Greenhouse Gas Life Cycle Assessment of the Manitoba–Minnesota Transmission Project

The Pembina Institute

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About the Pembina Institute

The Pembina Institute is a national non-partisan think tank that advances clean energy solutions through research, education, consulting and advocacy. We have spent close to three decades working to reduce the environmental impacts of Canada's energy production and use in several key areas:

- driving down energy demand by encouraging energy efficiency and transportation powered with cleaner energy sources;
- promoting pragmatic policy approaches for governments to avoid dangerous climate change, such as increasing the amount of renewable energy plugged into our electricity grids;
- and — recognizing that the transition to clean energy will include fossil fuels for some time — advocating for responsible development of Canada's oilsands and shale gas resources.

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1. Executive summary

Manitoba Hydro is proposing the development of the Manitoba–Minnesota Transmission Project (MMTP), which includes a new transmission line that will extend from the Dorsey converter station, through southeast Manitoba, to the U.S. border. The Project also includes the construction of terminal equipment at the Dorsey converter station, electrical upgrades within the Dorsey and Riel converter stations, and modifications at the Glenboro south station.

Manitoba Hydro contracted the Pembina Institute to prepare a quantitative greenhouse gas (GHG) life cycle assessment of the MMTP. This report presents details of the assessment process and the results for the MMTP.

The MMTP is estimated to result in 171,081 tonnes CO_{2eq} in GHG emissions due to its non-generation impacts. These impacts include GHG emissions related to the construction, operation, and decommissioning of the project's components as well as emissions related to land use change. Of this, the transmission line elements account for 165,298 tonnes of CO_{2eq} and the station upgrades account for 5,783 tonnes of CO_{2eq}. Figure 1 summarizes the results of the assessment by life cycle stage.

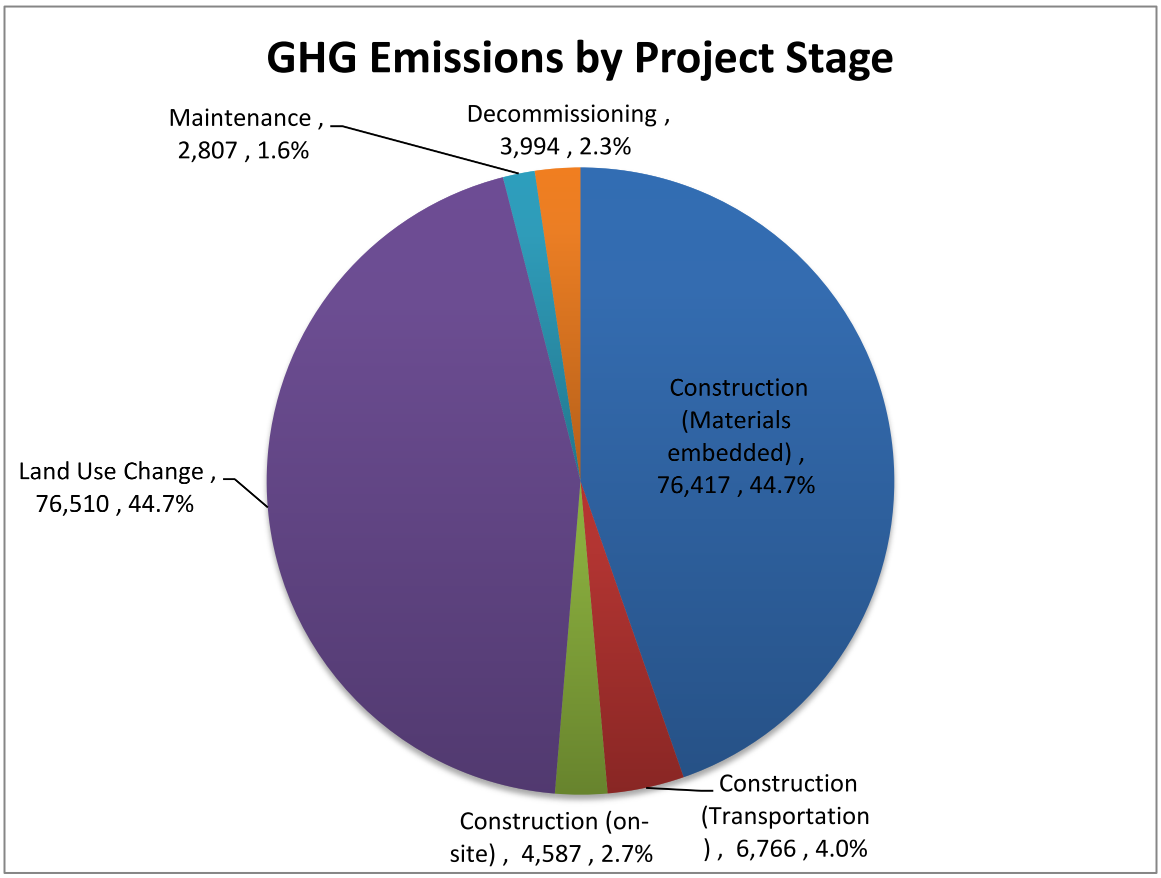

Figure 1: Summary of GHG emissions by project stage, excluding generation effects

Building transmission projects such as the MMTP can influence how generation is used on both sides of the border. These influences are referred to as "generation effects." Predictions of generation effects are very uncertain and are typically much greater in magnitude than estimations of non-generation impacts[1]. When both the generation and non-generation impacts of the MMTP are considered, LCA indicates that the MMTP is expected to produce a net reduction in global GHG emissions. The implications of the MMTP's generation effects are not the primary objective of this report; however, estimates were prepared separately in analysis performed by Manitoba Hydro.

[1] World Bank, *"Impacts of Transmission and Distribution Projects on Greenhouse Gas Emissions"*, 2010

2. Introduction

2.1 Background[2]

Manitoba Hydro contracted the Pembina Institute to prepare a quantitative greenhouse gas (GHG) life cycle assessment (LCA) of the Manitoba–Minnesota Transmission Project (MMTP). This report presents details of the LCA process and the results.

Manitoba Hydro is proposing the construction of a 500-kilovolt (kV) alternating current (AC) transmission line from the Dorsey converter station to the international border between Manitoba and Minnesota, located south of the community of Piney. The MMTP also includes upgrades to associated Manitoba Hydro stations at Dorsey, Riel, and Glenboro South.

The transmission line has two main sections:

- Southern Loop Transmission Corridor Section (68 km) — Located between the Dorsey station (near Rosser) and the Riel station (east of Winnipeg), the Southern Loop Transmission Corridor (SLTC) follows the western and southern boundaries of the City of Winnipeg.
- Southern Loop Transmission Corridor to U.S. Border Section (148 km) — From the SLTC, the 500 kV transmission line will proceed southeast using a combination of new rights-of-way (ROWs) and existing Manitoba Hydro ROWs, including the Riel-Vivian Transmission Corridor, where feasible. New ROWs are expected to contribute approximately 121 km to the overall length and will cross the rural municipalities of Springfield, Tache, Ste. Anne, La Broquerie, Stuartburn and Piney.

The principles of the LCA process, methodology, and project objectives are described below. These sections are followed by a description of the project, the methodology used to quantify life cycle emissions for the project, and the results of the analysis and conclusions.

2.2 LCA process and methodology

The analysis presented in this report follows the ISO 14040 life cycle standard.[3] The following is a generic description of the LCA methodology. A more detailed description of the methodology used in this assessment is available in Section 3. In general, LCAs include five distinct steps:

1. **Goal definition:** This phase includes understanding the background of the project, listing the primary questions that need to be answered, and determining the objectives.
2. **Scoping:** This phase includes determining the common basis of comparison or functional unit, the key activities to be included in the project (e.g., producing cement for

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[2] Information for this section was obtained from *Manitoba–Minnesota Transmission Project – Project Description Draft*, Manitoba Hydro, November 2014

[3] ISO, "Environmental Management - Life Cycle Assessment - Principles and Framework," in *ISO 14040:2006(E)*, ed. ISO (2006).

construction of the tower bases), and the evaluation criteria that should be used. The appendices provide more detail about the scoping phase.

3. **Inventory assessment:** This phase includes gathering and analyzing data to fulfill the requirements of the goal definition and scoping stages. Manitoba Hydro provided the majority of the data used in the assessment. The Pembina Institute developed a custom LCA model to analyze the Manitoba Hydro data and calculate results. All data provided by Manitoba Hydro and acquired from public sources for use in the assessment are available in the appendices.

   Comparisons with other options are not included in this assessment. The results will be used to establish the life cycle GHG emissions associated with the project as part of an Environmental Impact Statement (EIS), and not to compare with other options.

4. **Impact assessment:** This phase includes assessing the results of the inventory assessment in a broader context. Manitoba Hydro will compare and discuss the broader context of the MMTP, including the relative magnitude of its life cycle GHG emissions, in the Environmental Impact Statement.

5. **Report writing:** The final phase includes the communication of the above steps in a concise and transparent report. All results, methodologies, assumptions, and sources should be included in the final report. This report and its appendices satisfy this portion of the life cycle methodology.

This analysis also follows the ISO LCA principles:

1. Life cycle perspective
2. Environmental focus
3. Relative approach and functional unit
4. Iterative approach
5. Transparency
6. Comprehensiveness
7. Priority of scientific approach

2.3 Project objectives

The primary objective of this LCA is to quantify the non-generation life cycle GHG emissions associated with the construction, operation, and decommissioning of the MMTP for incorporation into its EIS. In addition to impacts on climate change, the EIS will evaluate environmental impacts of the MMTP that are not directly assessed in this LCA. The EIS will be submitted to both provincial and national regulatory agencies and made available for public engagement participants.

3. Detailed information on MMTP

Manitoba Hydro is proposing the MMTP to achieve the following:

1. Capitalize on the opportunity provided by the additional surplus generation capacity of new northern generating facilities to contract export power to out-of-province customers.
2. Improve system reliability in Manitoba by allowing for additional import of electricity in emergency and drought situations.

The project is called the MMTP in Manitoba which links, from the U.S. border, to another project, the Great Northern Transmission Line (GNTL) in Minnesota. Figure 2 displays the preferred transmission route[4] as of January 2015. The MMTP will include the construction of the following:

- A 500-kV high voltage AC transmission line from the Dorsey station to the Manitoba-US border, where it will connect with the GNTL (to be constructed by Minnesota), which terminates at the Blackberry station near Grand Rapids.
- Upgrades to associated stations at Dorsey, Riel and Glenboro South in Manitoba.

The construction is estimated to collectively require the following materials, as detailed in Table 1 below.

[4] Manitoba Hydro, Manitoba–Minnesota Transmission Project preferred route. https://www.hydro.mb.ca/projects/mb_mn_transmission/pdfs/mmtp_preferred_route_map_january_2015.pdf

Table 1: Estimated materials required for construction in tonnes

Material (Tonnes)	Transmission line	Station upgrades	Total
Aluminum	3,763	75	3,838
Steel	5,863	500	6,363
Copper	0	149	149
Ceramics	394	156	550
Concrete	9,680	1,204	10,884
Wood Matting	8,650	-	8,650
Diesel[5]	1,026	46	1,072

The MMTP is estimated to cover almost 3,200 ha of land of which approximately 550 ha will be permanently disturbed to maintain the right-of-way (ROW), station upgrades, and the tower footprint.

[5] Diesel volumes include the diesel consumed for on-site activities: clearing of ROW, and construction of transmission line and station upgrades

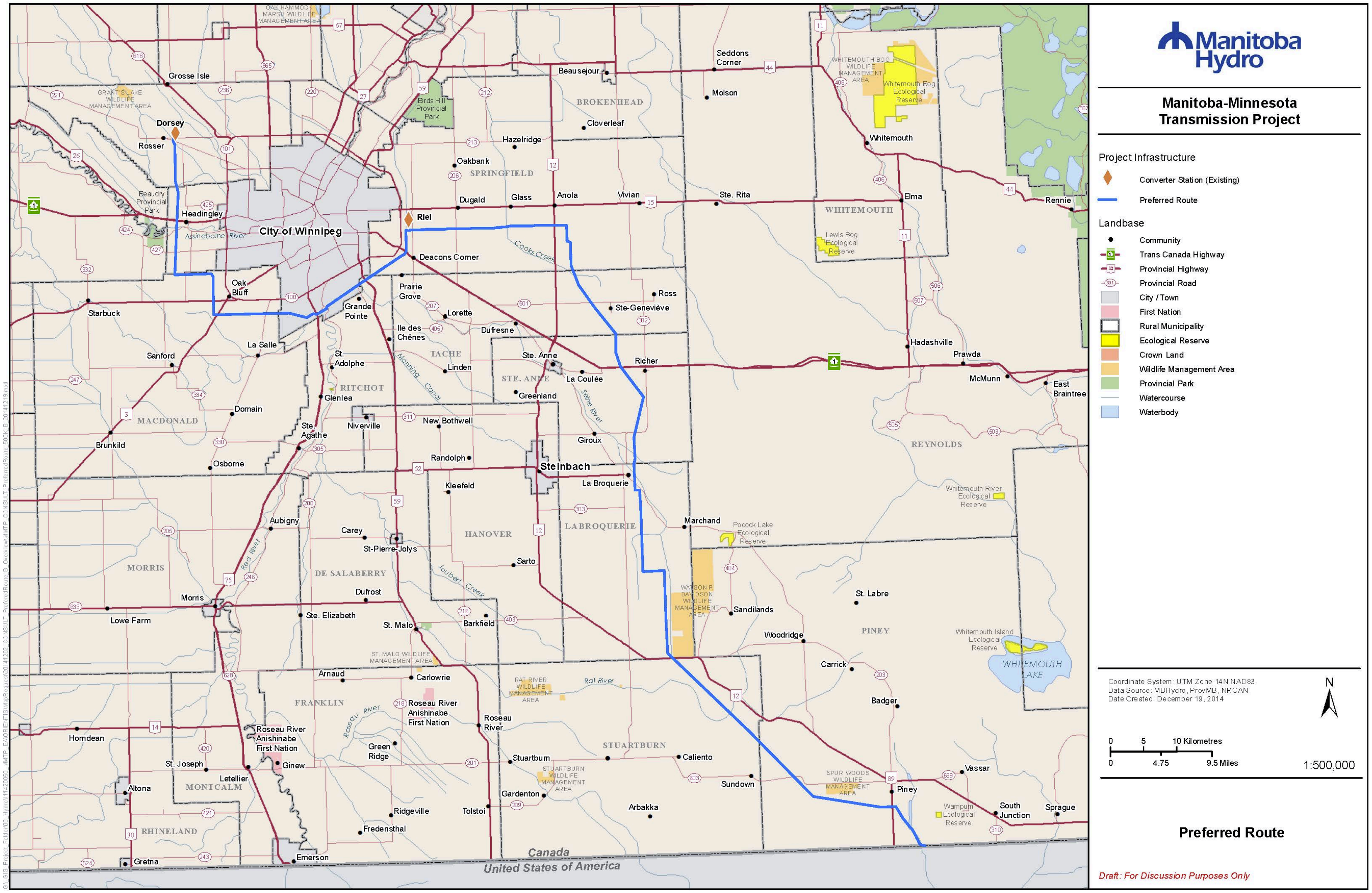

Figure 2: Final preferred route as of January 2015

4. Methodology

4.1 Basis of analysis

This assessment derives life cycle GHG emissions associated with the MMTP through an analysis of the materials and energy-use associated with the proposed route and required capital equipment. The results are presented as both absolute emissions (in the body of the report) and on an intensity basis as tonnes CO_{2eq} per GWh of additional transmitted electricity (in Appendix 3 – Detailed Results).

Criterion [Metric/Indicator]	**Relevance and Importance**
Greenhouse gases (GHGs) [t CO_{2eq}]	Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. Emissions scenarios leading to CO_2-equivalent concentrations in 2100 of about 450 ppm or lower are likely to maintain warming below 2°C over the 21st century relative to pre-industrial levels. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010, and emissions levels near zero or below in 2100.[6] In Canada, electricity and heat generation account for 12.7% of the national emissions in 2012.[7] World-wide, electricity and heat generation contributed to 33% of the total emissions in 2011[8]

To assess the impact of GHG emissions on long-term global climate change, this LCA uses the Intergovernmental Panel on Climate Change's (IPCC) 100-year baseline model to calculate tonnes CO_2eq. Although multiple metrics are available, 100-year global warming potentials (GWPs) are industry standard. This study uses the GWPs from the IPCC's 4th assessment report, which is currently used by Environment Canada for GHG reporting purposes.[9]

4.2 Boundary selection

The first step in the LCA process is to determine the boundaries of the assessment. This consists of defining which activities, such as producing steel or concrete, are significant and which should

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[6] *Climate Change 2014 Synthesis Report Summary for Policymakers,* IPCC 5th Assessement Report.

[7] *Canada's Electricity Industry*, Canadian Electricity Association, http://www.electricity.ca/media/Electricity101/Electricity101.pdf

[8] CAIT International Dataset available through https://www.google.com/publicdata/overview?ds=cjsdgb406s3np_

[9] *Global Warming Potentials* (Environment Canada) http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=CAD07259-1

be included in the assessment. Figure 3 shows a simplified life cycle activity map of the activities considered for inclusion in the analysis. A more detailed activity map is available in Appendix 1 – Scoping, along with a detailed list of included and excluded activities.

The life cycle of the MMTP was divided into three phases: construction; operation and maintenance of the proposed structures; and finally decommissioning of the proposed structures. Emissions due to land use change were also included in the analysis.

In addition to selecting which MMTP phases to include, the activities within each of those phases had to be assessed for inclusion. Accounting for and quantifying the life cycle emissions associated with every material required for the construction and operation of the MMTP is not practical from a time and cost perspective. In addition, including all activities does not necessarily materially change the results. For example, for a theoretical project that required 100 kilograms of titanium and 20,000 tonnes of steel, the amount of analysis required to include the titanium is the same as including the steel; however, the titanium is only 0.0005% of the mass of the steel and would likely have a similarly negligible impact on the results of the analysis.

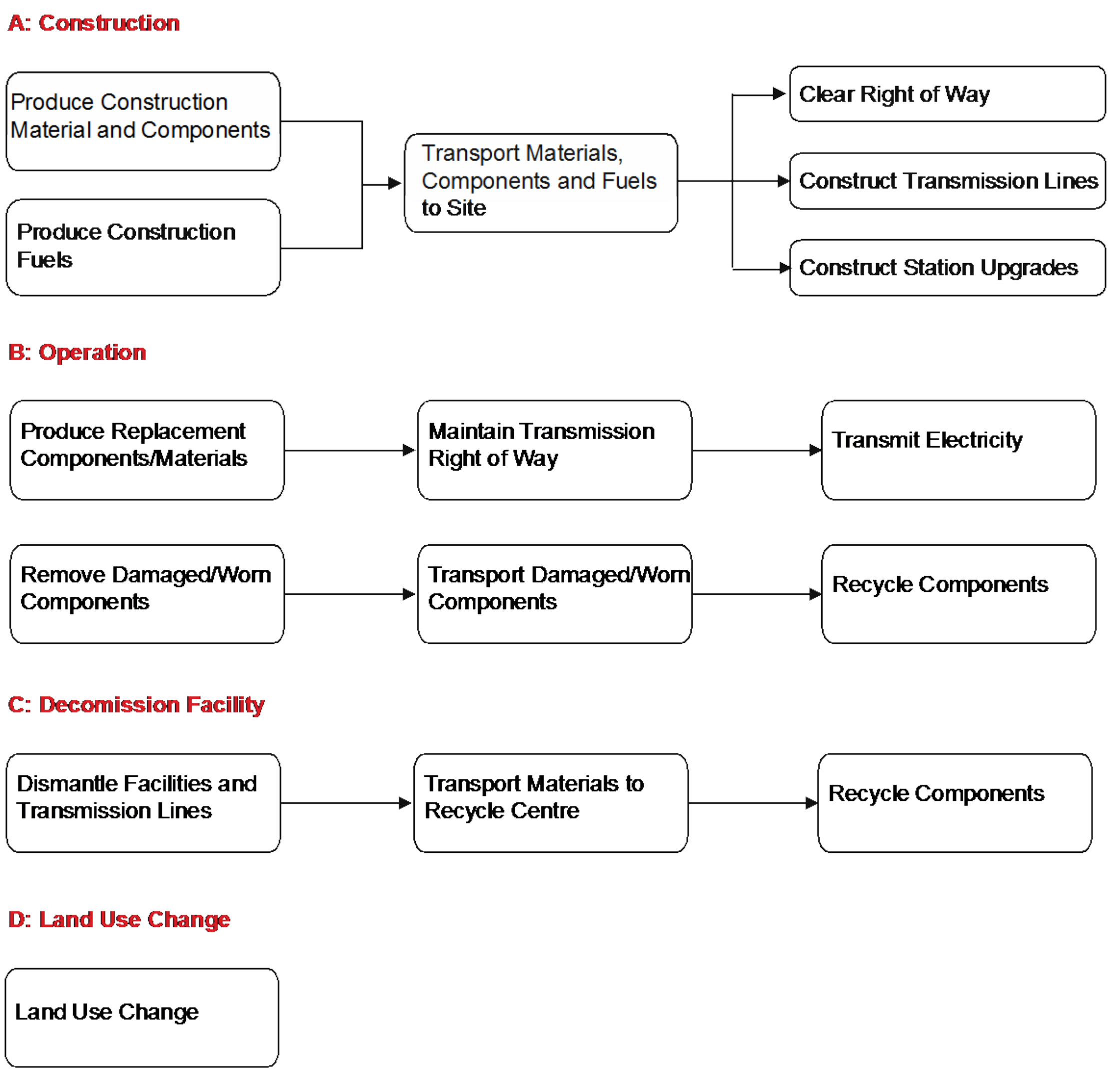


Figure 3: Simplified life cycle activity map

The Pembina Institute used the following principles to determine which activities to include and which to exclude:

1. **Relative mass, energy or volume:** If the activity required an insignificant amount (by mass, volume or energy) of material or fuel relative to the whole, then the input was excluded. Significance was evaluated as greater than 1% of total material mass, volume, or energy input to the life cycle. For example, the main inputs to the system are concrete, aluminum, steel, copper, ceramics, and diesel fuel. Any material input less than 1% of the total mass of concrete and steel was generally not included, unless Principles 2 or 3 were true.

2. **Environmental effect:** If the material or fuel production was particularly GHG-intensive then the material or fuel was included even if it did not satisfy Principle 1. For example, the project could emit 1.61 kg of sulphur hexafluoride (SF_6) per year over the life of the project; there is a high degree of uncertainty regarding this estimate. On a mass basis this contribution is relatively minor. However, SF_6 has a global warming potential 22,800

times that of CO_2, so SF_6 was included in the analysis as it is responsible for ~1% of life cycle emissions.

3. **Data availability:** Regardless of Principles 1 and 2, if the data was readily available then the value was included.
4. **MMTP Physical Boundary:** The MMTP is a component of an international transmission line that also involves another project, the GNTL in Minnesota. Only MMTP sub-components were evaluated in this LCA. As its own project, the GNTL will be undergoing its own separate environmental evaluation.

A detailed list of included and excluded activities is available in Appendix 1 – Scoping.

4.3 Calculation methodology

Calculations carried out in the model generally took the form of Equation 1 shown below:

$$\boldsymbol{Material\ Quantity \times Emissions\ Factor = Quantity\ of\ Carbon\ Dioxide\ Equivalent}$$

Equation 1: General form of calculations

Appendix 5 – Model Functionality presents both a high-level overview of how the model was used to generate emissions results, and a sample calculation using steel production as an example. Emission factors for specific processes were generally taken from the results of publically available LCA studies. The model, and hence the calculation methodology, was adapted from previous LCAs that have been performed for Manitoba Hydro project analyses, such as for Conawapa and Keeyask Generation Projects and for the Bipole III transmission line.

4.4 Key assumptions

The LCA was based on several important assumptions and notable facility details that influenced the results of the analysis. The most significant assumptions and details are listed below. A more detailed list of assumptions and justifications is available in Appendix 1 – Scoping.

- **Functional unit:** The functional unit for this assessment is 1 GWh of additional transmitted electricity, i.e. electricity imported and exported across the border as a result of the new transmission line that are additional to the imports and exports on current interconnections. The import and export estimates are based on Manitoba Hydro analysis. Results in the main body of the report are in total emissions. Intensity results are available in Appendix 3 – Detailed Results.
- **Cement production and transportation:** Manitoba Hydro has yet to contract cement suppliers at this design stage. This assessment assumed that all cement is produced in Edmonton and then transported to the construction sites by rail and truck[10] — a process that Manitoba Hydro has followed in the past for its hydro and transmission construction projects. The concrete is assumed to be manufactured at local batch processing facilities in Manitoba.

[10] Manitoba Hydro, personal communication, March 2009.

- **Steel production and transportation:** Steel components may be sourced from many different locations around the world. This assessment conservatively assumes that all steel comes from India and is shipped to Vancouver by ship, then by rail to Winnipeg, and by truck to site.
- **Replacement components:** This assessment assumes that all components will last the lifetime of the MMTP. Any replacements due to malfunction will have negligible impact.
- **Recycling:** All steel, aluminum and copper materials removed at the end of the MMTP are recycled. Aluminum and copper recycling emission intensities are based on generic North American recycling factors.[11] Steel recycling is based on Manitoba-specific recycling factors. Manitoba Hydro is not credited for displacing virgin materials.
- **Project life:** The assessment assumes a project life of 50 years. However, when considering land use change we assume the forest cleared will not be allowed to regenerate in a 100-year period (see land use change below). In addition, any landfill modeling is carried over the standard practice of 100 years, with the emissions being reported as annual rates.
- **Land use change:** This assessment assumes that any forested and/or treed land along the full width of the ROW is completely cleared and converted to grassland. Other areas of low-lying vegetation such as wetlands, peatland, agricultural, riparian and shrub lands along the ROW are assumed to be minimally disturbed and, when disturbed for construction, are assumed to return to their natural state within the project life.

  Any disturbance of forested land is assumed to be permanent; that is, it will remain as grassland throughout the duration of the MMTP, and will contribute to life cycle GHG emissions. None of the cleared tree covered areas are treated as temporary in this analysis.

  Using the above assumptions, the MMTP is expected to permanently disturb approximately 550 ha of forested, semi-forested land, and non-forested land. This disturbance is associated with land clearing for the transmission line right of way (conversion to grassland), while a small portion of this land associated with the foundations for the transmission towers and station upgrades will be further impacted (permanent conversion from grassland to paved area).

  This assessment follows the IPCC's guidance document for land use change calculations, while carbon contents are from the Canadian Forest Service.[12,13] The IPCC document provides direction on calculation methodology and the Canadian Forest Service provides

[11]Copper based on K.J. Martchek, *The Importance of Recycling to the Environmental Profile of Metal Products* (2000): 10. http://www.alcoa.com/global/en/environment/pdf/importance_of_recycling.pdf; and G.P. Hammond and C.I. Jones, *Inventory of Carbon and Energy (ICE) Version 1.6a*(Sustainable Energy Research Team, 2008),www.bath.ac.uk/mech-eng/sert/embodied/

Aluminum from: NREL U.S. Life Cycle Inventory Database.

Steel from: Gerdau Ameristeel. Personal communication fuel use for steel recycling, 2009.

[12]C.H. Shaw, J.S. Bhatti, and K.J. Sabourin, *An Ecosystem Carbon Database for Canadian Forests*(Canadian Forest Service, 2005), pp. 89-90, 108-109

[13]Intergovernmental Panel on Climate Change, *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (2003).http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

carbon contents for different forest types. See Land use change assumptions in Appendix 1 – Scoping for more information.

- **Decommissioning:** The assessment includes decommissioning of the transmission line and station upgrade equipment. All metal materials are recycled.

4.5 Limitations of study

Although the Pembina Institute has made every effort to develop reasonable assumptions and to quantify the life cycle emissions based on accurate and current data, there are several limitations to this assessment. These limitations are discussed below.

- **Aluminum production:** Aluminum production is the most energy-intensive and therefore emission-intensive material process associated with the MMTP. However, aluminum components used could be produced in many different countries. In addition, Manitoba Hydro has yet to contract specific companies to provide equipment made from aluminum. This assessment assumes aluminum components are sourced from India, a conservative assumption with respect to transportation distance. However, the emissions factor used is for average production in North America. While this emission factor is likely representative of emissions from aluminum facilities, it may be different than the actual emissions from the facilities used to produce the final components. We further assume all aluminum comes from virgin sources. The assessment includes a sensitivity analysis on the aluminum GHG emission factor.
- **Components:** The transmission line and station upgrades require numerous pieces of equipment, each with its own life cycle emissions. Instead of determining life cycle emissions for each of these components, this assessment uses generic emission factors for material production and an estimate of GHG emissions associated with manufacturing activities. For example, the life cycle GHG emissions for the aluminum conductors include emissions from aluminum production and emissions for extruding aluminum.
- **Transportation distances:** Manitoba Hydro provided some direction as to the distances that materials will be transported to site. However, the final sources of many materials, such as steel and aluminum, are not known. In place of actual data this assessment uses plausible, conservative transportation distances. A list of all transportation distances is available in Appendix 2 – Inventory Assessment.
- **Stage of development:** All materials, labour, and fuel requirements are calculated from best estimates provided by Manitoba Hydro based on the most recent design documents. The MMTP's design has not been finalized, thus the actual construction of the transmission line may require different material quantities and route considerations.
- **MMTP Physical Boundary:** Only MMTP components were evaluated in this LCA. The results of this LCA cannot be used to evaluate the impact of the entire international transmission line, which includes another project, the GNTL.
- **Additional Transmission:** Additional electricity imports and exports were estimated, by Manitoba Hydro, based on the aggregation of multiple modelled projections. Actual additional system transmission over the life of the MMTP will vary depending on multiple variables including, but not limited to, future river flow conditions, electricity

market prices, Manitoba electricity load, electricity contracts, environmental policies, and industry development plans.

4.6 Methodology for Power Generation Impacts

It was determined that while the original LCA scope sufficiently met the LCA's primary objective, that scope may not be sufficiently assessing the overall GHG impact of the MMTP. Since it is a transmission project that connects with US electricity grid, the MMTP's impact on global GHG emissions may go beyond its non-generation emissions: While in operation the MMTP will influence the sources, quantities, and buyers of electricity in both Manitoba and the inter-connected region. Studies have shown that the operational impacts of transmission and distribution projects on power generation emissions are normally much greater than the impacts of their non-generation impacts.[14]

The future function of the MMTP within Manitoba Hydro and the Midcontinent Independent System Operator's (MISO) interconnected grid is complex and depends on a wide range of possible future scenarios and influences. This makes quantification of the generation GHG effects of the MMTP very intricate and uncertain. Calculation of these generation effects was done by Manitoba Hydro, separate from the main inventory assessment. A summary of Manitoba Hydro's work can be found in Technical Memorandum A - Overview of Manitoba Hydro's Assessment of the Greenhouse Gas Generation Effects of the Manitoba-Minnesota Transmission Project.

[14] World Bank, *"Impacts of Transmission and Distribution Projects on Greenhouse Gas Emissions"*, 2010

5. Results and discussion

5.1 Introduction

The quantitative LCA results are divided into three main categories:

- Non-Generation Emissions - emissions from material production, transportation, fuel use, and land use change
- Transmission Loss – emissions due to the additional generation required to make up for transmission losses, a sub-component of generation emissions
- Generation Emissions – indirect emissions from the impact of cross-border trade along the 500-kV transmission line

For a detailed breakdown of what activities are included for the transmission line and station portions see Appendix 1 - Scoping. The results are further disaggregated into construction emissions (material production, transportation, and construction of the transmission lines and stations), land use change emissions (from land clearing), emissions from the operation and maintenance of the transmission lines and stations, and eventual decommissioning of the MMTP. More detailed results are presented in Appendix 3 – Detailed Results.

5.2 Manitoba–Minnesota Transmission Project life cycle results

5.2.1 Non-Generation GHG Emissions

Table 2 summarizes the non-generation GHG emissions per life cycle stage for the transmission line and the station upgrades. The construction phase includes emissions from producing necessary construction materials and transporting them to site, as well as on-site emissions to construct the transmission line and stations. The operation phase includes emissions from site maintenance. Decommissioning primarily includes dismantling existing structures and recycling components. Land use change emissions are broken out separately and are primarily associated with permanent conversion of forest to shrub or grassland for the ROW.

Table 2: Summary of non-generation GHG emission sources for the Manitoba–Minnesota Transmission Project

		Total		Within Manitoba		Outside Manitoba	
Timeline	**Phase**	**Tonnes CO_2eq**	**% of total emissions**	**Tonnes CO_2eq**	**% of total emissions**	**Tonnes CO_2eq**	**% of total emissions**
Aug 2017 - Mar 2020	**Transmission Line Construction**	**84,133**	**49%**	**21,975**	**13%**	**62,158**	**36%**
Aug 2017 - Apr 2018	Southern Loop	21,707	13%	2,103	1%	19,605	11%
May 2018 - Mar 2020	Riel to U.S. Border	47,117	28%	4,564	3%	42,553	25%
2017 - 2117	Wood matting production & disposal in landfill	15,309	9%	15,309	9%	-	0%
Aug 2017 - Nov 2019	**Station Upgrades**	**3,637**	**2%**	**176**	**0%**	**3,461**	**2%**
2017 - 2067	**Operating Emissions**	**2,807**	**2%**	**2,807**	**2%**	**-**	**0%**
2067-2069	**Decommissioning**	**3,994**	**2%**	**1,426**	**1%**	**2,568**	**2%**
Aug 2017-June 2018	**Land Use Change**	**76,510**	**45%**	**76,510**	**45%**	**-**	**0%**
Aug - June 2018	Existing Corridors	9,290	5.4%	9,290	5.4%	-	0.0%
May - June 2018	New ROW	67,219	39.3%	67,219	39.3%	-	0.0%
Total		**171,081**	**100%**	**102,895**	**60%**	**68,187**	**40%**

Transmission line construction accounts for 49% of the MMTP's non-generation life cycle GHG emissions, generating 84,133 tonnes CO_{2eq}. Aluminum and steel production make up the majority of the construction emissions.

Station upgrades, land use change, operation and maintenance, and decommissioning together generate the remaining 51% of GHG emissions, 86,949 tonnes CO_{2eq}. Land use change emissions are primarily associated with the conversion of forested areas to grassland or shrub land for the new ROW. This carbon will most likely be released at the beginning of the project when the forest clearing occurs (estimated as first two months of transmission construction, although different sections will be cleared at different times in the construction phase). Operation phase emissions are primarily associated with diesel combustion for line maintenance and SF_6 emissions. Emissions during the decommissioning phase are primarily associated with recycling metal materials.

The transmission line's life cycle generates more GHG emissions mainly because the transmission line requires more material. For example the line requires 3,763 tonnes of aluminum, an energy-intensive material, while the station upgrades only require 75 tonnes.

Figure 4 (repeat of Figure 1) presents the results in Table 2 by percentage contribution to life cycle GHG emissions.

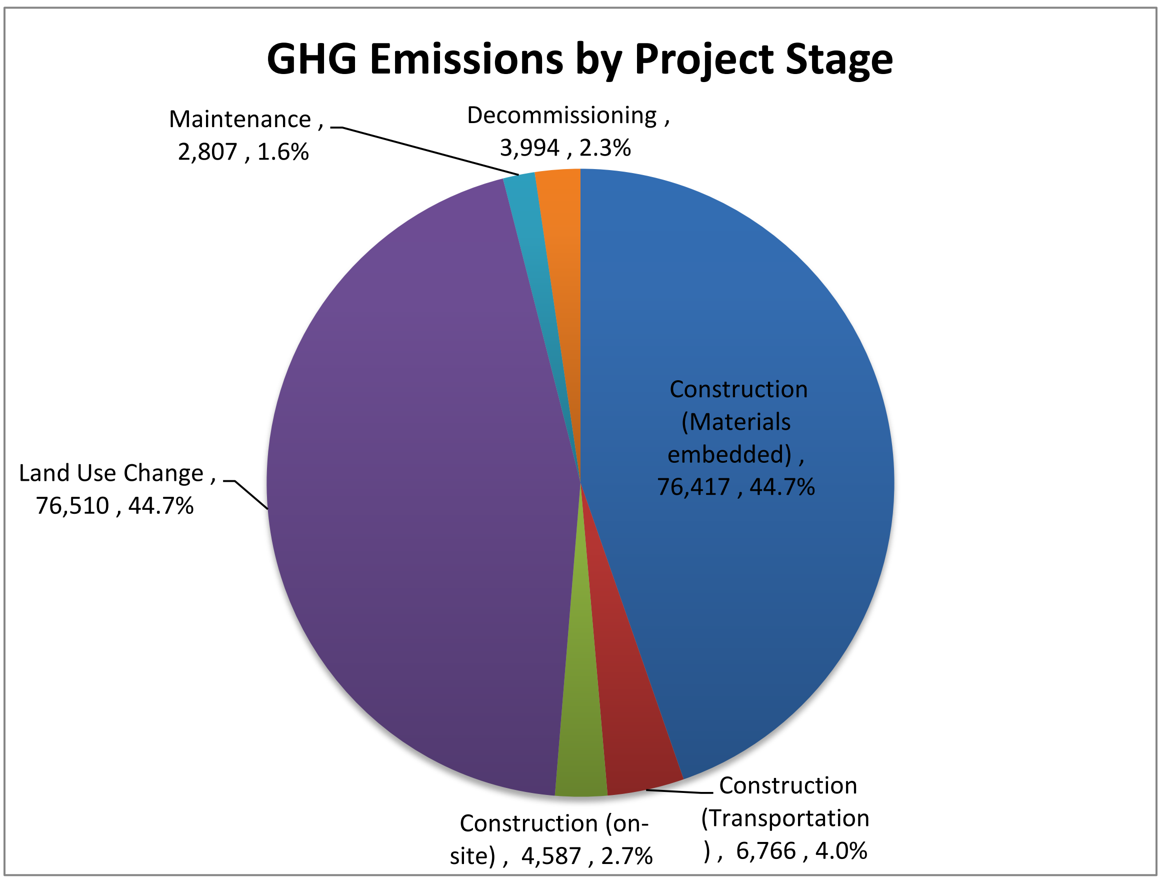


Figure 4: Breakdown of GHG emissions per primary activity

As

Figure 4 shows, the construction and land use change phases account for the majority of the project life cycle emissions (96%). Operation and maintenance account for 2%, and decommissioning accounts for 2%.

5.2.2 Direct Generation Effects: Line Losses

Line losses are a unique generation impact as LCA methodologies consider them to be a direct generation impact while the other generation impacts are considered to be indirect.[15] Conservative analysis of generation effects indicated that, on average, yearly line-loss emissions along the MMTP are expected to average approximately 4,590 tonnes of CO_{2eq}. Figure 5 displays the combined emissions from both non-generation impacts and direct generation impacts, over the life of the project.

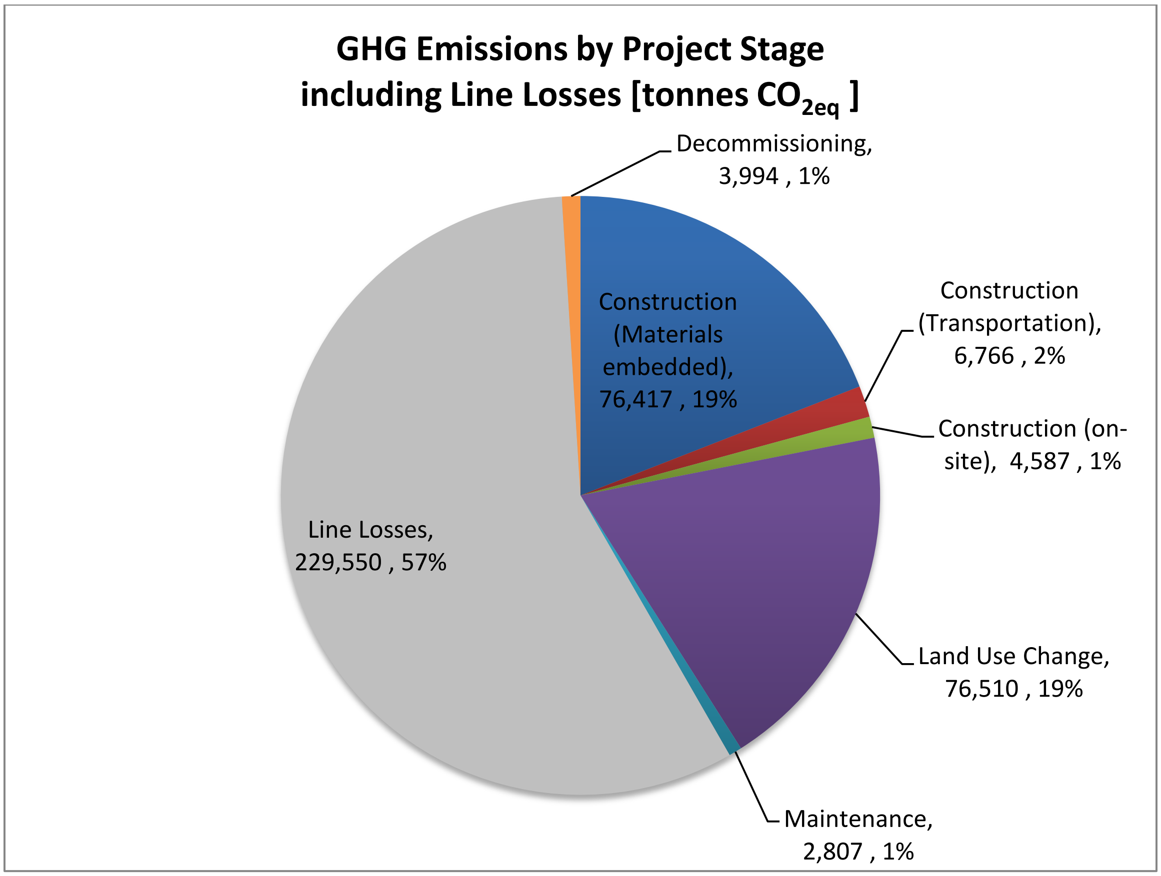


Figure 5: Breakdown of GHG emissions per primary activity and Line losses

[15] World Bank, *"Impacts of Transmission and Distribution Projects on Greenhouse Gas Emissions"*, 2010

5.2.3 All Generation Effects

Quantifying generation effects of the MMTP requires comparing future scenarios against hypothetical baseline scenarios where the MMTP is not constructed. To assess the overall impact of the generation effects of the project Manitoba Hydro compared two future resource plan projections with two similar corresponding plans that did not contain the construction of the MMTP. Manitoba Hydro also evaluated the impact of different future MISO generation scenarios. Analysis of all evaluated scenarios indicated that the MMTP will likely indirectly reduce overall power electrical system emissions even though direct non-generation emissions are positive. Summarized results are listed in the Manitoba Hydro report provided in Technical Memorandum A - Overview of Manitoba Hydro's Assessment of the Greenhouse Gas Generation Effects of the Manitoba-Minnesota Transmission Project.

5.3 Summary of sensitivity analysis

Pembina performed sensitivity analyses on three elements of the inventory: aluminum production, land use change, and wood matting. Descriptions of the sensitivity analyses and a summary of the results are provided below. Additional details can be found in Appendix 4 – Sensitivity Analysis.

- Aluminum production intensity: Aluminum production accounts for almost 25% of the project life cycle emissions and is based on a generic aluminum production GHG intensity factor.[16] This sensitivity tests the impact of increasing or decreasing the GHG intensity of aluminum production by 30% on the results of the analysis. A 30% increase or decrease results in a +/- 7% change to overall results.
- Wood matting re-use: The MMTP requires the use of wood matting to allow driving equipment on the access roads in the summer. The production and disposal accounts for almost 10% of the total emissions. The base scenario conservatively assumes the wood matting is only used once for construction and then disposed. In the sensitivity scenario, the wood matting was assumed to be used twice and emissions associated with production and disposal allocated equally to both uses. This implies production and disposal emissions of wood for this project are reduced by 50%. In this scenario, the total emissions decreased by 4%.
- Wood matting use as biomass fuel: The wood matting is assumed to be disposed of in a wood waste landfill. However it would be feasible to combust the wood at a fuel-oil/biomass power plant. The result was an 8% decrease in total project emissions, and an additional reduction of 9,632 tonnes CO_{2eq} due to displacement of fuel oil combustion. This represents a significant opportunity for Manitoba Hydro to investigate in more detail, in terms of feasibility as well as environmental impact[17].

[16] Intensity factor for the production of an aluminum ingot from PE Americas, *Life Cycle Impact Assessment of Aluminum Beverage Cans* (2010), 127.

[17] This analysis is limited to GHG emissions; a detailed analysis of the use of wood matting and biofuel should include any associated Criteria Air Contaminants such as NOx and SOx emissions.

- Carbon content for land use change: The transmission line ROW is estimated to permanently disturb 550 ha of land, approximately 533 ha of which is forested. This assessment assumes carbon emissions associated with the disturbance are primarily associated with the changes in above ground biomass. The life cycle results are based on Manitoba specific carbon contents presented in “An Ecosystem Carbon Database for Canadian Forests”. The sensitivity is based on high-end generic carbon content emissions from the IPCC. As shown in Appendix 4 – Sensitivity Analysis, the results increase by 11% for the sensitivity case.

6. Conclusions

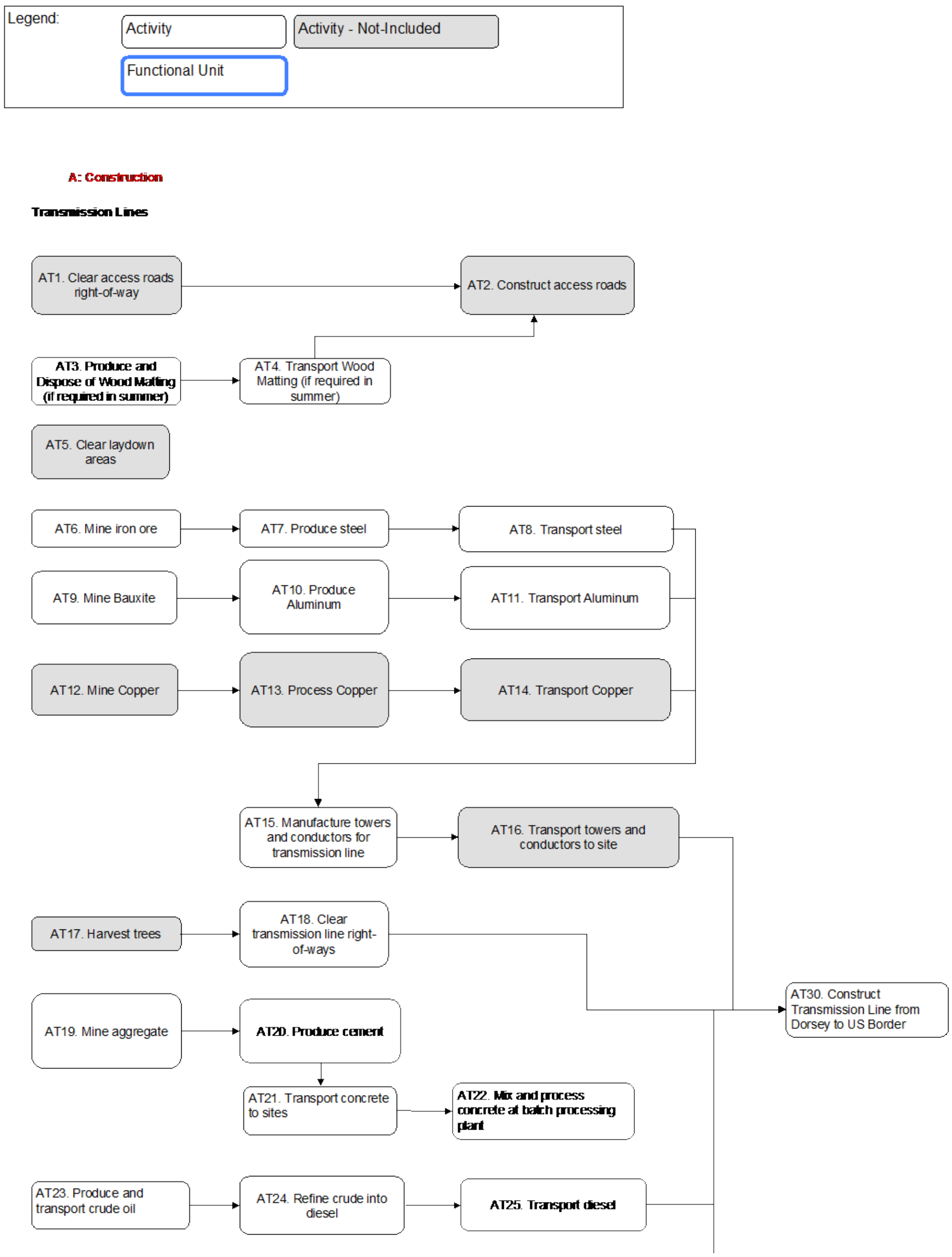
The primary conclusions of this LCA are as follows:

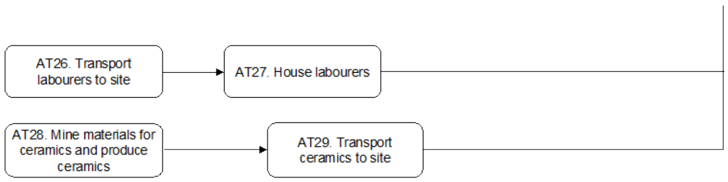
- Life cycle GHG emissions: The MMTP is estimated to directly generate 171,081 tonnes CO_{2eq} where the transmission line, including land use change, accounts for 165,298 CO_{2eq} tonnes (97%) and the station upgrades account for 5,783 tonnes CO_{2eq} (3%).
- Transmission line: The construction, land use change, operation and maintenance, and decommissioning associated with the transmission line account for 97% of life cycle GHG emissions for the MMTP. The activities responsible for the majority of transmission line emissions were aluminum extraction and processing, and associated land use change, which together account for 67% of project life cycle emissions. The transmission line uses 98% of the aluminum used in the project, and all of the land use changes are attributed to the clearing of the ROW for the line.
- Station Upgrades: Station construction, operation and maintenance and decommissioning account for the remaining 3% of life cycle GHG emissions.
- Decommissioning: Decommissioning contributes relatively little to the life cycle intensity of the MMTP (2%).
- Wood matting: Disposal of the wood matting in landfill accounts for almost 10% of the emissions. Using it to power a biomass plant instead could reduce total emissions by 8% and result in an additional reduction of 9,632 tonnes CO_{2eq} due to displacement of fuel oil combustion.
- Generation emissions: The impact of the MMTP line on generation in the interconnected region is likely much larger than the non-generation life cycle impacts (constructing, maintaining, and decommissioning the transmission and station structures), likely resulting in overall reduction of the power electrical system GHG emissions.

7. Appendices

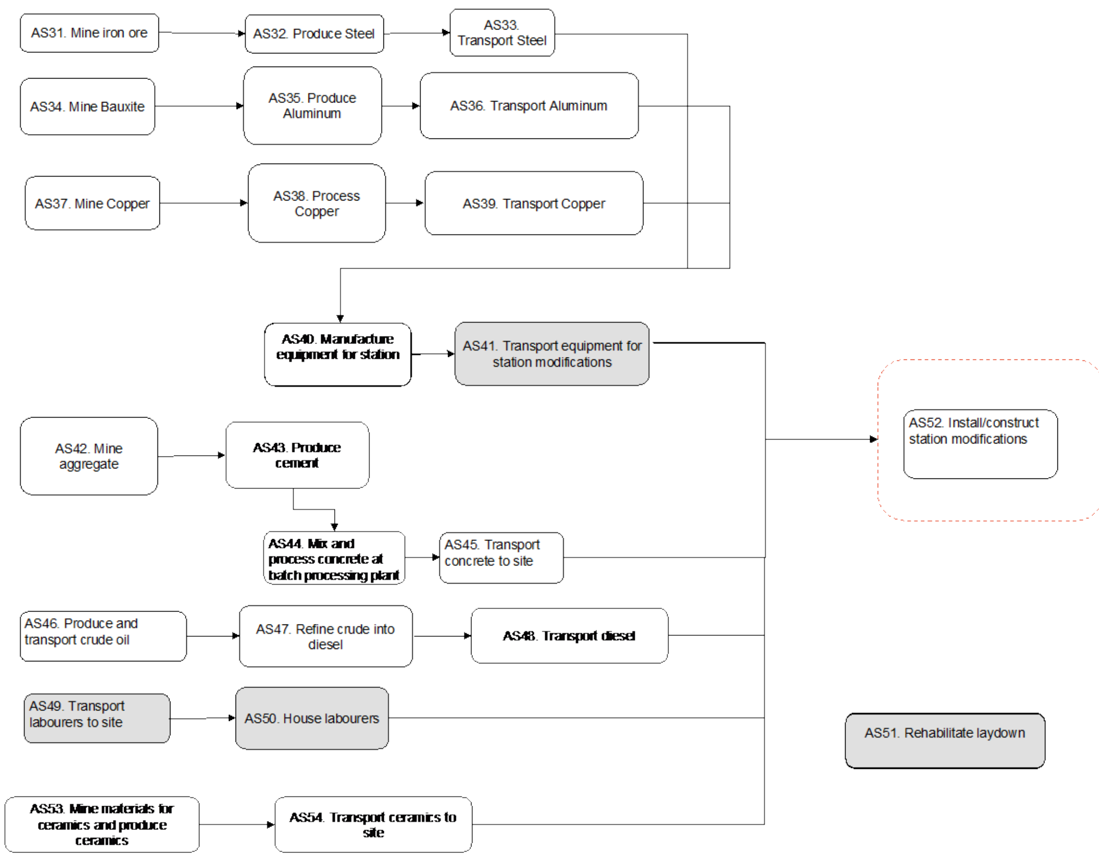
Appendix 1 – Scoping

System activity maps



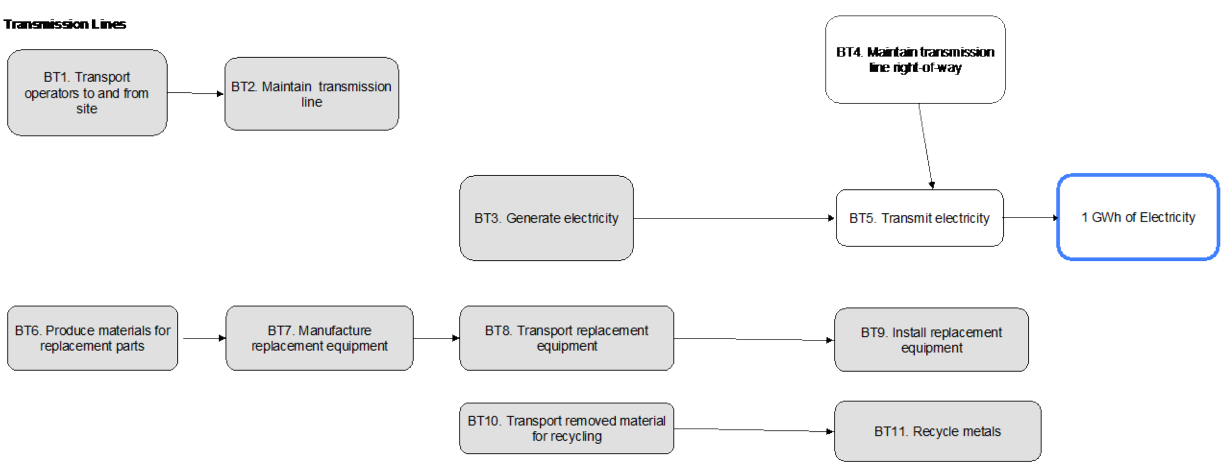


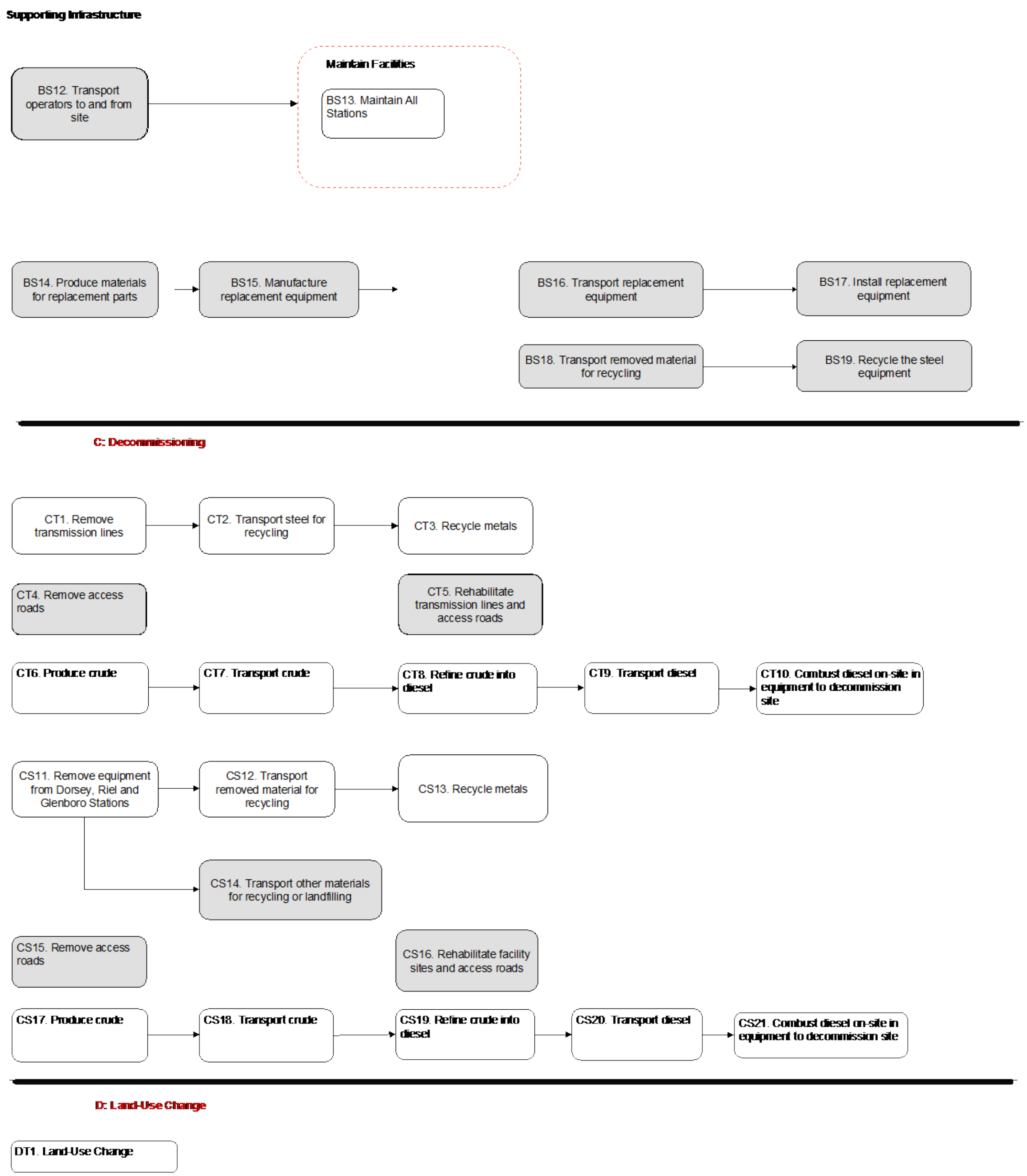
Station Upgrades



B: Operation and Maintenance

Transmission Lines




Supporting Infrastructure
BS12. Transport operators to and from site
Maintain Facilities
BS13. Maintain All Stations
BS14. Produce materials for replacement parts
BS15. Manufacture replacement equipment
BS16. Transport replacement equipment
BS17. Install replacement equipment
BS18. Transport removed material for recycling
BS19. Recycle the steel equipment
C: Decommissioning
CT1. Remove transmission lines
CT2. Transport steel for recycling
CT3. Recycle metals
CT4. Remove access roads
CT5. Rehabilitate transmission lines and access roads
CT6. Produce crude
CT7. Transport crude
CT8. Refine crude into diesel
CT9. Transport diesel
CT10. Combust diesel on-site in equipment to decommission site
CS11. Remove equipment from Dorsey, Riel and Glenboro Stations
CS12. Transport removed material for recycling
CS13. Recycle metals
CS14. Transport other materials for recycling or landfilling
CS15. Remove access roads
CS16. Rehabilitate facility sites and access roads
CS17. Produce crude
CS18. Transport crude
CS19. Refine crude into diesel
CS20. Transport diesel
CS21. Combust diesel on-site in equipment to decommission site
D: Land-Use Change
DT1. Land-Use Change

Key assumptions

Table 3: Key assumptions per activity for the Manitoba-Minnesota Transmission Project

Legend

(grey)	Not Included
(white)	Included

Activity #	Title	Assumption/Comment	Rationale
AT1.	Clear access roads right-of-way	No additional diesel consumption to clear access ways	Access roads exist in the centre of the corridor so require no additional clearing.
AT2.	Construct access roads	No additional diesel consumption to construct access roads	Access roads exist in the centre of the corridor so require no additional construction required.
AT3.	Produce and Dispose of Wood Matting (if required in summer)	No gravel material required for roads	Access roads are not engineered and usually consist of compacted snow. In the summer, wood matting is used
		Wood is disposed of in a landfill after being used only once.	Conservative assumption
AT4.	Transport Wood Matting (if required in summer)	No transportation of gravel required	Access roads are not engineered and usually consist of compacted snow. In the summer, wood matting maybe required.
		Wood matting is produced in Manitoba	There are wood matting sources in Manitoba
AT5.	Clear laydown areas	No laydown areas	Material will be stored on the right of way
AT6. & AT7.	Mine iron ore & Produce steel	Galvanized steel is used for all towers	Galvanized steel is the expected tower material
		Emissions are primarily associated with steel production and galvanizing	They are the most emission intensive activities
AT8.	Transport steel	Materials are procured from India (by sea to Vancouver, rail to Winnipeg and then road to site)	Manitoba Hydro has not chosen a steel supplier, but it will likely be from Europe, India, North America or South America. India is a conservative assumption
AT9. & AT10.	Mine Bauxite & Produce Aluminum	A generic aluminum GHG emission factor is appropriate.	A comparison of two emission factors showed an 8% difference in intensity. Both studies were for average aluminum ingot production.
		Aluminum production occurs overseas	As per data from Manitoba Hydro

AT11.	Transport Aluminum	Materials are procured from India (sea to Vancouver, rail to Winnipeg and then road to site)	Manitoba Hydro has not chosen a steel supplier, but it will likely be from Europe, India, North America or South America. India is a conservative assumption
AT12. & AT13.	Mine Copper & Process Copper	Not included	No copper required for transmission line
AT14.	Transport Copper	Not included	No copper required for transmission line
AT15.	Manufacture towers and conductors for transmission line	Producing conductors is similar to extruding aluminum	No life cycle data sets exist for producing conductors.
		Manufacture of tower is excluded	Portion of manufacture occurs on site (assembly), and majority of emissions are associated with producing and forming steel.
AT16.	Transport towers and conductors to site	Not Included	Included in transport steel
AT17.	Harvest trees	Not Included	Emissions from harvesting trees are included in clearing activities.
AT18.	Clear transmission line right-of-ways	Estimate is based on machinery, fuel and time.	Best estimate available
AT19.	Mine aggregate	Aggregate is mined in/near Edmonton	Consistent with assumptions for previous MH inventories
AT20.	Produce cement	Cement is manufactured in/near Edmonton	Consistent with assumptions for previous MH inventories
AT21.	Transport concrete to sites	Cement from Edmonton	Closest cement source. Same assumption for other Manitoba Hydro life cycle assessments
		Transportation of cement from Edmonton to Winnipeg by rail car	Rail line extends from Edmonton to Winnipeg
		Local concrete mixing plant is in Winnipeg	Likely source given proximity
		Aggregate is available in Winnipeg and transported to site by road	Likely source of aggregate given proximity
AT22.	Mix and process concrete at batch processing plant	No concrete mixing at site. Processing happens at a local batch processing plant.	As per information from Manitoba Hydro

AT23. to AT25.	Produce and transport crude oil to Transport diesel		
AT26.	Transport labourers to site	Assume labourers are flown in from Ottawa	Large urban centre with access to labourers
AT27.	House labourers	All labourers are housed in Winnipeg hotels or in a town halfway between Winnipeg and the US border	As per information from Manitoba Hydro. No need for camps as travel distances allow for daily commuting
AT28.	Mine materials for ceramics and produce ceramics	Ceramics or glass could be used as insulator. This assessment assumes ceramics.	There exists little information on life cycle of glass insulators. The data for ceramics is more recent and from a reliable source.
		Assume ceramics are produced outside Manitoba	Similar to assumption for Bipole III analysis
AT29.	Transport ceramics to site	Ceramic insulators can be sourced within 3,000 km of Winnipeg	Manitoba Hydro has not identified an insulator provider. Manufacturing capacity exists within 3,000 km.
AT30.	Construct Transmission Line from Dorsey to US Border	Diesel combustion is the only emission source associated with the construction of the transmission line	Only diesel is required to power construction equipment.
		The impact of the use of 1 tonne of explosives is not included in the analysis.	Explosives, only 1 tonne of which will be used, constitute only 0.003% of the total mass of materials and were hence excluded. The emission factor for nitric acid, often used in manufacture of explosives, is 2 to 9 kg N_2O/tonne nitric acid, which is 0.6 to 2.7 tonnes of CO_{2eq} and less than 0.005% of the inventory.
AS31. & AS32.	Mine iron ore & Produce Steel	Galvanized steel used for all components	Simplified assumption based on transmission line
		Emissions primarily associated with steel production and galvanizing	They are the most emission intensive activities
AS33.	Transport Steel	Materials are procured from India (sea to Vancouver, rail to Winnipeg and then road to site)	Manitoba Hydro has not chosen a steel supplier, but likely will be from Europe, India, North America or South America. India is a conservative assumption
AS34. & AS35.	Mine Bauxite & Produce Aluminum	A generic aluminum GHG emission factor is appropriate.	A comparison of two emission factors showed an 8% difference in intensity. Both studies were for average aluminum ingot production.
		Aluminum production occurs overseas	As per data from Manitoba Hydro

AS36.	Transport Aluminum	Materials are procured from India (sea to Vancouver, rail to Winnipeg and then road to site)	Manitoba Hydro has not chosen a steel supplier, but likely will be from Europe, India, North America or South America. India is a conservative assumption
AS37. & AS38.	Mine Copper & Process Copper	Assume copper is mined and processed outside Manitoba	Assumption consistent with Bipole III analysis
AS39.	Transport Copper	50% from North America and 50% from Overseas	Same assumption as for Bipole III
		Overseas is Chile	One of larger copper producers in the world. Approximately 1/3rd of global production in 2008. 1. USGS. 2008 Mineral Yearbook - Chile [Advanced Release].; 2008. Available at: http://minerals.usgs.gov/minerals/pubs/country/2008/myb3-2008-ci.pdf.
		Copper in North America comes from Arizona	Arizona is a major copper producer. Produced 5.5 billion dollars worth in 2007 Unpublished USGS data, subject to change; data rounded and may not add to totals shown; final 2005 -2007 data will be published in the Arizona Chapter of the USGS Mineral Yearbook, Area Reports: Domestic 2005 - 2007, volume II
AS40.	Manufacture equipment for station modifications	Specific emission factors for systems are not included, generic emission factor for metal production and forming is used as proxy.	Finding emission factors for every piece of equipment is not practical. In general metal equipment will require mining, refining, transportation and casting regardless of the end product.
		All manufacturing of components is outside Manitoba	Consistent with assumptions for Bipole III analysis
AS41.	Transport equipment for station modifications	Transportation estimates include 50% overseas and 50% North American sourced materials	Actual sources are unknown and could be supplied from many regions in the world. Included in transport of raw material
AS42.	Mine aggregate		
AS43.	Produce cement	Cement requirements calculated from concrete use, using concrete to cement ratios for other Manitoba Hydro projects.	Best estimate available.
		Cement is manufactured in/near Edmonton	Consistent with assumptions for previous MH inventories
AS44.	Mix and process	No concrete mixing at site. Processing happens at a	As per information from Manitoba Hydro

	concrete at batch processing plant	local batch processing plant.	
AS45.	Transport concrete to site	Cement from Edmonton	Closest cement source and assumed for other Manitoba Hydro life cycle assessments
		Transportation of cement from Edmonton to Winnipeg by rail car	Rail line extends from Edmonton to Winnipeg
		Local concrete mixing plant is in Winnipeg	Likely source given proximity
		Aggregate is available in Winnipeg and transported to site by road	Likely source of aggregate given proximity
AS46. to AS48.	Produce and transport crude oil & Refine crude into diesel & Transport diesel	Assume diesel is produced in Edmonton.	Detailed information available for crude oil and diesel produced in Alberta.
AS49.	Transport labourers to site	Not Included	Included as part of transmission line
AS50.	House labourers	Not Included	Included as part of transmission line calculations
AS51.	Rehabilitate laydown areas	Not Included	No active rehabilitation
AS54.	Transport ceramics to site	Ceramics or glass could be used as insulator. This assessment assumes ceramics.	There exists little information on life cycle of glass insulators. The data for ceramics is more recent and from a reliable source.
		Assume ceramics are produced outside Manitoba	Similar to assumption for Bipole III analysis
AS54.	Transport ceramics to site	Ceramic insulators can be sourced within 3,000 km of Winnipeg	Manitoba Hydro has not identified an insulator provider. Manufacturing capacity exists within 3,000km.
BT1.	Transport operators to and from site	Not Included	No additional operator transport required
BT3.	Generate electricity	Not Included	No electricity generated as part of maintenance activities
BT4.	Maintain transmission line right-of-way	Emissions from maintaining transmission line equivalent to average for Great Britain's transmission	Manitoba Hydro has no estimate; however flyovers and physical inspection would generally be the same.

		network.	
BT5.	Transmit electricity	Emission intensity and line losses calculated separately by Manitoba Hydro as part of indirect emissions	Based on forecasts for generation and transmission.
BT6.	Produce materials for replacement parts	Assume 0% of components are replaced over life of project	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BT7.	Manufacture replacement equipment	Not Calculated	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BT8.	Transport replacement equipment	Assume 0% of components are replaced over life of project	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BT9.	Install replacement equipment	Not Included	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BT10.	Transport removed material for recycling	No replacement activities	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BT11.	Recycle metals	No replacement activities	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BS12.	Transport operators to and from site	Not Included	No additional operators required due to station modifications
BS13.	Maintain All Stations	Primary emission sources is SF_6 emissions	From Manitoba Hydro: "Based on technology advancements we're assuming the new installs will have release rates from 0%-1% a year, likely close to 0%. Around 75kg of SF_6 is being installed with the new equipment. At 1% (high-end) we'd be looking at 0.75kg a year...and would be quite conservative. Even ½ that (0.375kg) would be conservative."
BS14.	Produce materials for replacement parts	Not Calculated	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BS15.	Manufacture replacement equipment	Not Calculated	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BS16.	Transport replacement equipment	Not Included	As per Manitoba Hydro, the components are expected to last for the lifetime of the project

BS17.	Install replacement equipment	Not included	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BS18.	Transport removed material for recycling	Not included	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
BS19.	Recycle the steel equipment	Not included	As per Manitoba Hydro, the components are expected to last for the lifetime of the project
CT1.	Remove transmission lines	Fuel requirements are approximately 50% of construction fuel requirements	Best estimate by Manitoba Hydro
CT2.	Transport Materials for Recycling	Steel recycling occurs in Manitoba	Manitoba has steel recycling capacity
		All other recycling occurs within a 3,000 km radius	Recycling capacity exists within this area
CT3.	Recycle metals	Steel is recycled in Manitoba and the primary energy source is electricity	Gerdau Ameristeel recycles steel using an electric arc-furnace and uses Manitoba's electricity grid.
		Aluminum and copper are recycled in North America	Recycling capacity exists in North America
CT4.	Remove access roads	Not included	No access roads constructed
CT5.	Rehabilitate transmission lines and access roads	Not included	No access roads constructed
CT6. to CT9.	Produce crude to Transport diesel	Assume diesel is produced in Edmonton.	Detailed information available for crude oil and diesel produced in Alberta.
CT7.	Transport crude	Not calculated	Included in emission factor for diesel
CT8.	Refine crude into diesel	Not calculated	Included in emission factor for diesel
CT9.	Transport diesel	Not calculated	Included in emission factor for diesel
CT10.	Combust diesel on-site in equipment to decommission site	Not calculated	All diesel combustion included in CT1
CS11.	Remove equipment	Fuel requirements are approximately 50% of	Best Estimate by Manitoba Hydro

	from Dorsey, Riel and Glenboro Stations	construction fuel requirements	
CS12.	Transport removed material for recycling	Steel recycled in Manitoba, copper in North America.	Steel recycling capacity exists in Winnipeg and copper in North America.
		All other recycling occurs within a 3,000 km radius	Recycling capacity exists within this area
CS13.	Recycle metals	Steel, aluminum, and copper recycled	Steel, aluminum and copper are the primary metals in the stations
CS14.	Transport other materials for recycling or landfilling	Not calculated	Included in CS13. Most materials are recyclable. Landfill material is assumed to be immaterial.
CS15.	Remove access roads	Not included	Any access roads will be allowed to reclaim naturally
CS16.	Rehabilitate facility sites and access roads	Not included	Will rehabilitate naturally
CS17. to CS20.	Produce crude to Transport diesel	Assume diesel is produced in Edmonton.	Detailed information available for crude oil and diesel produced in Alberta.
CS18.	Transport crude	Not calculated	Included in emission factor for diesel
CS19.	Refine crude into diesel	Not calculated	Included in emission factor for diesel
CS20.	Transport diesel	Not calculated	Included in emission factor for diesel
CS21.	Combust diesel on-site in equipment to decommission site	Not Included	Included in other activities

Land use change assumptions

Land use change emissions (activity D1 in the model) from land clearing for the transmission line ROW are based on IPCC guidance documents[18] and carbon contents are from the Canadian Forest Service[19]. Pembina used the following overarching assumptions to guide calculations. Detailed calculations can be found in the spreadsheet, "GHG Emissions Resulting from Land Use Change for MMTP Transmission Line".

- Forested and/or treed land along the ROW is completely cleared and converted to grassland/shrub land. Recently cleared land is included and categorized as mixed wood forest.
- Other land types (wetlands, grassland, agricultural land, water bodies etc.) are minimally disturbed and, when disturbed for construction, returned to their natural state within the project life. "Developed" vegetation structures are assumed to have negligible above ground carbon content.
- Temporarily disturbed land is immaterial; all forested/treed areas cleared are assumed to be permanently disturbed
- CO_2 is released at the time of clearing because all biomass is combusted
- There is no significant decay
- Carbon content of soils is assumed to be unchanged after clearing
- There are no new road right-of-ways. Access will be along existing road structure or the transmission line ROW
- The carbon content of all forest types being cleared are based on Manitoba specific carbon contents
- Tree cover multipliers apply to forested areas only. All forested areas assumed to be dense (100% coverage) in the absence of other data. "Shrubland" vegetation structure was assumed to be sparse, mixed Boreal (25% tree cover).
- The new ROW is assumed to have a width of 100 m, which is a conservative estimate given that typically only an 80 m wide area will likely need to be cleared. Tower footprint and station upgrade land is assumed to be originally grassland (which it will become after clearing), and will have zero carbon content in the modified state.
- Since tower footprint area is unknown at the time of this analysis, emissions from tower footprint were estimated based on the proportional land area occupied by the tower footprint in Bipole III project.

[18] Intergovernmental Panel on Climate Change, "Good Practice Guidance for Land Use, Land-Use Change and Forestry."

[19] C.H. Shaw, et al, "An Ecosystem Carbon Database for Canadian Forests", Canadian Forest Service, Northern Forestry Centre, 2005, pp. 89-90, 108-109

Appendix 2 – Inventory Assessment

Inputs

Most of the inputs provided by Manitoba Hydro originated from work done by, and staff in, the Transmission Planning & Design, Transmission Construction & Line Maintenance, Power Sales & Operations, and Power Planning Divisions.

Note: Some of the earlier inputs from Manitoba Hydro were prorated to correspond to the change in expected line length from 235km to 215.6 km.

Table 4: List of material, energy and distance inputs used in the LCA

Activity #	Title	Material Used	Source
AT3.	Produce and Dispose of Wood Matting (if required in summer)	30,000 m^2 of wood matting	Manitoba Hydro
AT4.	Transport Wood Matting (if required in summer)	30,000 m2 of wood matting	Manitoba Hydro
AT6. & AT7.	Mine iron ore & Produce steel	4,161 tonnes of steel for towers 1,702 tonnes of steel for conductors	Manitoba Hydro
AT8.	Transport steel	17,441 km by ship from India to Vancouver 1,927 km by rail from Vancouver to MB border 367 km by rail from MB border to Winnipeg 70 km average distance from Winnipeg to transmission line	http://www.searates.com/reference/portdistance/ Google maps Distance to line calculated by Manitoba Hydro
AT9. & AT10.	Mine Bauxite & Produce Aluminum	3,763 tonnes of Aluminum	Manitoba Hydro
AT11.	Transport Aluminum	17,441 km by ship from India to Vancouver 1927 km by rail from Vancouver to MB border 367 km by rail from MB border to Winnipeg 70 km average distance	http://www.searates.com/reference/portdistance/ Google maps Distance to line calculated by Manitoba Hydro

		from Winnipeg to transmission line	
AT15.	Manufacture towers and conductors for transmission line	4,161 tonnes of steel for towers 1,702 tonnes of steel for conductors	Manitoba Hydro
AT18.	Clear transmission line right-of-ways	900 L/ha diesel use to clear ROW 5 km^2 of ROW for 215.6km of line length	Manitoba Hydro
AT19.	Mine aggregate	5505 cu yd of concrete Cement to aggregate ratio = 0.25	Manitoba Hydro
AT20.	Produce cement	5505 cu yd of concrete Cement to aggregate ratio = 0.25	Manitoba Hydro
AT21.	Transport concrete to sites	939 km by rail from Edmonton to MB border 367km by rail from MB border to Winnipeg 70km by road from Winnipeg to line	Google maps Distance to line calculated by Manitoba Hydro
AT22.	Mix and process concrete at batch processing plant	5505 cu yd of concrete Cement to aggregate ratio = 0.25	Manitoba Hydro
AT23. to AT25.	Produce and transport crude oil to Transport diesel	900 L/ha diesel use to clear ROW 5 km^2 of ROW for 215.6km of line length	Manitoba Hydro
AT26.	Transport labourers to site	An average of 93 labourers 677 total work days Ratio of trucks to labourers = 0.67 Average distance from Winnipeg to line = 70km	Manitoba Hydro
AT27.	House labourers	An average of 93 labourers	Manitoba Hydro
AT28.	Mine materials for ceramics and produce ceramics	394 Tonnes of ceramics	Manitoba Hydro
AT29.	Transport ceramics to site	3000km by rail 367km by rail from western MB border to Winnipeg Average distance from Winnipeg to line = 70km	Estimate Google maps Manitoba Hydro
AT30.	Construct Transmission Line from Dorsey to US Border	215.6 km transmission line 3,500 L/km diesel use	Manitoba Hydro
AS31. &AS32.	Mine iron ore & Produce Steel	500 tonnes of steel	Manitoba Hydro
AS33.	Transport Steel	17,441 km by ship from	http://www.searates.com/reference/p

		India to Vancouver 1927 km by rail from Vancouver to MB border 367 km by rail from MB border to Winnipeg 70 km average distance from Winnipeg to transmission line	ortdistance/ Google maps Distance to line calculated by Manitoba Hydro
AS34. & AS35.	Mine Bauxite & Produce Aluminum	75 tonnes of aluminum	Manitoba Hydro
AS36.	Transport Aluminum	17441 km by ship from India to Vancouver 19627 km by rail from Vancouver to MB border 367 km by rail from MB border to Winnipeg 70 km average distance from Winnipeg to transmission line	http://www.searates.com/reference/portdistance/ Google maps Distance to line calculated by Manitoba Hydro
AS37. & AS38.	Mine Copper & Process Copper	149 tonnes of Copper	Manitoba Hydro
AS39.	Transport Copper	11,060km by ship from Chile to Vancouver (50% from Chile) 1927 km by rail from Vancouver to MB border 367 km by rail from MB border to Winnipeg 3,095km by rail from North American source to MB border 110 km by rail from southern MB border to Winnipeg 70 km average distance from Winnipeg to transmission line	www.searates.com CN rail map Google maps Manitoba Hydro
AS40.	Manufacture equipment for station modifications	500 tonnes of steel 149 tonnes of copper 75 tonnes of aluminum (ceramics included in AS53)	Manitoba Hydro
AS42.	Mine aggregate	100 cu yd of cement Cement to aggregate ratio = 0.25	Manitoba Hydro

AS43.	Produce cement	100 of cement Cement to aggregate ratio = 0.25	Manitoba Hydro
AS44.	Mix and process concrete at batch processing plant	100 of cement Cement to aggregate ratio = 0.25	Manitoba Hydro
AS45.	Transport concrete to site	939 km by rail from Edmonton to MB border 367 km by rail from MB border to Winnipeg 70km by road from Winnipeg to line	Google maps Distance to line calculated by Manitoba Hydro
AS46. to AS48.	Produce and transport crude oil & Refine crude into diesel & Transport diesel		Estimated using mass ratios with material used for transmission line
AS52.	Install/construct station modifications		Estimated using mass ratios with material used for transmission line
AS53.	Mine materials for ceramics and produce ceramics	156 tonnes of ceramics	Manitoba Hydro
AS54.	Transport ceramics to site	156 tonnes of ceramics	Manitoba Hydro
BT4.	Maintain transmission line right-of-way	10.9 tonnes/TWh UK flyover emissions intensity	UK flyover emissions intensity for transmission line ROW inspection
BS13.	Maintain All Stations	1.61kg/yr. SF_6 release	Manitoba Hydro
CT1.	Remove transmission lines	1,750L/km diesel used for decommissioning	Manitoba Hydro
CT2.	Transport Materials for Recycling and Disposal	5,863 tonnes of steel 3,763 tonnes of aluminum 394 tonnes of ceramics 70 km by road 3,000 km by rail for aluminum 110 km by rail to MB border	Manitoba Hydro Google maps Distance to line calculated by Manitoba Hydro
CT3.	Recycle metals	5,863 tonnes of steel 3,763 tonnes of aluminum	Manitoba Hydro
CT6. to CT9.	Produce crude to Transport diesel	1,750L/km diesel used for decommissioning	Manitoba Hydro
CS11.	Remove equipment from Dorsey, Riel and Glenboro Stations		Estimated using mass ratios with material used for transmission line
CS12.	Transport removed material for recycling and disposal	500 tonnes of steel 149 tonnes of copper 75 tonnes of aluminum 156 tonnes of ceramics	Manitoba Hydro

		3,000 km by rail 70 km by truck	
CS13.	Recycle metals	500 tonnes of steel 149 tonnes of copper 75 tonnes of aluminum	Manitoba Hydro
CS17. to CS20.	Produce crude to Transport diesel	Estimated as 50% of fuel required for construction of station upgrades.	Manitoba Hydro

Appendix 3 – Detailed Results

Table 5 includes the results per activity for the LCA. The activities highlighted in grey were either not calculated or are included in other activities. The intensity calculations are based on an estimated electricity transmission of 88,950 GWh over the project life (assumed to be 50 years).

Table 5: Detailed life cycle results

Summary Table of GHG Life Cycle Emissions		Total			In MB	Outside MB
Activity #	Activity	t CO_2e	t CO_2e / GWH	% CO_2 total	t CO_2e	t CO_2e
DT1.	Land use Change	76,510	0.86	44.72%	76,510	-
AT1.	Clear access roads right-of-way	-	0.00	0.00%	-	-
AT2.	Construct access roads	-	0.00	0.00%	-	-
AT3.	Produce and Dispose of Wood Matting (if required in summer)	15,309	0.17	8.95%	15,309	-
AT4.	Transport Wood Matting (if required in summer)	97	0.00	0.06%	97	-
AT5.	Clear laydown areas	-	0.00	0.00%	-	-
AT6. & AT7.	Mine iron ore & Produce steel	15,878	0.18	9.28%	-	15,878
AT8.	Transport steel	1,908	0.02	1.12%	74	1,834
AT9. & AT10.	Mine Bauxite & Produce Aluminum	36,502	0.41	21.34%	-	36,502
AT11.	Transport Aluminum	1,225	0.01	0.72%	47	1,177
AT12. & AT13.	Mine Copper & Process Copper	-	0.00	0.00%	-	-
AT14.	Transport Copper	-	0.00	0.00%	-	-
AT15.	Manufacture towers and conductors for transmission line	3,236	0.04	1.89%	-	3,236
AT16.	Transport towers and conductors to site	-	0.00	0.00%	-	-
AT17.	Harvest trees	-	0.00	0.00%	-	-
AT18.	Clear transmission line right-of-ways	1,269	0.01	0.74%	1,269	-
AT19.	Mine aggregate	17	0.00	0.01%	-	17
AT20.	Produce cement	1,797	0.02	1.05%	-	1,797
AT21.	Transport concrete to sites	102	0.00	0.06%	68	34
AT22.	Mix and process concrete at batch processing plant	61	0.00	0.04%	61	-
AT23. To AT25.	Produce and transport crude oil to Transport diesel	1,197	0.01	0.70%	6	1,191
AT26.	Transport labourers to site	1,927	0.02	1.13%	1,870	57

AT27.	House labourers	1,125	0.01	0.66%	1,125	-
AT28.	Mine materials for ceramics and produce ceramics	413	0.00	0.24%	-	413
AT29.	Transport ceramics to site	25	0.00	0.01%	5	20
AT30.	Construct Transmission Line from Dorsey to US Border	2,046	0.02	1.20%	2,046	-
AS31. & AS32.	Mine iron ore & Produce Steel	1,354	0.02	0.79%	-	1,354
AS33.	Transport Steel	163	0.00	0.10%	6	156
AS34. & AS35.	Mine Bauxite & Produce Aluminum	728	0.01	0.43%	-	728
AS36.	Transport Aluminum	26	0.00	0.02%	3	23
AS37. & AS38.	Mine Copper & Process Copper	454	0.01	0.27%	-	454
AS39.	Transport Copper	22	0.00	0.01%	2	20
AS40.	Manufacture equipment for station modifications	270	0.00	0.16%	-	270
AS41.	Transport equipment for station modifications	-	0.00	0.00%	-	-
AS42.	Mine aggregate	2	0.00	0.00%	-	2
AS43.	Produce cement	224	0.00	0.13%	-	224
AS44.	Mix and process concrete at batch processing plant	8	0.00	0.00%	8	-
AS45.	Transport concrete to site	13	0.00	0.01%	8	4
AS46. To AS48.	Produce and transport crude oil & Refine crude into diesel & Transport diesel	53	0.00	0.03%	0	53
AS49.	Transport labourers to site	-	0.00	0.00%	-	-
AS50.	House labourers	-	0.00	0.00%	-	-
AS51.	Rehabilitate laydown areas	-	0.00	0.00%	-	-
AS52.	Install/construct station modifications	148	0.00	0.09%	148	-
AS53.	Mine materials for ceramics and produce ceramics	164	0.00	0.10%	-	164
AS54.	Transport ceramics to site	10	0.00	0.01%	2	8
BT1.	Transport operators to and from site	-	0.00	0.00%	-	-
BT2.	Maintain transmission line	-	0.00	0.00%	-	-
BT3.	Generate electricity	-	0.00	0.00%	-	-
BT4.	Maintain transmission line right-of-way	972	0.01	0.57%	972	-
BT5.	Transmit electricity	-	0.00	0.00%	-	-
BT6.	Produce materials for replacement parts	-	0.00	0.00%	-	-
BT7.	Manufacture replacement	-	0.00	0.00%	-	-

	equipment					
BT8.	Transport replacement equipment	-	0.00	0.00%	-	-
BT9.	Install replacement equipment	-	0.00	0.00%	-	-
BT10.	Transport removed material for recycling	-	0.00	0.00%	-	-
BT11.	Recycle metals	-	0.00	0.00%	-	-
BS12.	Transport operators to and from site	-	0.00	0.00%	-	-
BS13.	Maintain All Stations	1,835	0.02	1.07%	1,835	-
BS14.	Produce materials for replacement parts	-	0.00	0.00%	-	-
BS15.	Manufacture replacement equipment	-	0.00	0.00%	-	-
BS16.	Transport replacement equipment	-	0.00	0.00%	-	-
BS17.	Install replacement equipment	-	0.00	0.00%	-	-
BS18.	Transport removed material for recycling	-	0.00	0.00%	-	-
BS19.	Recycle the steel equipment	-	0.00	0.00%	-	-
CT1.	Remove transmission lines	1,023	0.01	0.60%	1,023	-
CT2.	Transport Materials for Recycling	270	0.00	0.16%	64	206
CT3.	Recycle metals	2,021	0.02	1.18%	238	1,783
CT4.	Remove access roads	-	0.00	0.00%	-	-
CT5.	Rehabilitate transmission lines and access roads	-	0.00	0.00%	-	-
CT6. To CT9.	Produce crude to Transport diesel	369	0.00	0.22%	2	368
CT7.	Transport crude	-	0.00	0.00%	-	-
CT8.	Refine crude into diesel	-	0.00	0.00%	-	-
CT9.	Transport diesel	-	0.00	0.00%	-	-
CT10.	Combust diesel on-site in equipment to decommission site	-	0.00	0.00%	-	-
CS11.	Remove equipment from Dorsey, Riel and Glenboro Stations	74	0.00	0.04%	74	-
CS12.	Transport removed material for recycling	18	0.00	0.01%	5	12
CS13.	Recycle metals	192	0.00	0.11%	20	172
CS14.	Transport other materials for recycling or landfilling	-	0.00	0.00%	-	-
CS15.	Remove access roads	-	0.00	0.00%	-	-
CS16.	Rehabilitate facility sites and access roads	-	0.00	0.00%	-	-
CS17.	Produce crude to	27	0.00	0.02%	0	27

To CS20.	Transport diesel					
CS18.	Transport crude	-	0.00	0.00%	-	-
CS19.	Refine crude into diesel	-	0.00	0.00%	-	-
CS20.	Transport diesel	-	0.00	0.00%	-	-
CS21.	Combust diesel on-site in equipment to decommission site	-	0.00	0.00%	-	-
Construction Emissions		84,133	0.95	49%	21,975	62,158
Station Upgrade Construction		3,637	0.04	2%	176	3,461
Operating Emissions		2,807	0.03	2%	2,807	-
Decommissioning Emissions		3,994	0.04	2%	1,426	2,568
Land Use Change		76,510	0.86	45%	76,510	-
Total Emissions		**171,081**	**1.92**	**100%**	**102,895**	**68,187**

Appendix 4 – Sensitivity Analysis

Pembina performed sensitivity analyses on aluminum production, land use change, and project construction. These three sensitivities, assumptions, and results are described below.

Table 6 summarizes the results of the MMTP's life cycle GHG emissions (non-generation) assessment. The sensitivity results are compared directly with these results.

Table 6: Base case emissions

Air Emission	**Construction**			**Land Use Change**	**Operation**	**Decommissioning**	**Total**
Tonnes CO_{2eq}	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	76,417	6,766	4,587	76,510	2,807	3,994	171,081

Aluminum production intensity

Aluminum production accounts for almost 25% of the project's life cycle GHG emissions. However, the GHG emissions are estimated based on a generic aluminum production GHG intensity value. This assessment uses an aluminum production intensity of 9.70 kg CO_2eq/kg aluminum ingot from "*Life Cycle Impact Assessment of Aluminum Beverage Cans*"[20]. To test the sensitivity of the life cycle results to this emission factor, we increased the intensity by 30% to 12.61 kg CO_2eq/kg. The results show a difference of 7% in the total direct and embedded emissions

[20]Americas P." *Life Cycle Impact Assessment of Aluminum Beverage Cans*"; 2010:127.

Table 7: Summary of life cycle results and percent difference with modified aluminum production intensity

Air Emission	**Construction**			**Land Use Change**	**Operation**	**Decommissioning**	**Total**
Tonnes CO_{2eq}	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	87,586	6,766	4,587	76,510	2,807	3,994	182,250

Percent Difference

Air Emission	**Construction**			**Land Use Change**	**Operation**	**Decommissioning**	**Total**
	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	15%	0%	0%	0%	0%	0%	7%

Forest carbon contents

The transmission line ROW will permanently disturb over 550 ha of forested land. Our assessment assumes carbon emissions associated with this disturbance are primarily associated with the changes in above ground biomass. The life cycle results are based on

Manitoba specific carbon contents presented in "*An Ecosystem Carbon Database for Canadian Forests*".[21] The sensitivity is based on high-end generic carbon content emissions from the IPCC. As Table 9 shows, the results increase by 11% for the sensitivity case.

Table 8: Summary of changes to carbon content

Type of Forest	Carbon content in base case (tonnes C/ha)[22]	Sensitivity carbon content (tonnes C/ha)[23]
Boreal Forests – Coniferous	31.4	65.5
Boreal Forests – Pine	31.4	65.5
Boreal Forests – Broadleaf	55.1	65.5
Boreal Forests - Mixed	69	65.5

Table 9: Summary of changes to results and percent difference based on different carbon contents

Air Emission	**Construction**			**Land Use Change**	**Operation**	**Decommissioning**	**Total**
Tonnes CO2eq	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	**Offsite**	**Decommissioning Activities**	
Green-house Gas	76,417	6,766	4,587	94,509	2,808	3,994	189,081

[21] *C.H. Shaw, et al, "An Ecosystem Carbon Database for Canadian Forests", Canadian Forest Service, Northern Forestry Centre, 2005, pp. 89-90, 108-109.*

[22] *C.H. Shaw, et al, "An Ecosystem Carbon Database for Canadian Forests", Canadian Forest Service, Northern Forestry Centre, 2005, pp. 89-90, 108-109.*

[23] High generic values from IPCC, *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Anx 3A.1, Table 3A.1.2

Percent Difference

Air Emission	Construction			Land Use Change	Operation	Decommissioning	Total
	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line right-of-way	Offsite	Decommissioning Activities	
Green-house Gas	0.00%	0.00%	0.00%	28.46%	0.00%	0.00%	11%

Wood Matting Disposal: Re-use Scenario

The MMTP requires the use of wood matting for vehicle access in the summer. The majority of the emissions for this activity are due to the methane emissions resulting from the disposal of the wood matting in a landfill. It is unclear at this stage of project planning whether the matting would be re-used or landfilled after the first use. The base case assumes that the wood matting is only used once. In the sensitivity scenario, the wood is re-used once before being landfilled. The landfill emissions are hence allocated between the two uses, and are essentially halved for the MMTP. Table 10 summarizes the changes to the MMTP's life cycle results and the percent difference relative to the base case.

Table 10: Summary of changes to results and percent difference

Air Emission	Construction			Land Use Change	Operation	Decommissioning	Total
Tonnes CO_{2eq}	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	68,763	6,766	4,587	76,510	2,807	3,994	163,427

Percent Difference

Air Emission	Construction			Land Use Change	Operation	Decommissioning	Total
	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	-10%	0.00%	0.00%	0.00%	0.00%	0.00%	-4%

Wood Matting Disposal: Biomass Fuel

This scenario assumes that after being used, the wood matting is combusted in a biomass power plant. The plant's alternative fuel is fuel oil, so the wood matting is assumed to displace any fuel oil that may be combusted. The plant is contractually required to be dispatched and it is assumed that the availability of the wood matting does not affect its dispatching. It is assumed that all energy needs of the plant process are met through the electricity generated with the biomass and have otherwise minimal GHG emissions.

Table 11: Summary of changes to results and percent difference

Air Emission	Construction			Land Use Change	Operation	Decommissioning	Total
Tonnes CO_{2eq}	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	61,898	6,766	4,587	76,510	2,807	3,994	156,562

Avoided Emissions from fuel oil combustion: 9,632 tonnes CO_{2eq}

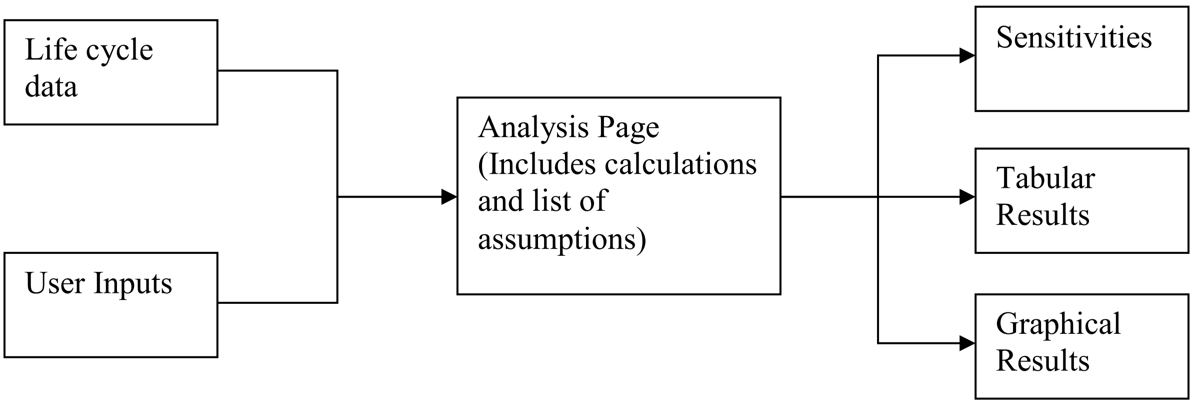
Percent Difference

Air Emission	Construction			Land Use Change	Operation	Decommissioning	Total
	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line ROW	Offsite	Decommissioning Activities	
Green-house Gas	-19.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-8%

In addition to the above savings, the use of wood as biofuel can displace 9,632 tonnes of CO_{2eq} in emission from burning fuel oil.

Appendix 5 – Model Functionality

Pembina used a customized Excel-based life cycle model to contain all the data and calculate the life cycle results in the model. We've made every attempt to include all the important details and assumptions in the body of this report. However, those who would like to replicate the results would need access the model itself. Manitoba Hydro has the version of the model on which the results calculated in this report are based. A high-level diagram of the model and a brief description is available below.



In general the model can be broken down into three components: input, calculations and output. The input data includes all the life cycle data sets for activities like concrete manufacture that provide emission factors. In addition key data, such as transport distances, can be varied in the user input section. The analysis page combines all the life cycle data and user inputs to calculate emissions for all of the parts of the construction, operation and decommissioning of the project. The analysis page then outputs the calculations to the various results pages. The results pages organize the information into the graphs and tables that are included in this report. The sensitivities are also outputted to a separate page in the model.

Sample Calculation

The calculation shown in Equation 2 demonstrates how carbon dioxide equivalent emissions were calculated in the model, using steel production as an example.

$$\textit{Material Quantity} \times \textit{Emissions Factor} = \textit{Quantity of Carbon Dioxide Equivalent}$$

$$(3,581\ tonnes_{steel})\left(\frac{2397.94gCO2\ \ e}{kg_{steel}}\right)\left(\frac{1000kg_{steel}}{tonne_{steel}}\right)\left(\frac{tonne_{CO_2e}}{1\times 10^6 gCO_2e}\right) \cong 8,586\ tonneCO_2e$$

Equation 2: Sample Calculation for Steel Production

The emissions factor for steel production was obtained from Jamie K. Meil, Vice-President of the ATHENA Sustainable Materials Institute. 2002. SS_Galvanized steel sheet, at plant.xls: National Renewable Energy Database, www.nrel.gov/lci and Helene Berg and Sandra Haggstrom. "LCA Based Solution Selection." Chalmers University of Technology, 2002.

Technical Memorandum A - Overview of Manitoba Hydro's Assessment of the Greenhouse Gas Generation Effects of the Manitoba-Minnesota Transmission Project

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Introduction

The impact a project has on global climate change is one of several potential environmental implications that should be considered. To provide appropriate climate change analysis Manitoba Hydro contracted the Pembina Institute to prepare a quantitative greenhouse gas (GHG) life cycle assessment (LCA) of the proposed Manitoba-Minnesota Transmission Project (MMTP).

The primary objective of the LCA was to quantify the life cycle GHG emissions associated with the construction, operation, and decommissioning (referred to as "non-generation effects") of the MMTP. It was subsequently determined that while evaluation of these non-generation effects sufficiently met the LCA's primary objective, and exceeded the requirements of The Environment Act, the assessment's scope may not have been sufficiently considering the potential overall climate change impact of the MMTP.

By providing a new avenue for cross-border trade the MMTP will indirectly impact electricity generation (referred to as "generation effects") throughout the interconnected region. To provide a more complete picture of potential climate change impacts Manitoba Hydro analyzed these generation effects. Manitoba Hydro performed the assessment of generation effects as it required corporation specific knowledge related to Manitoba Hydro's unique hydroelectric system, transmission & distribution (T&D) operations, development plans, and interactions with the interconnected electricity market.

This overview provides details on the approach and methodology used for and the limitations, results, and conclusions of Manitoba Hydro's assessment of the GHG generation effects of the MMTP.

Assessment Approach and Methodology

While in operation the MMTP will impact cross-border trade, primarily by increasing both exports from and imports into Manitoba. These electricity trade impacts will have effects on power generation in both Manitoba and Manitoba Hydro's export region. However, analysis of these generation effects differs in methodology from the analysis of non-generation effects in two distinct ways:

- Firstly, the assessment of non-generation effects relies primarily on tangible project specific inputs such as material and fuel quantities and land cover

surveys. Conversely, the assessment of generation effects requires projections of inputs that are non-project specific and much more uncertain. These include projections of future watershed flow conditions, Manitoba electrical load, energy prices, and electric power markets.
- Secondly, analyzing the generation effects of the MMTP requires comparing future projected scenarios against comparable hypothetical baseline scenarios where the only substantial difference is that in the baseline scenarios the MMTP is not constructed. This differs from Pembina Institute's LCA as the baseline scenario for non-generation effects is simply zero as all the material and energy associated with the MMTP are not consumed.

To assess the overall impact of the generation effects of the MMTP Manitoba Hydro compared two long term resource plan projections against two similar corresponding baseline plans that did not include the construction of the MMTP. Since Manitoba Hydro is not currently modelling resource plan projections without the MMTP, NFAT[1] plans were evaluated. Manitoba Hydro also analyzed the impact of three future U.S. export market scenarios. In each scenario the market evolves differently, ranging from a coal heavy future to one where U.S. coal generation drops off substantially. By evaluating a range of plans and electricity market scenarios Manitoba Hydro was able to estimate a range of potential outcomes.

Assessment Limitations

When estimating the MMTP's generation effects a large range of potential outcomes is inevitable as projecting trends several decades into the future is highly uncertain. Some of the key areas of future uncertainty affecting the assessment of generation effects are as follows:

- Manitoba Hydro's hydroelectric generation levels are heavily dependent on watershed flow conditions which vary substantially and are difficult to predict over the long term. Estimations of future cross-border trade activity are influenced considerably by predicted hydroelectricity generation levels in Manitoba.
- Export market prices, a key input into estimates of future cross-border trade levels, are dependent on multiple variables. These variables include future commodity prices, system resource mix, load growth in and outside of MB, capital costs of new generation, environmental policies, government incentives and directives, T&D system capabilities and constraints, and weather.
- Future long term resource development by Manitoba Hydro will highly influence the use of the new 500-kV line. Over the expected life of the new 500-kV line there is uncertainty regarding potential development options and decisions.

[1] NFAT plans were developed for the 2014 Needs For and Alternatives To review by the Manitoba Public Utilities Board.

The GHG generation effects of the MMTP include both operating margin and build margin effects. Operating margin effects include short term generation implications, such as during a drought situation when the new 500-kV transmission line will allow for additional imported energy to be brought into Manitoba, instead of Manitoba Hydro's fossil-fueled generation resources being ramped up. Build margin effects are those that relate to the long term implications of the MMTP. For example, in terms of both reliability and required power to meet load, the new 500-kV transmission line inherently delays the need for other resource options to be developed. Conversely, it may allow for the acceleration of the decommissioning of existing supply resources and encourage the development of specific new renewable technologies. While Manitoba Hydro considered many operating and build margin effects, it was not feasible to quantify them all.

Pembina Institute's LCA of the non-generation effects of the MMTP spanned the entire 50-year expected life of the Project. Due to projection data limitations, assessment of the MMTP's generation effects was only extended to 2047.

Assessment Results

When contrasting the generation effects of projected plans that include the MMTP versus baseline plans that exclude it, four key indirect influences of the MMTP were assessed:

- The MMTP increasing exports into the export region: This includes the resulting effects of increased Manitoba hydroelectric generation, decreased fossil-fueled generation in the export region, and the temporal shifting of generation in both regions.
- The MMTP increasing imports from the interconnected region: This includes the resulting effects of increased generation in the export region, decreased fossil-fueled generation in Manitoba, and the temporal shifting of generation in both regions.
- The MMTP influencing the in-service dates (ISDs) of new generation: While evaluated plans with the MMTP had earlier ISDs for the Keeyask Generation Project, they also had delayed ISDs for future generation development in Manitoba (compared to the baseline scenarios).
- The MMTP influencing the choice of new generation technologies: When evaluating a potential natural gas generation expansion in Manitoba, the projected plan without the MMTP required several additional combined cycle natural gas plants, compared to the projected plan with the MMTP that relied more on simple cycle plants.

Table 1 presents the aggregated results of Manitoba Hydro's analysis of the MMTP's generation effects. All net outcomes present negative emissions, indicating that all scenarios evaluated produced an overall net reduction in global GHG emissions. It was deemed out-of-scope to perform a probabilistic analysis on the likelihood of these scenarios. As such, no average expected value was calculated.

Table 1: Net GHG Generation Effects of the Proposed MMTP, Multiple U.S. Market Scenarios and Manitoba Hydro Development Plan Scenarios

	Net Generation Effects of the MMTP 2019-2047 (tonnes of CO_2e emitted)	
Scenario	**New* Natural Gas Generation Built in MB**	**New* Hydroelectric Generation Built in MB**
No Climate Change Policy in the U.S.	-1,090,000	-6,940,000
Reference Case Forecast (U.S. Market)	-3,340,000	-6,680,000
Strict Climate Change Policy in the U.S.	-4,850,000	-6,080,000

* All plans evaluated for the assessment of GHG generation effects assume the completion of the Keeyask Generation Project.

Assessment Conclusions

The primary conclusions of Manitoba Hydro's assessment of the GHG generation effects of the MMTP are as follows:

- Over a wide range of potential future scenarios assessed, analysis indicates that the MMTP is expected to produce an overall net reduction in global GHG emissions. It should be considered that there is a substantial range of uncertainty when quantifying the GHG generation effects of the MMTP.
- It is very likely that the GHG generation effects of the MMTP will be more substantial than the GHG non-generation effects.
- The MMTP provides access to an alternative source of energy than Manitoba Hydro's fossil-fueled generation in some low flow conditions. The corresponding displacement of GHG emissions in Manitoba provides benefits to both corporate and provincial GHG emission profiles.
- The MMTP will diminish existing transmission constraints allowing for the capture of additional surplus hydroelectric energy in certain high flow scenarios, resulting in a corresponding decrease in fossil-fueled generation in the export region.
- The MMTP will likely contribute to higher levels of global GHG emission reductions if new hydroelectric generation is developed in MB.