Needs For and Alternatives To

APPENDIX 7.3

Life Cycle Greenhouse Gas Assessment Overview

Life Cycle Greenhouse Gas Assessment Overview

Introduction

Manitoba Hydro contracted the Pembina Institute to prepare a detailed quantitative life cycle analysis (LCA) of the greenhouse gas (GHG) emissions for both the Keeyask and Conawapa Generation Projects (including the associated principal and supporting structures and infrastructure). This document describes both the LCA methodology applied to Keeyask and Conawapa and presents the results of the analyses. The GHG life cycle impact for these projects are compared with that of six other electricity generating technologies. The displacement of GHG emissions due to increased energy exports are also considered and the net positive global life cycle GHG implications of the proposed generating stations are estimated.

LCA Approach and Methodology – Keeyask and Conawapa Generation Projects

LCA studies were used to estimate the GHG emissions resulting from the construction, land-use change, operation and decommissioning phases of the Keeyask and Conawapa Generation Projects. The LCA studies were conducted by the Pembina Institute using the ISO "Environmental Management – Life-Cycle Assessment – Principles and Framework" in ISO 14040:2006. Both the Keeyask and the Conawapa LCAs were based on a project life of 100 years.

The Keeyask and Conawapa G.S. were compared to common electricity generating technologies based on the life cycle GHG emissions produced as a result of delivering one gigawatt-hour (GWh) to the electrical distribution network. By using one GWh of electricity delivered as opposed to one GWh of electricity produced, these assessments took into consideration any losses associated with the transfer of electricity.

The LCA studies conducted for the Keeyask and Conawapa Generation Projects consider global GHG emission implications. The assessments, utilizing activity maps highlighting the major materials and processes, focused on four distinct phases of the projects: construction, land-use change, operation and maintenance, and decommissioning. Considering raw materials required, manufacturing of generating station components and transportation requirements, there are GHG emissions which occur outside of the province of Manitoba but are nonetheless captured in each LCA.

Life cycle GHG emissions associated with all significant materials and activities were accounted for and quantified within these studies. The Pembina Institute used the following principles to determine which activities to include in the analysis:

- Relative mass, energy or volume – If the activity required an insignificant amount of material or fuel, in terms of mass, volume or energy, relative to the whole, then the input was excluded. For this study a significant amount was qualified as greater than 1% of total material mass, volume or energy input to the life cycle.
- Environmental impact – If the material or fuel production is particularly GHG intensive then the material or fuel may be included even if it did not satisfy the relative mass principle. Some activities, such as the production of aluminum, are energy intensive, so while the mass used in the production of the generating station may be small, the environmental impact is comparatively large.
- Data availability – Regardless of the two points above, if the data was readily available then the value was included.

The majority of the data used in each LCA was based on early design stage material estimates provided by Manitoba Hydro in response to inquiries from the Pembina Institute. This data was supplemented with emission factor information from public life cycle data sets as necessary. A custom LCA model was developed to calculate the results and analyze the data.

In general, the LCA model can be broken down into three components: input, calculations and output. The input data includes all the life cycle data sets for activities such as steel manufacture. In addition, key factors such as transport distances, can be varied in the user input section. The analysis combines all the life cycle data and user inputs to calculate emissions for all of the stages of the hydroelectric facilities including construction, operation and decommissioning. The model summarizes the results in various tables and graphs.

GHGs include gases that absorb infrared radiation emitted by the Earth's surface. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the principal GHGs relevant to Keeyask and Conawapa.

The LCA for both Keeyask and Conawapa are based on several important assumptions and notable details that influenced the results of the analyses. The most significant assumptions are listed below.

- **Delivered Electricity**: Transmission of electricity over long distances results in losses of energy. Incorporating transmission losses into a LCA reduces the amount of consumable energy at major load centers and correspondingly increase the GHG emission intensity of the project facility. Thermal generation plants, such as natural gas-fired turbines, can be located closer to the actual users of the electricity while the Keeyask and Conawapa Generation Projects are a considerable distance from the consumer. After accounting for these losses, the LCA analysis assumes that the Keeyask and Conawapa Generation Projects will deliver annual energies of 4,000 GWh and 6,300 GWh respectively for use at major load centers.
- **Material Sourcing:** The data used in the LCA was based on the best available at the time of analysis. In general, specific material suppliers (such as concrete and steel) were not known. Therefore, assumptions were made based on past Manitoba Hydro experience and to ensure the analyses were conservative. For example, while steel production contains a significant portion of recycled iron, the analyses assumed 100% virgin material.
- **Land use change**: Manitoba Hydro considered GHG implications associated with the various land areas required for each of the projects. Specific types of land disturbance

are treated differently within each of the studies. The life cycle assessments categorize areas of land use change as either temporary or permanent. Areas such as borrow areas are considered temporary disturbances that are subject to equivalent re-growth within the time frame of the life cycle assessment and as such, are not included in the GHG emission calculations. Areas categorized as permanent include those that would remain permanently cleared or would be permanently changed to a different density of above ground biomass. For these types of disturbances, the net change in above ground biomass (initial minus final) is considered. For example, the biomass cleared for transmission right-of-ways are partially offset by new shrub and grassland biomass. For areas such as the roads and permanent infrastructure areas, the initial above ground biomass is not offset by any re-growth. Reservoirs are another area of permanent land-use change. GHG emissions resulting from flooding are a result of the conversion of a portion of the flooded carbon in vegetation and soils primarily to CO_2 and CH_4. An Intergovernmental Panel on Climate Change (IPCC) methodology was used to determine reservoir GHG emissions. In addition to the aquatic emissions associated with flooding, GHG emission estimates include emissions from the clearing and assumed burning of the above ground biomass prior to flooding.

Comparison Technologies Methodology

The six comparison technologies researched for these assessments were supercritical pulverized coal combustion, coal with carbon capture and storage, natural gas fired combined cycle, natural gas fired single/simple cycle, wind and nuclear. The Pembina Institute determined the life cycle emission intensities for the comparison technologies using a different approach than the one used for the hydroelectric generating stations. The comparison technology intensities were based on the results of a literature survey of published life cycle values. Once the literature review was complete, the list of values (a minimum of six for each technology) was analyzed and the median, average, maximum and minimum values determined. A brief description of the characteristics of the technologies from the literature survey is presented below:

Supercritical and Subcritical Pulverized Coal Combustion (PCC)

In older power plants, coal is combusted to produce subcritical steam, but greater efficiencies can be obtained by using higher steam pressures and temperatures in the supercritical range. Both subcritical and supercritical processes begin with grinding the coal into a fine powder. The powdered coal is blown with air into the boiler through a series of burner nozzles where combustion takes place at over 1,300°C. Higher steam temperature and pressures allow for higher achievable energy efficiencies of 38–45%, compared with 33% for subcritical plants. PCC plants generate a reliable supply of electricity, typically used to provide base load power to the grid, with an average capacity factor of 70–90%. However, coal power plants have limited flexibility to meet peak demand.

Coal with Carbon Capture and Storage (CCS)

CCS may become feasible for large point sources of CO_2, such as new or existing coal-fired power plants. During the CCS process CO_2 is separated from the other exhaust gases by using a commercial capture technology such as chemical or physical absorption. The captured CO_2 is compressed and transported in pipelines at high pressure to a storage location within or outside a plant's boundaries. The CO_2 is eventually pumped underground for storage.

Storage options in Canada include deep saline aquifers as well as depleted gas, oil and bitumen reservoirs. Another Canadian storage option is to inject CO_2 into existing oil and gas reservoirs that are nearing depletion in order to increase oil and gas recovery (i.e. enhanced oil recovery).

Capturing and compressing CO_2 requires a large amount of energy and increases the fuel requirements of a coal-fired plant by 25–40%, according to the IPCC. There are currently four industrial-scale CCS projects in operation worldwide.

Combined Cycle Gas Turbine (CCGT)

A CCGT plant combusts natural gas in a gas turbine to produce electricity. The turbine produces a significant amount of hot exhaust gas, which in a combined cycle power plant is used to generate steam. This steam is then used to produce additional electricity in a steam turbine. A CCGT plant can have efficiencies up to 60% and can be built in modules to accommodate a range of power demands. This type of electricity plant supplies both base load and peak demands. Capacity factors for a natural gas fired power plant are typically between 50-70%.

Simple Cycle Gas Turbine (SCGT)

The SCGT combustion process is identical to combined cycle except excess heat is wasted and not captured for further electricity generation. Single cycle gas turbine plants are sometimes installed as emergency or peaking capacity to help balance electricity production and loads on the electrical grid. The efficiency of a SCGT plant is 35–40%. These plants can be built modularly to satisfy a range of electricity demand.

Wind (Larger than 100 MW)

Wind farms consist of multiple wind turbines that convert wind energy into electricity from blades turning a generator. Turbines are built to adapt to changing wind conditions. The blades can be positioned to face the wind to optimize electricity generation from wind coming from nearly any direction. Wind farms contain individual turbines as large as three megawatts (MW). Since wind speeds are not constant, typical wind farms exhibit capacity factors of 20–40%. Wind power is intermittent therefore one critique is that wind cannot supply reliable base load electricity to the grid.

Nuclear

There are several reactor technologies used in the world, but all of them operate on the same principle: Fission heat is used to generate steam which is subsequently used to generate electricity in a steam turbine. Canadian nuclear power plants use Canadian Deuterium-Uranium

(CANDU) reactor technology to generate electricity. The Enhanced CANDU 6 design delivers a gross output of 740 MW per unit. Nuclear power generation is a consistent source of electricity for base load power, but there is almost no flexibility to meet peak demand. Nuclear power plants have capacity factors from 60–100%. There are currently five commercial nuclear power generating stations in Canada, all using CANDU reactors.

Results

The quantitative LCA results are disaggregated into emissions from construction (material production, transportation and construction of the facility), land use change, operation and maintenance and decommissioning of the generating station after 100 years of operation. The comparison technology life cycle data are based on a literature survey of published life cycle journal articles. Some of the journal articles are themselves literature surveys. The results below are therefore based on the median of many LCAs.

Table 1 summarizes the GHG emissions per project phase for the proposed Keeyask and Conawapa G.S. The construction phase includes all emissions on and off the project site released while the facility is being constructed. The operation phase includes all emissions from the first day of operation to when the facility is decommissioned, namely material replacement related GHG emissions. The decommissioning phase includes only emissions associated with decommissioning the facility and recycling available materials. Land use change emissions include carbon stock changes that occur during the construction phase due to clearing for permanent project features and reservoir emissions during the operation phase including biomass decomposition.

Table 1. SUMMARY OF LIFE CYCLE GHG EMISSIONS FOR THE PROPOSED KEEYASK AND CONAWAPA GENERATION PROJECTS

Construction			**Land Use Change**	**Operation**	**Decommissioning**	**Total**
Building Material Manufacture	Transportation	On-Site Construction Activities	Reservoir and Carbon Stock Changes	Maintenance and Refurbishment	Decommissioning and Recycling Activities	
Keeyask Generation Station						
0.68 t CO_2e/GWh	0.12 t CO_2e/GWh	0.34 t CO_2e/GWh	1.24 t CO_2e/GWh	0.03 t CO_2e/GWh	0.05 t CO_2e/GWh	**2.46 t CO_2e/GWh**
Conawapa Generation Station						
0.76 t CO_2e/GWh	0.15 t CO_2e/GWh	0.32 t CO_2e/GWh	0.15 t CO_2e/GWh	0.01 t CO_2e/GWh	0.04 t CO_2e/GWh	**1.43 t CO_2e/GWh**

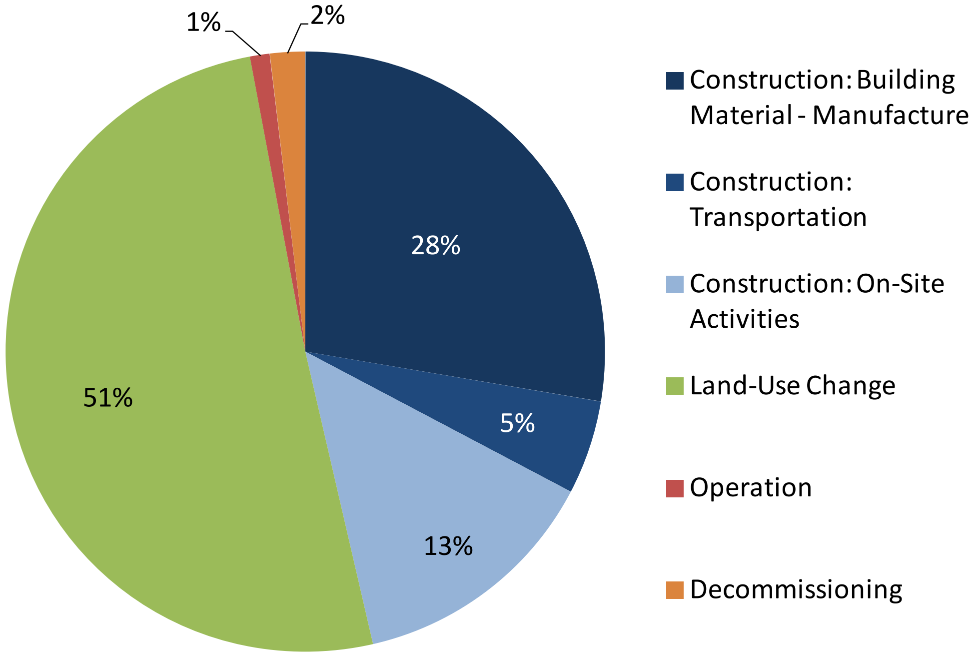
Keeyask Generation Project GHG LCA Results

Over its 100 year life, the Keeyask Generation Project is estimated to produce approximately 980,000 tonnes of CO_2e (carbon dioxide equivalent. GHG emissions associated with the construction phase of the project account for approximately 46% of the life cycle GHG emissions. The majority (60%) of the construction phase emissions result from building material manufacture. GHG emissions from the transportation of the materials and components to site are significant contributors to the construction phase emissions. The lengthy transportation distances assumed (the quantity of steel sourced from overseas for example) are responsible for the conservatively high life cycle transport related emissions. Emissions from onsite construction activities result from diesel combustion in construction equipment including trucks, backhoes, excavators and bulldozers.

Estimated land use change emissions account for 51% of all GHG emissions. The majority of land use change emissions are associated with the flooding of the reservoir (95%). The remaining 5% result from land cleared for roadways, transmission lines and the dykes. GHG emissions during the operation phase of the Keeyask project are primarily associated with offsite activities such as the production of replacement equipment, recycling of the damaged or worn steel components and concrete replacement. The majority of the GHG emissions associated with decommissioning result from recycling of steel components and onsite diesel combustion in demolition equipment.

Figure 1 presents the life cycle Keeyask GHG emissions disaggregated by project phase.

Figure 1. **KEEYASK GENERATION PROJECT - BREAKDOWN OF GHG EMISSIONS PER PRIMARY ACTIVITY**



Conawapa Generation Project GHG LCA Results

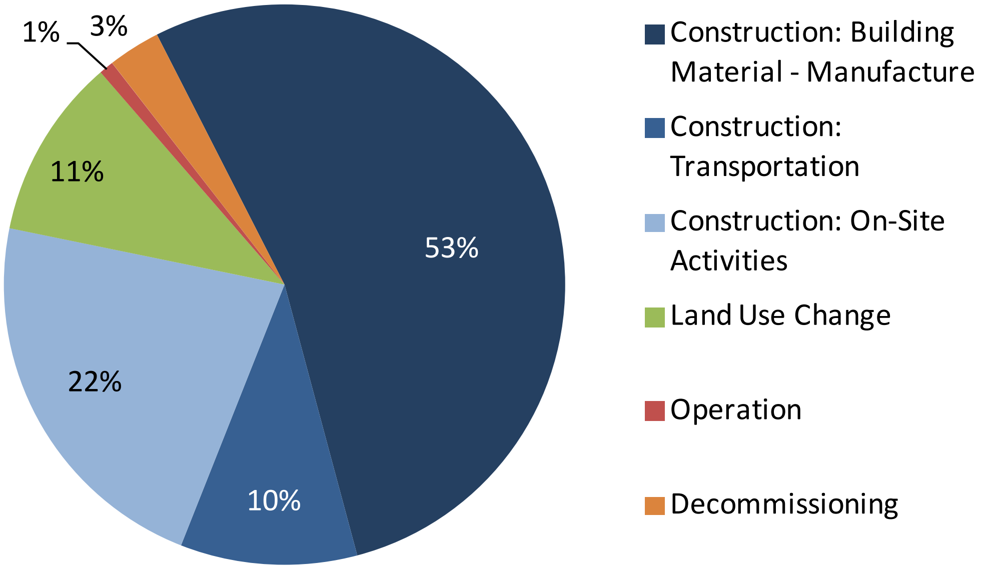
Over its 100 year life, the Conawapa Generation Project is estimated to produce approximately 900,000 tonnes of CO_2e. The construction phase is responsible for the majority (86%) of life cycle GHG emissions. Within the construction phase, 62% of emissions result from building material manufacture. Steel production including mining and processing is responsible for 33% of construction emissions and 28% of total life cycle GHG emissions. GHG emissions resulting from on-site construction activities, namely combustion of diesel for construction equipment, amount to 25% of construction emissions. GHG emissions from the transportation of the materials and components to site contribute roughly 12% of construction phase emissions. As with Keeyask Project, the lengthy transportation distances assumed (the quantity of steel sourced from oversees for example) are responsible for the conservatively high life cycle transport related emissions.

Land use change emissions account for 10% of all GHG emissions. This is significantly lower than the results of the LCA completed for the Keeyask Project. Conawapa is expected to produce more electricity but the area flooded is less than 25% of the area flooded by the Keeyask Project. The lower ratio of flooded land to electricity produced yields a much lower contribution of land use to overall GHG emissions in the Conawapa LCA. Land use change emissions associated with reservoir flooding and burning of biomass accounted for the majority (77%) of overall land use change emissions. The remaining 23% result from land cleared for roadways, portages, the dam and cofferdam, work areas and other terrestrial areas not associated with the reservoir.

As with the Keeyask Project, GHG emissions during the operation phase of the project are primarily associated with off-site activities such as the production of replacement equipment, and recycling and transportation of the damaged or worn steel components. The majority of the GHG emissions associated with decommissioning result from recycling of steel components and on-site diesel combustion in demolition equipment.

Figure 2 presents the life cycle Conawapa Generation Project GHG emissions disaggregated by project phase.

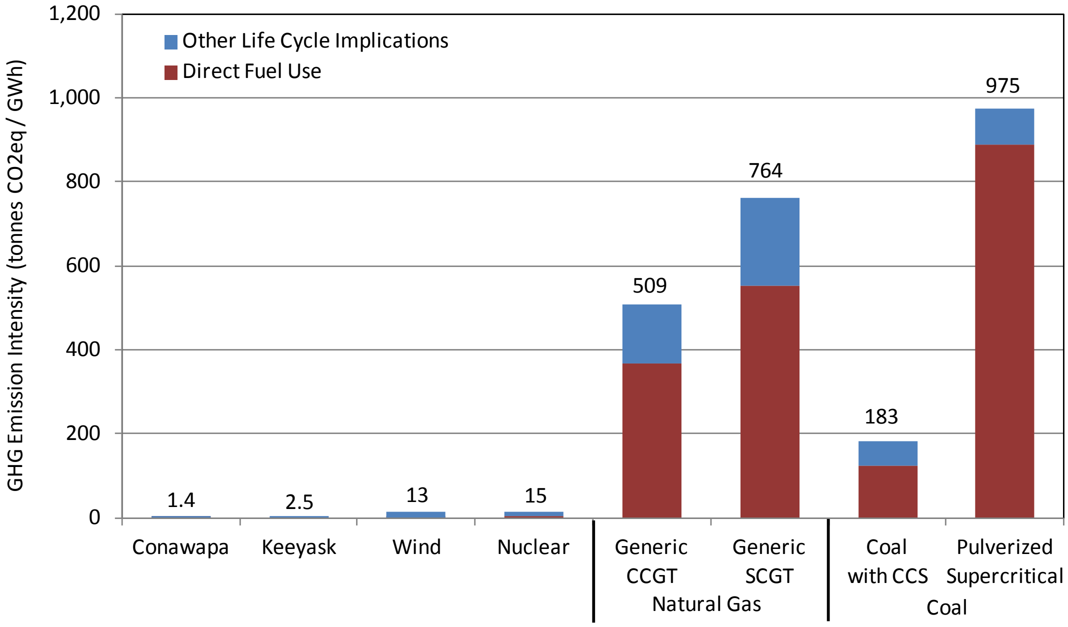
Figure 2. CONAWAPA GENERATION PROJECT - BREAKDOWN OF GHG EMISSIONS PER PRIMARY ACTIVITY



Comparison with Other Power Generation Technologies

As shown in Figure 3, life cycle GHG emissions on a per GWh basis are significantly lower for the proposed hydro electric generation projects than for all of the fossil fuel alternatives (supercritical PCC, CCGT, SCGT, coal with CSS). In addition, the life cycle GHG results for both Keeyask and Conawapa projects indicate lower emission intensities than the two non-fossil fuel options: nuclear and large commercial scale wind generation. To illustrate the magnitude of the difference between technologies, consider that over its 100 year life, the Keeyask project is estimated to result in 980,000 tonnes of CO_2e. Using the data from Figure 3, an identically sized combined cycle natural gas fired generation facility would release the same GHG emissions in less than half a year of continuous full capacity operation. Gross life cycle GHG emissions from the Conawapa project were determined to be even lower. For Conawapa, an identically sized combined cycle natural gas fired generation facility would release the same GHG emissions in less than 100 days of continuous full capacity operation.

Figure 3. **COMPARISON OF LIFECYCLE GHG EMISSIONS FOR ELECTRICITY GENERATION**



Greenhouse Gas Displacement

It is assumed that the energy produced by Keeyask and Conawapa Generation Projects (less transmission losses) will displace a variety of fossil-fuelled generation. The electricity sector is well integrated and changes to the Manitoba Hydro system have effects beyond the provincial borders of Manitoba. The U.S. mid-west, which Manitoba Hydro is interconnected with and exports energy to, relies heavily on fossil fuel generation. Analysis of the electricity market allows an estimate of the avoided GHG emissions due to energy being injected into the regional energy markets from Manitoba.

Conventional coal generation is typically on the order of 900 to 1,100 tonne CO_2e/GWh while natural gas can range from about 300 to 800 tonnes CO_2e/GWh depending on the specific technology and its efficiency. Manitoba Hydro currently assumes that its net exports displace and its imports result in 750 tonnes CO_2e/GWh. This reflects a marginal generation mix of various fossil-fuels and technologies. Given that the current marginal generation remains primarily coal the 750 tonnes of CO_2e/GWh factor used by Manitoba Hydro is considered to underestimate the emissions displaced by exports.

Comparing the 750 tonnes CO_2e/GWh displacement intensity with the 1.4 and 2.5 tonnes CO_2e/GWh (see figure 3) LCA GHG intensities of the proposed projects, there is a clear net GHG emission displacement benefit of approximately 748 tonnes CO_2e/GWh. The net positive effect of the Keeyask and Conawapa Generation Projects on climate change reflects the small life cycle GHG emissions of the proposed projects versus the much more significant emission reductions that will result from the displacement of high GHG intensity sources of generation.