission Estimates [a]	
Emissions – Construction (tonnes CO_2e)	Scenario Conservative;	Likely
Annual average over 8 years (fuel use)	52,128	45,329
Fuel total (8-year construction period)	417,024	362,629
Electricity and construction materials total (8-year construction period)	1,066,685	634,596
Construction sub-total (8 years) - fuel, electricity, and construction materials	**1,483,708**	**997,225**
Emissions – Operation (tonnes CO_2e)	Scenario Conservative;	Likely
Annual average over 100 years [a]	58,200	43,400
Operations sub-total (100 years)	**5,824,820**	**4,343,633**
Emissions – Total Construction and Operations (tonnes CO_2e)	Scenario Conservative;	Likely
Annual average over 108 years [b]	**57,795**	**43,576**
Total over 108-year period – excluding electricity and construction materials	**6,241,844**	**4,706,262**
Total over 108-year period – including Construction, and construction materials	**7,308,528**	**5,340,858**
Emissions Intensity		
Generating Capacity (MW)	1,100	
Electricity Generation (GWh/year)	5,100	
	Scenario Conservative;	Likely
Emissions Intensity [c] (g CO_2e/kWh) - not including Construction	11.4	8.5
Emissions Intensity [d,] (g CO_2e/kWh) - including Construction	~~13~~14.3	10.5~~9.7~~

NOTES:

[a] Averaged annual emission estimates are rounded to the nearest 100 tonnes CO_2e/year (Volume 2 Appendix S Greenhouse Gases Technical Report)

[b] CO_2 equivalents (CO_2e) calculated on a 100-year global warming potential of 21 for CH_4 and 310 for N_2O

[c] Values represent 100-year average

[d] Includes emissions from construction fuel combustion and electricity use, and life cycle GHGs from construction materials, averaged over 108 years

15.3.4 Mitigation Measures

Initiatives to mitigate the GHG emissions have been incorporated into the design of the Project.

15.3.4.1 Mitigation of Construction GHG Emissions

The majority of GHG emissions during construction result from the burning of fossil fuels, namely the burning of diesel and gasoline in vehicles and heavy equipment. As a result, reduced GHG emissions are linked directly to reductions in fossil fuel consumption and implementation of fuel conservation strategies.

For this reason, greenhouse gas emission mitigation measures will be developed within the Project's detailed Environmental Management Plans, targeted at fleet management to:

- Reduce fuel usage to reduce greenhouse gas emissions
- Increase fuel efficiency to reduce greenhouse gas emissions

Further mitigation, in the form of carbon stored in merchantable timber that is harvested during site preparation, is considered and quantified in the carbon modelling described above.

15.3.4.2 Mitigation of Operations GHG Emissions

There is limited ability or capacity to apply mitigation measures to reduce GHG emissions during operation of a hydroelectric facility. As outlined in IPCC (2006), emissions resulting from land use change are relative to the land area converted from forest to non-forested land. For this reason, greenhouse gas mitigation during operations was taken into consideration in the design of the project, where long-term conversion of land from current conditions was minimized to the fullest extent. As noted above, there is carbon stored in the merchantable timber, and this has potential to be stored over the long term, i.e., sequestered. This is quantified in the carbon modelling results described above.

15.3.5 Summary of Effects Assessment and Mitigation Measures

A summary of potential effects and mitigation measures is shown for greenhouse gases in Table 15.9.

Table 15.9 Project Effects and Mitigation Measures on Greenhouse Gases

Project Phase	Potential Effects	Mitigation Measures	Mitigation Effectiveness	Responsibility
Construction	Emission of GHGs from construction activities	Fleet management to reduce fuel consumption and increase fuel efficiency	The application of mitigation must be a part of standard best practice by construction crew to be most effective	BC Hydro in cooperation with delivery agency or partner
Operation	Release of GHGs during operation	Long-term conversion of land will be minimized while achieving the purpose of the Project	The application of mitigation for operations must be considered at the design phase to be effective	BC Hydro in cooperation with delivery agency or partner

15.3.6 Other Mitigation Options Considered

Other mitigation measures have been considered by BC Hydro, including evaluating design options that would result in little reduction in generating potential, yet reductions in GHG emissions, as well as options for transmission lines and roads that would minimize the amount of land conversion, thus reducing GHG emissions. For detail on additional mitigation considerations, please refer to the Greenhouse Gases Technical Report (in Volume 2 Appendix S).

15.4 Residual Effects

15.4.1 Characterization of Residual Effects

The residual effects of the Project on GHG emissions were characterized using the criteria presented in Table 15.10.

Table 15.10 Characterization Criteria for Residual Greenhouse Gas Effects

Criterion	Description	Quantitative Measure or Definition of Qualitative Categories
Direction	This refers to the ultimate long-term trend of the environmental, social, economic, heritage, or health effect (e.g., increase, decrease, or neutral).	**Increase**: GHG emissions are increasing in comparison to baseline conditions and trends.
		Decrease: GHG emissions are decreasing in comparison to baseline conditions and trends.
		Neutral: GHG emissions are unchanged in comparison to baseline conditions and trends.
Magnitude	This refers to the amount of change in a key indicator or variable relative to baseline case (low, moderate, high); consideration is given to factors such as the uniqueness of the effect, and the comparison to natural or background variation.	**Low:** GHG emissions are measurable but within normal variability of baseline conditions; GHG Emissions < ~~105~~ 100,000 t/year CO_2e.
		Moderate: GHG emissions increase with regard to baseline but are within regular variability; GHG Emissions > ~~105~~ 100,000 and < ~~106~~ 1,000,000 t/year CO_2e.
		High: GHG emissions from the Project are substantive and above regular variability; GHG Emissions > ~~106~~ 1,000,000 t/year CO_2e.

Criterion	Description	Quantitative Measure or Definition of Qualitative Categories
Geographical Extent	This refers to the geographic area in which an environmental, social, economic, heritage, or health effect of a defined magnitude occurs (site-specific, local, regional, provincial, national, international).	**Local:** the expected change in GHG emissions are within the LAA.
		Regional: the expected change in GHG emissions are within the RAA.
		Global: the expected change in GHG emissions are of global extent.
Frequency	The number of times during a project or a specific project phase that an environmental, economic, social, heritage, or health effect may occur (e.g., once, daily, weekly, monthly, continuous).	**Once:** occurs once.
		Continuous: occurs on a regular basis and at regular intervals.
		Sporadic: occurs rarely and at irregular intervals.
Duration	The period of time required until the valued component returns to its baseline condition, or the effect can no longer be measured or otherwise perceived (short term, medium term, long term, permanent).	**Short term:** effect is limited to < 1 year.
		Medium term: effect occurs > 1 year but not beyond 50 years.
		Long term: effect occurs > 50 years but not beyond 100 years.
		Far future: effect extends > 100 years.
Reversibility	This refers to the degree or likelihood to which existing baseline conditions can be regained after the factors causing the effect are removed. Effects can be reversible or irreversible.	Effect **reversible** with reclamation, reduction in GHG emissions, or over time.
		Effect **irreversible** and cannot be reversed with reclamation, reduction in GHG emissions, or over time.
Context	This refers to the extent to which the area within which an effect may occur; has already been adversely affected by human activities; and is ecologically fragile and has little resilience and resistance to imposed stresses.	**Developed:** area has been substantially previously disturbed by human development or human development is still present.
		Undeveloped: area relatively pristine or not adversely affected by human activity.
Level of Confidence	This is an evaluation of the scientific certainty one has in the review of project specific data, relevant literature, and professional opinion; the EIS will include a statement on the level of confidence in the assessment of direction, magnitude, extent, duration, frequency and reversibility.	**Low:** low level of confidence.
		Moderate: moderate level of confidence.
		High: high level of confidence.
Probability	The likelihood that an adverse effect will occur (e.g., low, high or unknown).	**Low:** low probability of occurrence.
		High: high probability of occurrence.
		Unknown: probability of occurrence is unknown.

The net emissions of the Site C reservoir operation, over the 100-year operating lifespan of the project, would be approximately 58,200 t CO_2e/year under the conservative scenario, and 43,400 t CO_2e/year under the likely scenario, with an additional emission of approximately 45,329 t CO_2e/year for the fuel use during construction. This represents 0.2% and 0.01% of provincial and national emission, respectively (conservative operation plus construction). In the global context, these net emission rates represent a tiny fraction (0.002%) of the net anthropogenic emissions (5.5 to 6.3 billion t CO_2e/year).

In the context of increasing global energy demand and global climate change, evaluating generating facilities by their emissions (g CO_2e) per unit of energy generated (kWh) is an important relative measure when evaluating the potential climate warming impact of a project.

Using the IPCC Tier 3 calculations for reservoir emissions, not including construction and clearing emissions, the net emissions per unit energy generated averaged over the 100-year operating lifespan are 11.4 g CO_2e/kWh for the conservative scenario (Table 15.8). Initially (in the first years of after inundation), the emissions per unit energy are much higher, due to the initial flux of GHG from the reservoir and are estimated to be 212 g CO_2e/kWh, but by Year 20 this value is reduced to 4 g CO_2e/kWh and reaches 2 g CO_2e/kWh by Year 35 (Figure 15.4).

Under the likely emissions scenario, the average emission intensity, not including construction emissions, is 8.5 g CO_2e/kWh, and ranges from 146 to 2 g CO_2e/kWh.

These values are consistent with the average range of 8 to 60 g CO_2e/kWh presented by the IRN (2006) for boreal reservoirs, though at the lower extreme. This is not surprising, given that Site C would have a constant water supply from the upstream Williston Reservoir for electricity generation while inundating a relatively small area of land. This type of reservoir can be characterized as a run-of-river type project rather than a traditional reservoir hydro project. The IEA (2000) reported that run-of-river hydro projects are among the lowest emitting of all generating types, which is consistent with this study's results. In contrast to these data, IRN (2006) estimated that, among other sources of electricity, modern coal-fired generating stations emit approximately 1,000 g CO_2e/kWh, and existing natural gas combined cycle generators emit approximately 545 g CO_2e/kWh (Table 15.11). In fact over the life cycle of the Project, relative emission estimates more closely resemble those of wind turbine facilities than other types of generating facilities, but the Project also has the advantage of constant water supply, compared to sporadic wind supplies.

While the construction and operation of the Site C reservoir and generating station would result in a net increase in GHG emissions, they are "low" as described by the CEA Agency guidance (2003). The emissions are considered to be much lower than GHG emissions from the combustion of fossil fuels to generate equivalent amounts of electricity over the long term, given the biogenic origin of the Peace River emissions. In other words, as the emissions from the Project originate primarily from decomposition of organic matter currently stored in soils and plants, this carbon could be recaptured rapidly when compared to fossil fuel emissions, which are not returned to their original carbon stocks (i.e., oil, coal, natural gas). As approximately 95% of emissions from the Project would originate from biomass removal and only 5% from emissions related to construction and fuel use, an analysis of measures to mitigate carbon emissions from biomass decomposition may be useful.

Table 15.11 Emissions Intensity – Project Compared with Other Generation

Generating Facility Type	Range (g CO_2e/kWh)	Average (g CO_2e/kWh)
Tropical Hydroelectric	1,750 – 2,700	2,150
Modern Coal	959 – 1,042	1,000
IGCC (coal)	763 – 833	798
Diesel	555 – 880	717
NGCC (Natural Gas)	469 – 622	545
Photovoltaic	13 – 104	58
Canada Boreal Hydroelectric	8 – 60	36
Wind Turbines	7 – 22	14
BC Hydro Site C (Tier 3 – conservative, with embedded carbon, fuel, and electricity use)	—	14.3~~13.3~~
BC Hydro Site C (IPCC Tier 3 - conservative)	2 – 212 (annual range)	11.4 [a]
BC Hydro Site C (Tier 3 – likely, with embedded carbon, fuel, and electricity use)	—	10.5~~9.7~~
BC Hydro Site C (IPCC Tier 3 - likely)	2 – 146 (annual range)	8.5*

NOTES:

[a] The average value is the 100-year average estimate

Intensities for Modern Coal, IGCC (coal), Diesel, NGCC (Natural Gas), Photovoltaic, and Wind Turbines include life cycle emissions. For more information, see IRN 2006. Intensities for Boreal and Tropical Hydroelectric facilities include only reservoir emissions.

— not collected

Source: IRN 2006

Overall, the GHG emissions from the Project are considered to be low in relation to other forms of non-renewable electricity generation and in relation to the provincial, regional or national GHG emission totals (CEA Agency 2003). The Project will result in a net benefit from a GHG perspective, producing electricity with substantively lower GHG emissions compared to other forms of electricity generation.

The residual environmental effects associated with a change in greenhouse gas emissions during construction and operation, in light of mitigation described above, are characterized in terms of direction magnitude, geographic extent, duration and frequency, and rating of significance is provided with a level of confidence in Table 15.12.

Table 15.12 Characterization of Residual Greenhouse Gases Effects

Activity	Residual Environmental Effect							
	Direction	Magnitude	Geographic Extent	Duration and Frequency	Reversibility	Ecological or Social Context	Probability	Level of Confidence
Construction								
Dam, Generating Station, and Spillways, and Quarried and Excavated Materials	Increase	Low	Global	Short term/ Continuous	Reversible	Developed	High	High
Reservoir Clearing	Increase	Low	Global	Short term/ Continuous	Reversible	Developed	High	High
Transmission Line to Peace Canyon	Increase	Low	Global	Short term/ Continuous	Reversible	Developed	High	High
Construction Access	Increase	Low	Global	Short term/ Continuous	Reversible	Developed	High	High
Highway 29 Realignment	Increase	Low	Global	Short term/ Continuous	Reversible	Developed	High	High
Worker Accommodation	Increase	Low	Global	Short term/ Continuous	Reversible	Developed	High	High
Operations								
Spillway	Increase	Low	Global	Far future/ Sporadic	Reversible	Developed	High	High
Reservoir	Increase	Low	Global	Medium term/ Continuous	Reversible	Developed	High	High

15.4.2 Thresholds for Determining Significance

In the determination of significance for GHGs, the criteria described above (e.g., direction, magnitude, geographical extent, frequency, duration, reversibility, context, level of confidence, probability) are assessed and considered to establish the rating for the Project-related effects. Specifically, a significant adverse residual environmental effect of the Project on greenhouse gases is one where the release of GHGs (as a total) is of a quantity that is either medium or high, where those terms are used in the guidance provided by CEA Agency (2003). Since there is no clear quantitative threshold defined in the provincial or federal regulations, this qualitative definition is used to make the determination of significance.

15.4.3 Determination of Significance of Residual Effects

The net changes in GHG emissions as a result of changes in vegetation removal, growth, and management, and from the combustion of fossil fuels over the eight-year construction period were quantified and assessed. The overall net GHG emissions change associated with and during construction are expected to be low as inferred by CEA Agency (2003).

The net annual average GHG emissions from the operation of the reservoir and hydroelectric generating station have been assessed in detail using a detailed carbon model based on Tier 3 methodology. The plan is for these facilities to continue operating in perpetuity. It is thus of interest to consider the long-term average GHG emissions and place them in context with provincial and national emissions and GHG emissions from other sources of electricity. The average GHG emissions over the first 50 years of operation, taking into account the high rates in the early years, will fall into the range of 76,100 to 105,800 t CO_2e per year (likely to conservative). The average over the first 100 years will be between 43,400 and 58,200 t CO_2e per year.

The GHG emissions from operation activities associated with the Project are expected to be low in comparison to total emissions for the jurisdictions (Province of British Columbia; Canada) and to other sources of electricity generation. Canada's total anthropogenic GHG emissions were estimated to be approximately 692,000 kt CO_2e in 2010 (Environment Canada 2012). British Columbia's GHG emissions have decreased since 2007; the 2010 reported GHG emissions of 56,100 kt CO_2e put British Columbia on track to meet its 2012 reduction target of 6% of 2007 levels. The majority of the provincial GHG emissions are from road transportation (Environment Canada 2012).

The 1,100 MW hydroelectric generating facility has the potential to produce an average of 5,100 GWh of energy annually. Averaged over a 100-year operational lifespan, the net emissions intensity from Site C would be approximately 11.4 g CO_2e/kWh under the conservative scenario or 8.5 g CO_2e/kWh under the likely scenario. This intensity is much lower when compared to emission intensities of other generation types such as: 545 g CO_2e/kWh (natural gas), 1,000 g CO_2e/kWh (coal), and 717 g CO_2e/kWh (diesel) for other competing types of electricity generation (Table 15.10 and Figure 15.5) (IRN 2006).

The GHG emissions attributable to the Project during construction average approximately 45,329 t of CO_2e per year during construction and average approximately 43,400 t/year (likely) or 58,200 t/year per year (conservative) over its operating life.

These emission rates place the Project at the low end of the scale when compared with emissions from other sources of electricity generation, over the long term. Overall, the GHG emissions from the Project are considered to be low in relation to industry norms and in relation to the provincial, regional, or national GHG emission totals (CEA Agency 2003). The Project will result in a net benefit from a GHG perspective, producing electricity with substantively lower GHG emissions compared to other forms of electricity generation.

The CEA Agency (2003) recommends that net changes in GHG emissions as a result of a project be evaluated and detailed mitigation be considered if they are found to be medium or high. As the Project is considered to be a low emitter of GHG in the CEA Agency (2003) context, detailed mitigation beyond that of applicable regulations is not required.

The residual Project-related quantities of GHGs released to the atmosphere are a small fraction of the provincial, national, and global emissions, and are considered low (in terms of total and emission intensity), and not medium or high, in the context of the CEA Agency guidance (2003). Therefore, the environmental effects of the Project on Greenhouse Gases are rated not significant.

A summary of the assessment is provided in Table 15.13.

Table 15.13 Summary of Assessment of Potential Significant Residual Adverse Effects

Valued Component	Project Phase	Potential Adverse Effects	Key Mitigation Measures	Significance Analysis of Residual Effects
Greenhouse Gases	Construction	Emission of GHGs from construction activities	Fleet management to reduce fuel consumption and increase fuel efficiency	Not Significant
Greenhouse Gases	Operation	Release of GHGs during operation	Long-term conversion of land will be minimized while achieving the purpose of the Project	Not Significant

15.5 Cumulative Effects Assessment

15.5.1 Characterization of Cumulative Effects

Cumulative environmental effects associated with releases of GHGs to the atmosphere are not limited to the provincial or national borders; in other words, it is a global issue The sources of GHG emissions around the world are contributing to the environmental effect and these would act cumulatively with the Project.

While emissions from the Project will add to existing GHG emissions and potentially contribute to increasing GHG concentrations in the atmosphere, the status of the climate science to date cannot provide a clear statement on a direct cause-and-effect relationship between Project emissions and change in climate.

Releases of GHG emissions from past and current projects (and sources) are considered through the past and current emissions inventories of GHG emissions in British Columbia and Canada.

As noted above, the net emissions of the Site C reservoir operation, over the 100-year operating lifespan of the project, would be approximately 58,200 t CO_2e/year under the conservative scenario, and 43,400 t CO_2e/year under the likely scenario, with an additional emission of approximately 45,329 t CO_2e/year for the fuel use during construction. This represents 0.2% and 0.01% of provincial and national emissions, respectively (conservative operation plus construction). In the global context, these net emission rates represent a tiny fraction (0.002%) of the net anthropogenic emissions (5.5 to 6.3 billion t CO_2e/year).

15.5.2 Determination of Significance of Residual Cumulative Effects

Since the Project's contribution to a net change in global GHG emissions is small, relatively, and because the environmental effect of the Project-related GHG emissions (on its own) on global climate is not measurable, the change in GHG emissions as a result of the Project on its own (i.e., the Project contribution to the cumulative environmental effects) is not substantive.

However, increasing GHG emissions from the many sources globally and the resulting increase in GHG concentrations in the atmosphere, and the consequent changes to the global climate, are currently believed to be a significant cumulative environmental effect. Therefore, the cumulative environmental effects of a change in GHG emissions from the Project combined with existing and planned future projects, are rated significant. This rating is a result of the fact that the existing environmental effects of GHG emissions on global climate are significant, even in the absence of the Project.

15.6 Monitoring and Follow-Up

Recent monitoring of GHG emissions from reservoirs in northern latitudes has greatly improved the understanding of the GHG emissions from hydroelectric facilities in those regions (e.g., Bastien et al. 2007). The GHG emission generating activities will be tracked throughout construction and operation through monitoring. The main area of interest is the GHG emissions from the Project during operations. Therefore, the following activities will be implemented on an annual basis, during the first 10 years of operations:

- Monitor changes in GHG emissions from Site C reservoir to verify the GHG estimates and predictions presented in this EIS
- Monitor GHG emissions during operations and maintenance activities in accordance with BC Hydro corporate requirements, and report results to the province or other organizations per corporate reporting requirements

References

Literature Cited

Bastien, J., A.M. Blais, and A. Tremblay. 2007. Study of Greenhouse Gas Fluxes Emitted from the Smallwood Reservoir, Natural Lakes and the Peace River in Labrador; 2006 Results. Report prepared by Environnement Illimite Inc. for the direction Barrages et Environnement d'Hydro-Québec Production.

British Columbia Ministry of Environment (BCMOE). 2008. Climate Action Plan. Climate Action Secretariat.

Canadian Environmental Assessment Agency (CEA Agency). 2003. Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners.

Duchemin, E., M. Lucotte, R. Canuel, and A. Chamberland. 1995. Production of greenhouse gases CH_4 and CO_2 by hydroelectric reservoir of the boreal region. *Global Biogeochemical Cycles*. 9(4):529–540.

Duchemin, E., M. Lucotte, V. St. Louis, and R. Canuel. 2002. Hydroelectric Reservoirs as an Anthropogenic Source of Greenhouse Gases. *World Resource Review*. 14(3):334–353.

Galy-Lacaux, C. 1996. Modifications des échanges de constituants mineurs atmosphériques liées à la creation d'une retenue hydroélectrique. Impact des barrages sur le bilan du méthane dans l'atmosphère, PhD dissertation, Université Paul Sabatier, Toulouse (France), 200 p. In Duchemin, E., M. Lucotte, St. Louis and R. Canuel. 2002. Hydroelectric Reservoirs as an Anthropogenic Source of Greenhouse Gases. *World Resource Review*. 14(3):334-353.

Government of Canada. 2012. A Climate Change Plan for the Purposes of the *Kyoto Protocol Implementation Act*. Environment Canada. En11-11/2012E-PDF.

Hellsten, S.K, P. Martikainen, T.S. Vaisanen, A. Niskanen, J. Huttunen, M. Heiskanen, and O. Nenonen. 1996. Measured greenhouse gas emissions from two hydropower reservoirs in northern Finland, In IAEA Advisory group meeting on assessment of greenhouse gas emission from the full energy chain for hydropower, nuclear power and other energy sources, Hydro-Quebec, Montreal (Canada), 1-12 (1996). In Duchemin, E., M. Lucotte, St. Louis and R. Canuel. 2002. Hydroelectric Reservoirs as an Anthropogenic Source of Greenhouse Gases. *World Resource Review.* 14(3):334–353.

Houghton, R.A. 2007. Balancing the carbon budget. *Annual Review of Earth and Planetary Sciences.* 35:313–47.

Intergovernmental Panel on Climate Change (IPCC). 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry. J. Penman, M. Gytarsky, T. Hiraishi, T. Krug and D. Kruger (eds.). Institute for Global Environmental Strategies (IGES).

Intergovernmental Panel on Climate Change (IPCC). 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, H.S.

Jacques Whitford Axys. 2009. Peace River Site C Hydro Project, Stage 2, Baseline Greenhouse Gas Emissions Report.

Lima, I., F. Ramos, L. Bambace, and R. Rosa. 2007. Methane emissions from large dams as renewable energy resources: A developing nation perspective. Mitigation and Adaptive Strategies for Global Change. DOI 10.1007/s11027-007-9086-5.

Live Smart BC. 2012. Making Progress on B.C.'s Climate Action Plan.

Netherlands Environmental Assessment Agency. 2011. Long-Term Trend in Global CO_2 Emissions.

Soumis, N., M. Lucotte, and R. Canuel. 2005. Hydroelectric reservoir as anthropogenic sources of greenhouse gases. pp. 203-210. In: J.H. Lehr and J Keeley (eds.). Water Encyclopedia: Surface and Agricultural Water. Wiley-Interscience, Hoboken, NJ.

St. Louis, V.L., C.A. Kelly, E. Duchemin, J.W. Rudd, and D.M. Rosenberg. 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: A global estimate. *BioScience* Vol. 50(9):766–775.

Teodoru, C., J. Bastien, M. Bonneville, P.A. del Giorgio, M. Demarty, M. Garneau, J. Hélie, L. Pelletier, Y.T. Prairie, N. Roulet, I.B. Strachan, and A. Tremblay. 2012. The net carbon footprint of a newly created boreal hydroelectric reservoir. *Global Biogeochemical Cycles.* Vol. 26. GB2016. doi:10.1029/2011GB004187

Tremblay, A., J. Therrien, B. Hamlin, E. Wichmann, and L.J. LeDrew. 2005. GHG Emissions from Boreal Reservoirs and Natural Aquatic Ecosystems. p. 209–232 In Tremblay, A., Varfalvy, L., C. Roehm and M. Garneau, Eds. Greenhouse Gas Emissions: Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments. Environmental Science. New York: Springer. 732 pp.

Tremblay, A., L. Varfalvy, C. Roehm, and M. Garneau. 2004a. The issue of greenhouse gases from hydroelectric reservoirs: from boreal to tropical regions. In: Proceedings of the United Nations Symposium on Hydropower and Sustainable Development, Beijing, China, October 27–29, 2004.

Tremblay, A., M. Lambert, and L. Gagnon. 2004b. Do hydroelectric reservoirs emit greenhouse gases? *Environmental Management*. Vol. 33. (Suppl. 1):S509–S517.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2006. UNESCO Workshop on Greenhouse-Gas Emissions from Freshwater Reservoir. 5-6 December, 2006.

United States Environmental Protection Agency (US EPA). 2011. DRAFT: Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990 – 2030. Office of Atmospheric Programs Climate Change Division.

Internet Sites

Environment Canada. 2010. Greenhouse Gas Online Data Search. Available at: from http://www.ec.gc.ca/pdb/ghg/onlinedata/data Search_e.cfm. Accessed on October 24, 2012.

Environment Canada. 2012. National Inventory Report: (1990-2010) Greenhouse Gas Sources and Sinks in Canada, published in April 2012, Part 3: Annex 13. Available at: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php. Accessed: October 2012.

International Energy Agency (IEA). 2000. Implementing agreement for hydropower technologies and programs. Annex III: Hydropower and the environment. Available at: www.ieahydro.org. Accessed: November 2009.

International Rivers Network (IRN). 2006. Fizzy Science. Loosening the Hydro Industry's Grip on Reservoir Greenhouse Gas Emissions Research. 24 pp. Available at: www.irn.org. Accessed: October 2008.

Western Climate Initiative (WCI). Final Essential Requirements of Mandatory Reporting, 2011 Amendments for Harmonization of Reporting in Canadian Jurisdictions, December 2011, published in February 2012. Available at: http://www.westernclimateinitiative.org/document-archives/Reporting-Committee-Documents/Final-Essential-Requirements-of-Mandatory-Reporting-(Second-Update). Accessed: October 2012.