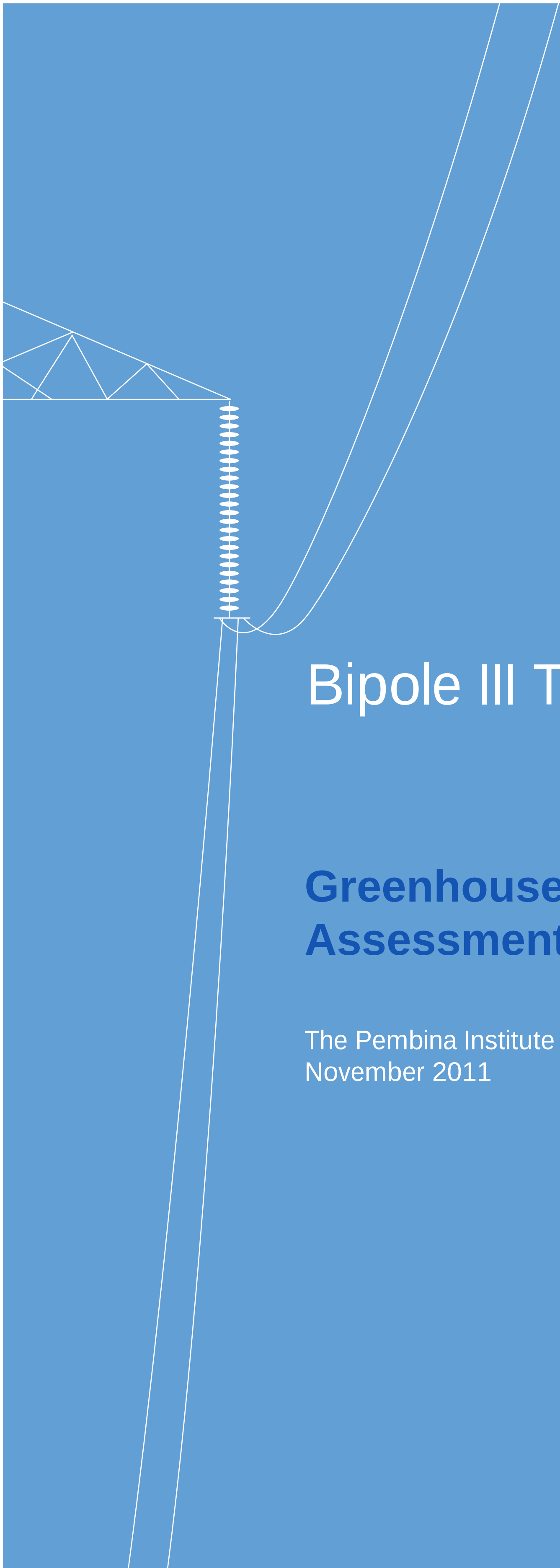

Bipole III Transmission Project

Greenhouse Gas Lifecycle Assessment Technical Report

The Pembina Institute

November 2011

Manitoba Hydro

Greenhouse Gas Life Cycle Assessment of Bipole III

The Pembina Institute

Jeremy Moorhouse • Ryan Kilpatrick • Jason Switzer

July 2011

the PEMBINA institute
Sustainable Energy Solutions

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Greenhouse Gas Life Cycle Assessment of Bipole III

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Greenhouse Gas Life Cycle Assessment of Bipole III

The Pembina Institute

Contents

List of Figures

List of Tables

1. Executive Summary

Manitoba Hydro is considering the construction of Bipole III, a new transmission line that will extend from the Keewatinoow converter station northeast of Gillam to the Riel converter station east of Winnipeg. Manitoba Hydro is considering the project to achieve the following:

1. Improve system reliability by reducing dependency on Bipole I and II by providing a second transmission corridor.
2. Reduce line losses.
3. Provide additional transmission capacity.

Manitoba Hydro contracted the Pembina Institute to prepare a quantitative greenhouse gas (GHG) life cycle analysis (LCA) of the Bipole III transmission and reliability project (the Project). This result summarizes the results of the analysis.

The project will generate 923,273 tonnes CO_{2eq} where the construction of the transmission line accounts for 760,989 CO_{2eq} tonnes and the converter stations 162,284 tonnes CO_{2eq}. Figure 1 summarizes the results of the analysis by life cycle stage.

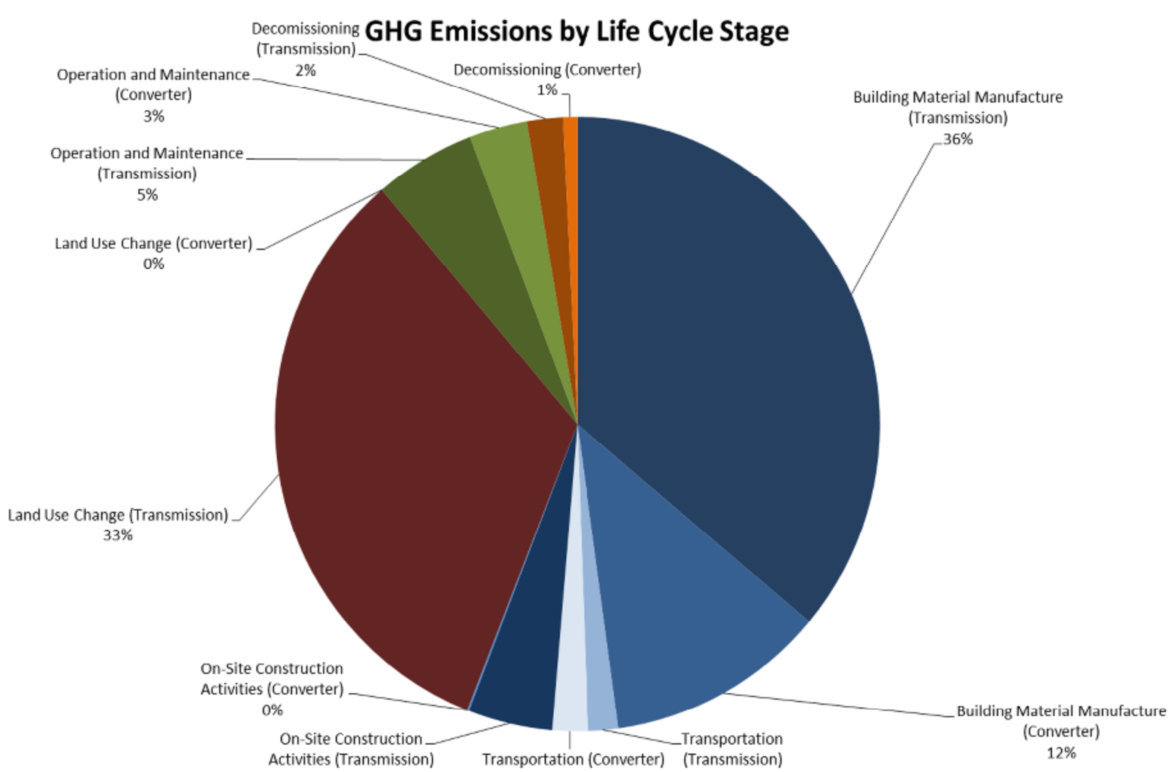

Figure 1: Summary of GHG emissions by life-cycle stage

2. Introduction

2.1 Background

Manitoba Hydro contracted the Pembina Institute to prepare a quantitative greenhouse gas (GHG) life cycle analysis (LCA) of the Bipole III transmission and reliability project (the Project). This report presents the results for the Project.

The final preferred route for the transmission line, as of March 2011, is the western study area. The Project includes 1,384 km of transmission lines, two converter stations (one in northern Manitoba northeast of Gillam and one east of Winnipeg at the Riel station site) and ground electrodes at each converter station. The transmission line will extend from east of Winnipeg to the Keewatinoow converter station northeast of Gillam.

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.[1] 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, LCA analyses 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 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 calculate results and analyze Manitoba Hydro data. All data provided by Manitoba Hydro and acquired from public sources for use in the assessment are available in the appendices.

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

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 Bipole III and 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 life cycle GHG emissions associated with the construction, operation and decommissioning of the Project for incorporation into the Environmental Impact Statement (EIS) for the project.

3. Detailed information on Bipole III

Manitoba Hydro is considering the Project to do the following:

1. Improve system reliability by reducing dependency on Bipole I and II by providing a second transmission corridor.
2. Reduce line losses.
3. Provide additional transmission capacity.

The current preferred route will extend from the Keewatinoow converter station northeast of Gillam to the Riel converter station east of Winnipeg. Figure 2 displays the transmission route and support infrastructure.

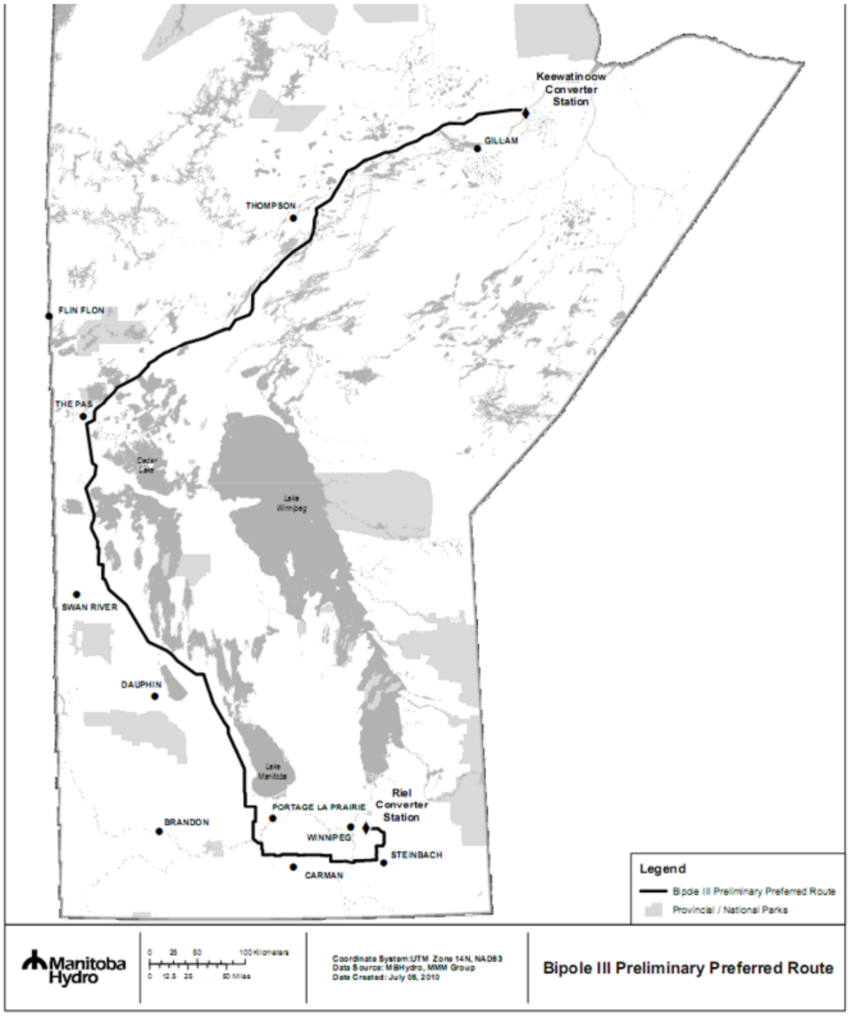

Figure 2: Final Preferred Route for the purposes of this study

The project will include the construction of the following:

- A 500-kilovolt high voltage direct current (HVDC) transmission line from the Keewatinoow converter station northeast of Gillam to the Riel converter station east of Winnipeg.
- Two new converter stations – one in northern Manitoba northeast of Gillam and one east of Winnipeg at the Riel converter station.
- Two ground electrodes – one at each converter station.
- 230 kV transmission line interconnections in the north to tie the new converter station into the existing northern alternating current (AC) system.

Bipole III will have a transmission capacity of 2,000 to 2,500 MW with actual transmission varying over the life of the project. Manitoba Hydro estimates that transmitted electricity will vary between 7,300 GWh/yr and 11,300 GWh/yr over the expected 50-year lifespan of the Project.

The construction of the components discussed above will collectively require the following materials:

- 59,498 tonnes of steel
- 279,614 tonnes of concrete[2]
- 21,722 tonnes of aluminum
- 3,935 tonnes of copper
- 2,570 tonnes of ceramics (insulators)
- 4,463 m^3 of diesel fuel

The Project will disturb 9,017 ha of land of which 3,270 ha of land will be permanently disturbed to maintain the right-of-way.

[2] Includes cement and aggregate for the transmission line and converter stations

4. Methodology

4.1 Basis of Analysis

This analysis derives life cycle GHG emissions associated with the Project through an analysis of the materials and energy used associated with the proposed route and capital equipment. The analysis is only for the preferred route, as of March 2011, and is not compared with any other proposed routes or transmission lines. 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 transmitted electricity (in the appendix).

Criterion [Metric/Indicator]	Relevance and Importance of Criteria
Greenhouse gases (GHGs) [t CO_{2eq}]	Emissions resulting from human activities are substantially increasing the atmospheric concentrations of several important GHGs, especially carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These gases are increasing the greenhouse effect, resulting in an overall average warming of the earth’s surface. Current climate science calls for an aggregate reduction in industrialized countries' emissions to 25–40% below the 1990 level by 2020, and 85–90% below 1990 levels by 2050.[3]

4.2 Boundary Selection

The first step in the life cycle analysis 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 be included in the assessment. Figure 3 displays a simplified life cycle activity map of all the activities included or excluded in the assessment. A more detailed activity map is available in Appendix 1.

The life cycle of the Project was divided into three distinct phases: construction; operation and maintenance of the proposed structures; and final decommissioning of the proposed structures.

In addition to selecting the Project 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 project is not practical from a time and cost perspective. In addition, including all activities does not materially change the results. For example, for a theoretical project that required 100 kilograms of copper and 20,000 tonnes of steel, the amount of analysis required to include the copper is the same as including the steel; however, the copper is only 0.0005% of the mass of the steel and would likely have a similarly negligible impact on the results of the analysis.

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[3] *The Case for Deep Reductions: Canada’s Role in Preventing Dangerous Climate Change*, An investigation by the David Suzuki Foundation and the Pembina Institute, 2005.

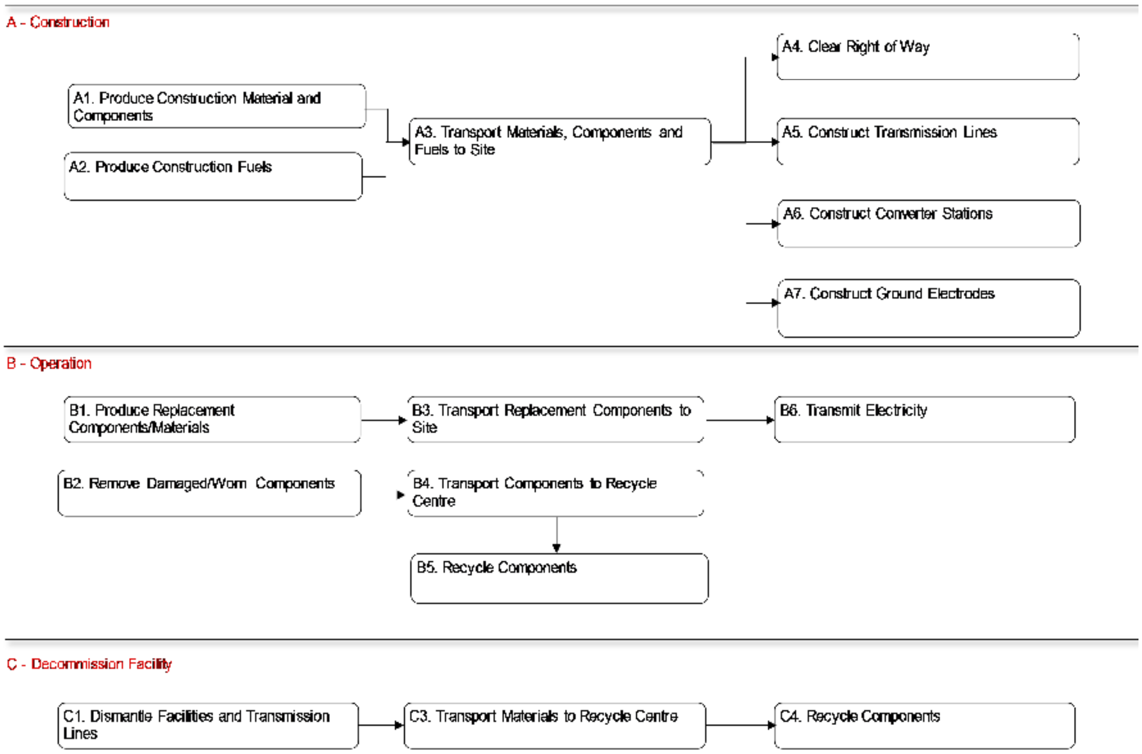

Figure 3: Simplified life cycle activity map

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 will emit 25 kg of SF_6 per year over the life of the project. 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 is responsible for ~2.5% of life cycle emissions.

3. **Data availability:** Regardless of Principles 1 and 2, if the data was readily available then the value was included. For example, this assessment included fuel use for site clearing for the converter station, which was estimated at 1 cubic metre of diesel — 0.02% of total diesel requirements — because the data was readily available.

A detailed list of included and excluded activities is available in Appendix 2 – Scoping.

4.3 Calculation Methodology

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

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

Equation 1: General form of calculations

Appendix 6 – 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.

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 notable details are listed below. A more detailed list of assumptions and justifications is available in Appendix 2 – Scoping.

- **Functional unit:** The functional unit for this assessment is 1 GWh of transmitted electricity. However, results in the main body of the report are in total emissions. Intensity results are available in Appendix 4 – Detailed Results.
- **Cement production and transportation:** Manitoba Hydro has not contracted 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[4] — a process that Manitoba Hydro has followed in the past in its construction of hydro facilities.
- **Steel production and transportation:** Steel components may be sourced from many different locations around the world. This assessment assumes all steel comes from China and is shipped to Vancouver by ship and then by rail to Winnipeg and by truck to site.
- **Replacement components:** In the absence of maintenance estimates, this assessment assumes 10% of all materials are replaced over the 50-year life of the project. This assumption follows assumed material replacement in a life cycle assessment of Great Britain's electricity transmission system.[5] Ideally, this assumption would be based on multiple public studies. However, transmission network LCAs are relatively rare. Pembina identified this source as the most relevant after a preliminary literature review.
- **Recycling:** All steel, aluminum and copper materials replaced during the life of the project and removed at the end of the project are recycled. Aluminum and copper recycling emission intensity are based on generic North American recycling factors[6].

[4] Manitoba Hydro, personal communication, March 2009

[5] Harrison GP, Maclean E (Ned) J, Karamanlis S, Ochoa LF. Life cycle assessment of the transmission network in Great Britain. Energy Policy. 2010;38(7):3622-3631. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421510001205.

[6] Copper based on Martchek KJ. *The Importance of Recycling to the Environmental Profile of Metal Products*. Pittsburgh; 2000:10. Available at:

Steel recycling is based on Manitoba specific recycle 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 right-of-way will be put back into use after the 50-year period and will be permanently disturbed. That is, the forest cleared will not be allowed to regenerate in a 100 year period.

- **Land use change:** This assessment assumes that land disturbances of more than 100 years (for example, the transmission line corridors) are permanent and may contribute to life cycle GHG emissions. The area of disturbances that are temporary in nature (<100 years), such as clearing for the borrow sources area, are not included in net GHG production calculations. Using the above assumptions, the Project permanently disturbs 3,270 ha of forested or semi-forested land. The majority of the disturbance is associated with land clearing for the transmission line corridor, the remainder from the foundations for the transmission towers. This assessment follows the Intergovernmental Panel on Climate Change's (IPCC) guidance document for land use change calculations and carbon contents are from the Canadian Forest Service.[7,8] The IPCC document provides direction on calculation methodology and the Canadian Forest Service provides carbon contents for different forest types. See Land-Use-Change Assumptions in Appendix 2 – Scoping for more information.

- **Line Losses:** Line losses are excluded from this analysis because they are included in the life cycle assessments for Keeyask and other generating stations. Manitoba Hydro expects line losses to be on the order of 709,000 MWhr/yr or approximately 3 – 4% of expected transmission. In addition, as Bipole III is transmitting electricity from hydro sources, the emissions associated with the line losses are expected to be small. For example, Keeyasks life cycle emission intensity is 2.46 tCO2eq/GWhr. Using losses of 709,000 MWhr/yr with a carbon intensity of 2.46 tCO2eq/GWhr results in 1,744 tonnes CO2eq/yr associated with line losses or 0.2% of Bipole III's life cycle emissions.

- **Decommissioning:** The assessment includes decommissioning of the transmission line, converter stations and ground electrodes. All metal materials are recycled.

http://www.alcoa.com/global/en/environment/pdf/importance_of_recycling.pdf. And Hammond, G.P. and C.I. Jones, 2008, "Inventory of Carbon and Energy (ICE) Version 1.6a" Sustainable Energy Research Team, University of Bath, UK. Available at www.bath.ac.uk/mech-eng/sert/embodied/ Aluminum from: NREL LCI Database, Franklin Associates (Division of ERG) and Steel from: Gerdau Ameristeel. 2009. Personal communication with Gerdau on fuel use for steel recycling.

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

[8] Intergovernmental Panel on Climate Change, "Good Practice Guidance for Land Use, Land-Use Change and Forestry," (International Panel on Climate Change, 2003).

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 Project. However, aluminum components used could be produced in many different countries. In addition, Manitoba Hydro has not yet contracted specific companies to provide equipment made from aluminum. This assessment assumes aluminum components are sourced from China, a conservative assumption relative 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, converter stations and ground electrodes 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 transport distances based on previous hydro projects. A list of all transport distances is available in Appendix 3 – Inventory Assessment.

- **Stage of development:** All materials and fuel requirements are calculated from best estimates provided by Manitoba Hydro based on the most recent design documents. The actual construction of the transmission line may require different material quantities.

5. Results and Discussion

5.1 Introduction

The quantitative LCA results are divided into two main categories, the transmission line and the converter stations. For a detailed breakdown of what activities are included the transmission line and converter station portions see Appendix 2 – Scoping. The results are further disaggregated into construction emissions (material production, transportation and construction of the transmission lines and converter stations), land use change (from land clearing), maintenance of the transmission lines (primarily the replacements of components over the projects life), operations (fuel use for electricity generation) and decommissioning of the Project after 50 years. More detailed results are presented in Appendix 3 – Inventory Assessment.

5.2 Bipole III Life Cycle Results

Table 1 summarizes GHG emissions per life cycle stage for the transmission line and the converter stations. The construction phase includes emissions from producing necessary construction materials and transporting them to site, plus on-site emissions to construct the transmission line and converter stations. The operation phase includes emissions from site maintenance and replacing and disposing of components. 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 right-of-way.

Table 1: Summary of GHG emission sources for Bipole III for the transmission line and converter stations

Component	Construction			Land Use Change	Operation	Decommissioning	Tonnes CO_{2eq}
	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing	Maintenance Activities	Decommissioning Activities	
Transmission Line	333,390	14,848	41,678	303,395	49,904	17,774	**760,989**
Converter Station	108,281	17,486	874	-	28,568	7,074	**162,284**
Total	**441,672**	**32,333**	**42,553**	**303,395**	**78,473**	**24,848**	**923,273**

The transmission line accounts for the majority of the Projects life cycle GHG emissions, creating 760,989 tonnes CO_{2eq}. The construction phase (building material manufacture, transportation and on-site construction activities) of the transmission line generates 389,916 tonnes CO_{2eq}, land use change 303,395 tonnes CO_{2eq}, operation 49,904 tonnes CO_{2eq}, decommissioning 17,774 tonnes CO_{2eq}. Aluminum and steel production make up the majority of the construction emissions. Land use change emissions are primarily associated with the conversion of forested areas to grassland or shrub land for the right-of-way. This carbon will most likely be released at the beginning of the project when the forest clearing occurs. Operation phase emissions are primarily associated with diesel combustion for line maintenance and the construction of replacement components. Emissions during the decommissioning phase are primarily associated with recycling metal materials.

Converter station construction, land use change, operation and maintenance and decommissioning generate comparatively fewer GHG emissions of 162,284 tonnes CO_{2eq}. The construction phase of the converter station generates 126,641 tonnes, land use change 0 tonnes CO_{2eq}, operation and maintenance 28,568 tonnes CO_{2eq} and decommissioning 7,074 tonnes CO_{2eq}. Construction phase emissions are primarily associated with steel and copper production and to a lesser extent cement production. Operation and maintenance phase emissions are primarily from SF_6 emissions. Materials recycling generate the majority of the decommissioning emissions.

The transmission line's life cycle generates more GHG emissions for two main reasons. First, the transmission line requires 21,722 tonnes of aluminum, an energy-intensive material that is not required in the construction of the converter stations. Second, the transmission line requires the conversion of 3,270 ha of land, resulting in land use change emissions.

Figure 4 presents the results in Table 1 by percentage contribution to life cycle GHG emissions.

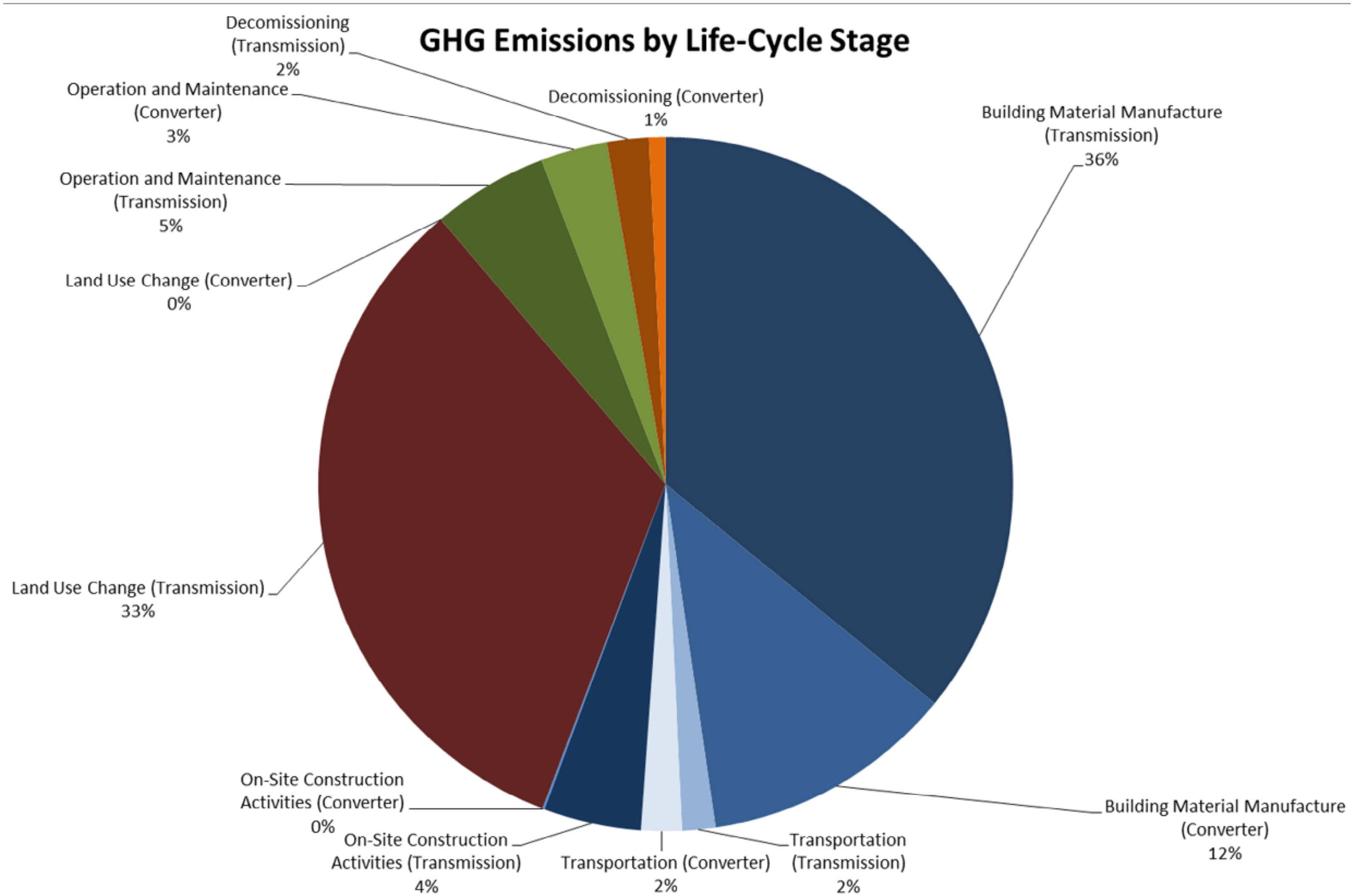

Figure 4: Breakdown of GHG emissions per primary activity

As Figure 4 shows, the construction (blue pie pieces in the figure) and land use change (maroon pie pieces in the figure) phases account for the majority of the Projects life cycle emissions (89%). Operation and maintenance (green pie pieces) account for 8% and decommissioning (orange pie pieces) accounts for 3%.

5.3 Summary of Sensitivity Analysis

Pembina performed 3 sensitivity analyses on aluminum production, land use change and project construction. Descriptions of the sensitivity analyses and a summary of the results are provided below. Appendix 5 – Sensitivity Analysis contains additional detail on the analysis.

- **Aluminum Production Intensity:** Aluminum production accounts for 27% of the project life cycle emissions and is based on a generic aluminum production GHG intensity factor.[9] 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 +/- 8% change to overall results.
- **Land Use Change –** The transmission line right-of-away will permanently disturb over 3,000 ha of forest land. The land use change associated with this disturbance is the second largest GHG contributor over the Project life cycle. Pembina initially used generic IPCC carbon contents for North American boreal forests[10]. However, given the magnitude of the emissions Pembina sought Manitoba specific carbon contents to improve accuracy. Calculations in this report are from the Canadian Forest Service's "An Ecosystem Carbon Database for Canadian Forests"[11]. Further refinement would require measured carbon content values along the current transmission corridor.

  The current carbon content calculations are based on a selection of plots in Manitoba. Carbon contents can vary significantly by region. For example, the IPCC notes a range of 12.3 to 131 tonnes dry matter/ha[12] for coniferous forests in Eurasia. This sensitivity tests the impact on the results of the analysis when using the high range of carbon contents. When using the high range of carbon contents land use change emissions become the single largest source of emissions and increase overall life cycle emissions by 39%. This is a significant change to the results. Manitoba Hydro could reduce the uncertainty of the land-use-change emissions by using carbon content values specific to the right-of-way of the transmission line.
- **Ground line electrode –** The Project requires the construction of a ground line electrode. However, Manitoba Hydro does not have material estimates for the ground line electrode. The line will likely be 15km and Manitoba Hydro estimates it will require 10% of the materials required for the construction of 230 kV connector lines. This sensitivity tests the impact of this assumption. The results of this sensitivity show that the ground line electrode will increase the Project's life cycle emissions by 0.2%; a relatively small increase in comparison with the other sensitivities.

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[9] Americas P. Life Cycle Impact Assessment of Aluminum Beverage Cans.; 2010:127. For the production of an aluminum ingot.

[10] Intergovernmental Panel on Climate Change. "Good Practice Guidance for Land Use, Land-Use Change and Forestry." International Panel on Climate Change, 2003. Anx 3A.1, Table 3A.1.2

[11]

[12] Carbon content is a portion of the dry matter. Intergovernmental Panel on Climate Change. "Good Practice Guidance for Land Use, Land-Use Change and Forestry." International Panel on Climate Change, 2003. Anx 3A.1, Table 3A.1.2

The Project life cycle GHG emissions are sensitive to assumptions on land-use-change emissions, specifically the carbon content of above ground biomass along the transmission right-of-way. The Project life cycle GHG emissions are less sensitive to aluminum production intensity assumptions and change very little with the assumed material requirements for the ground line electrode.

6. Conclusions

The primary conclusions of this LCA are as follows:

- **Life cycle GHG emissions.** The project will generate 923,273 tonnes CO_{2eq} where the transmission line accounts for 760,989 CO_{2eq} tonnes and the converter stations 162,284 tonnes CO_{2eq}.
- **Transmission Line:** The construction, land use change, operation and maintenance, and decommissioning associated with the transmission line account for 82% of life cycle GHG emissions for the Project. The main reasons for this difference are the amount of aluminum required and land use change emissions.
- **Converter Stations:** Converter station construction, operation and maintenance and decommissioning account for the remaining 18% of life cycle GHG emissions. This contribution is still significant but relatively minor compared with the transmission line.
- **Land use change and aluminum production**: Land use change and aluminum production alone account for 56% of life cycle emissions.
- **Decommissioning**: Decommissioning contributes relatively little to the life cycle intensity of the project (3%).
- **Results sensitive to land use change assumptions:** Modifying land use change assumption within known variability of has a significant impact on the results. Life-cycle emissions increased by 38% when using the high-end IPCC carbon content estimates for boreal forests.

7. Appendices

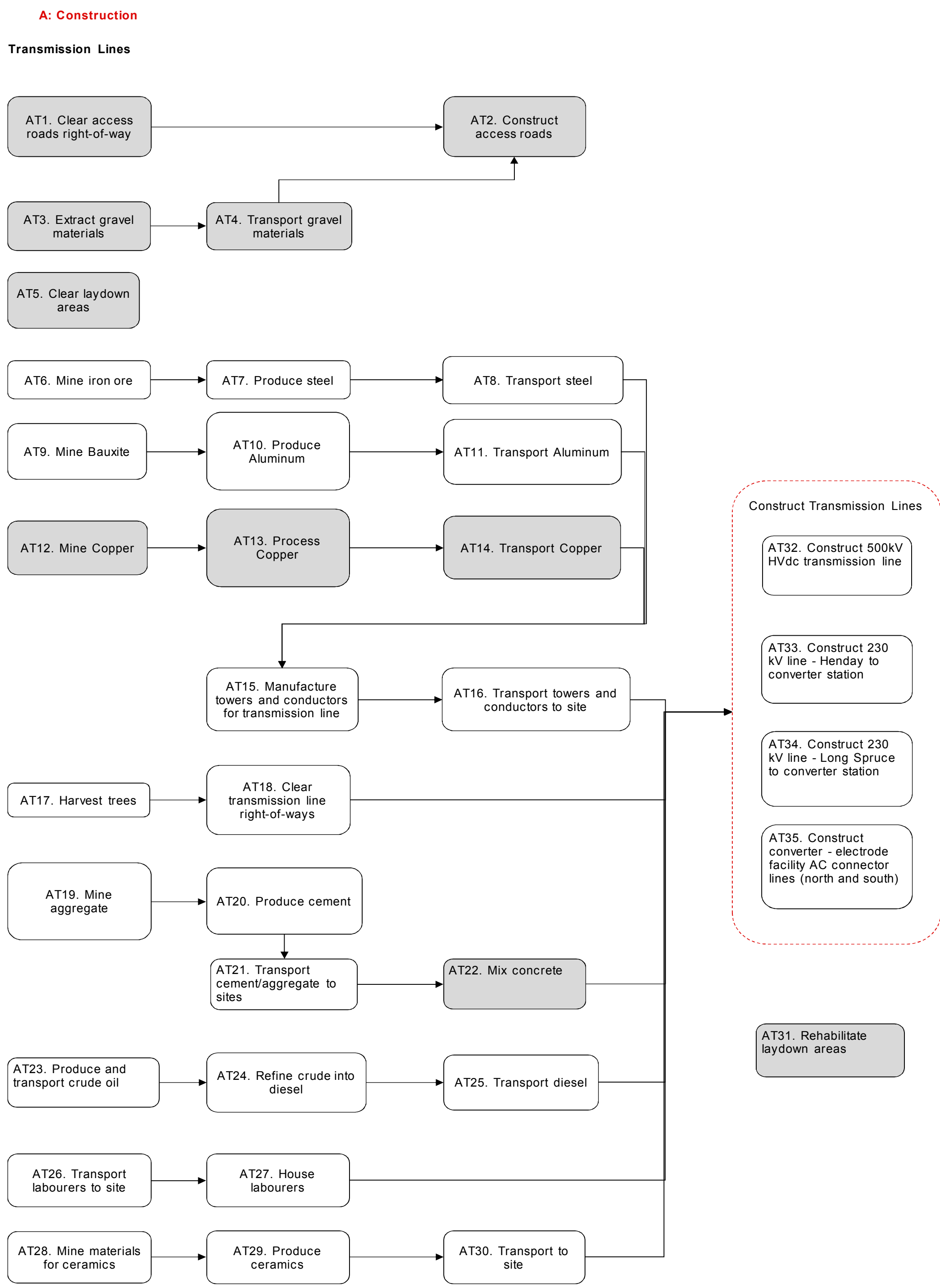
Appendix 1 – Goal Definition

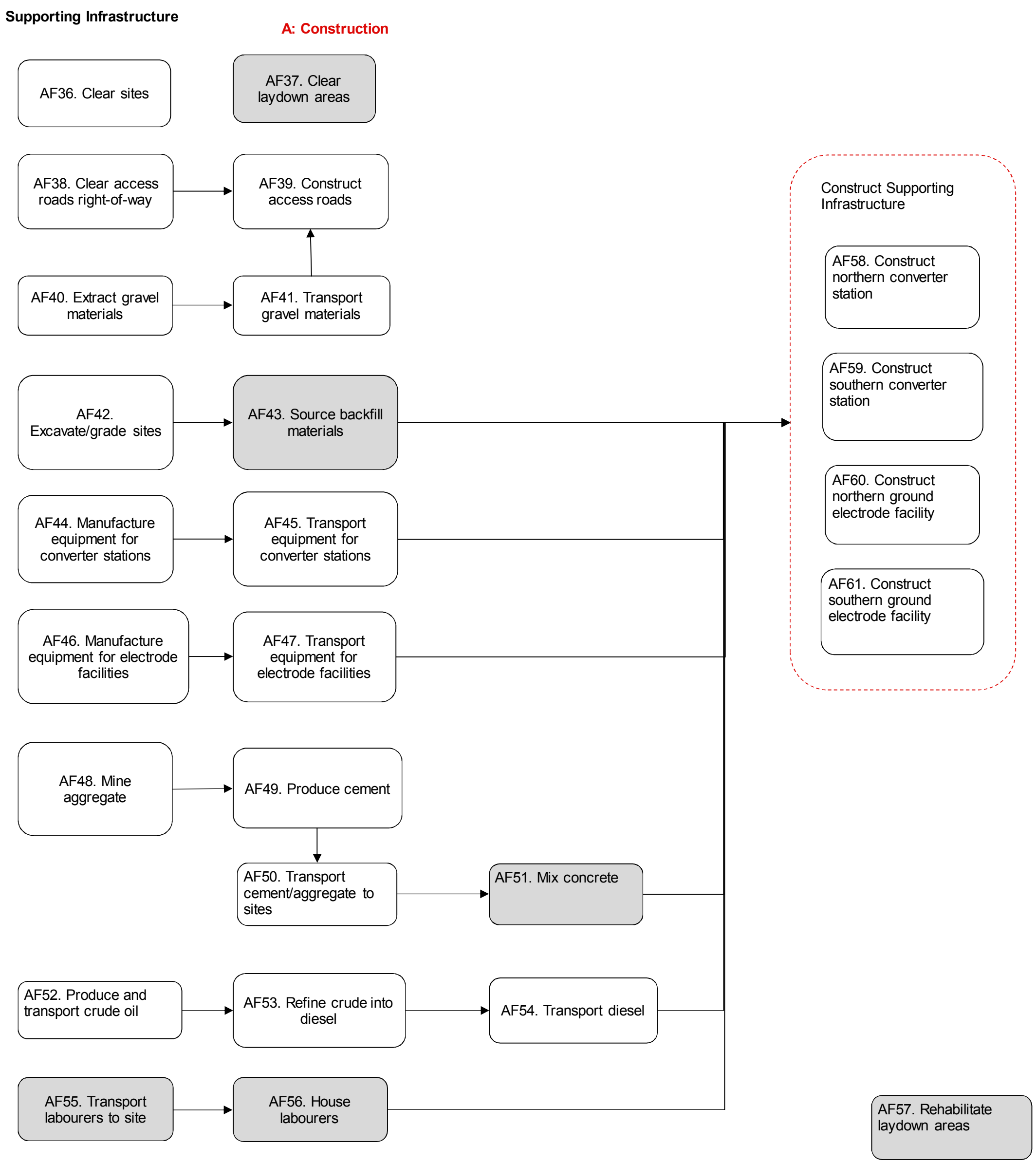
Comparison options

The results of this life cycle assessment will not be used to compare options. Rather, the results will be used to establish the life cycle GHG emissions as associated with the project as part of an Environmental Impact Statement. Therefore, comparisons are not included in this assessment.

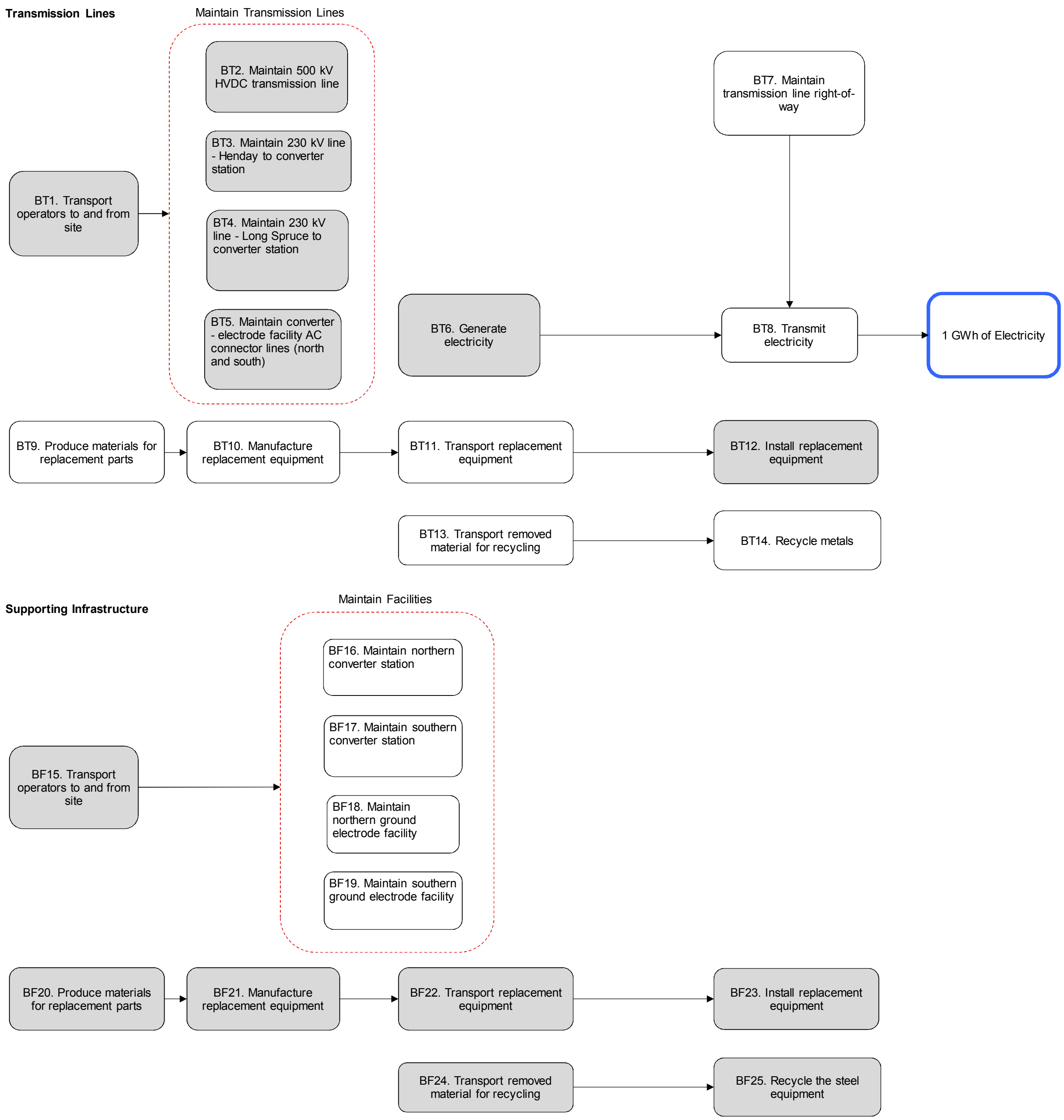
Appendix 2 – Scoping

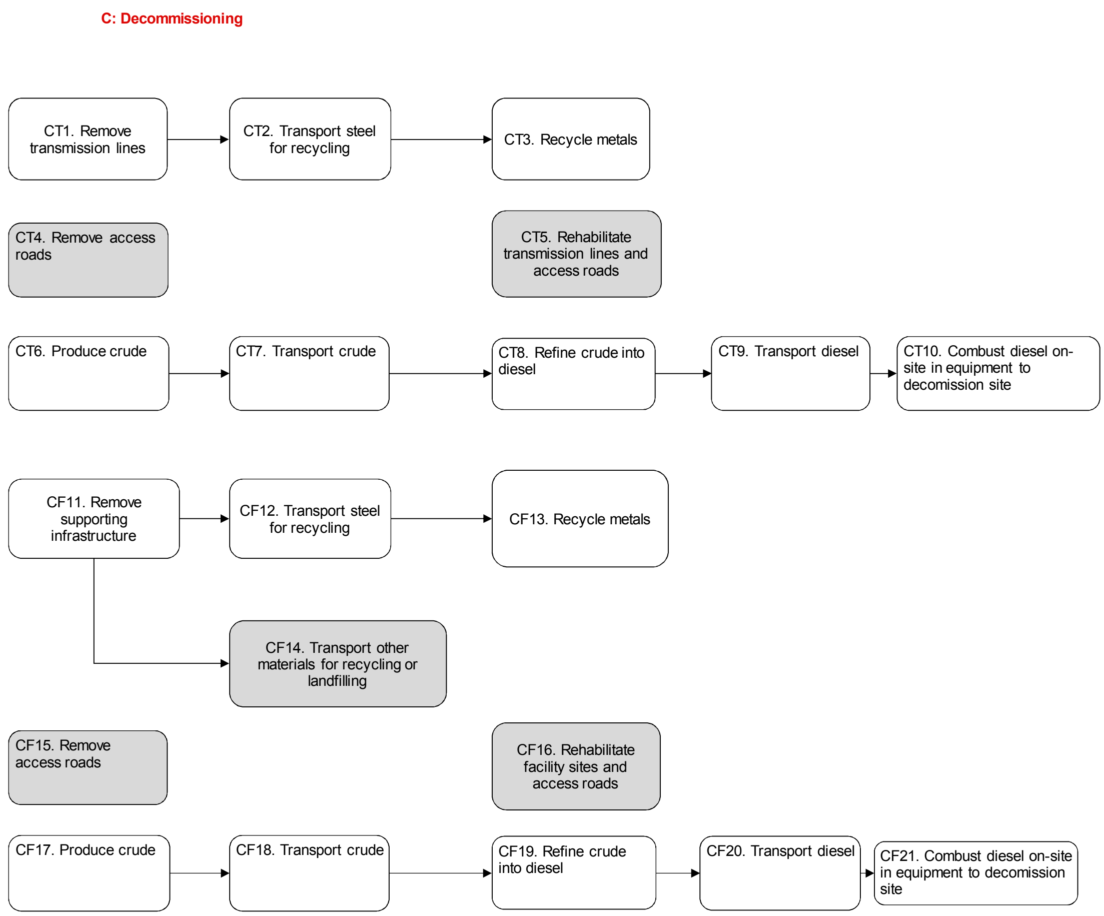
System Activity Maps




Supporting Infrastructure
A: Construction
AF36. Clear sites
AF37. Clear laydown areas
AF38. Clear access roads right-of-way
AF39. Construct access roads
AF40. Extract gravel materials
AF41. Transport gravel materials
AF42. Excavate/grade sites
AF43. Source backfill materials
AF44. Manufacture equipment for converter stations
AF45. Transport equipment for converter stations
AF46. Manufacture equipment for electrode facilities
AF47. Transport equipment for electrode facilities
AF48. Mine aggregate
AF49. Produce cement
AF50. Transport cement/aggregate to sites
AF51. Mix concrete
AF52. Produce and transport crude oil
AF53. Refine crude into diesel
AF54. Transport diesel
AF55. Transport labourers to site
AF56. House labourers
Construct Supporting Infrastructure
AF58. Construct northern converter station
AF59. Construct southern converter station
AF60. Construct northern ground electrode facility
AF61. Construct southern ground electrode facility
AF57. Rehabilitate laydown areas

B: Operation and Maintenance





Key Assumptions

Table 2: Key assumptions per activity for Bipole III

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 clear access ways.	Access roads exist in the centre of the corridor so require no additional clearing.
AT3.	Extract gravel materials	No gravel material required for roads	Access roads are not engineered and usually consist of compacted snow.
AT4.	Transport gravel materials	No transportation of gravel required	Access roads are not engineered and usually consist of compacted snow.
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 for all towers	Galvanized steel is the expected tower material.
AT8.	Transport steel	China (sea to Vancouver, rail to Winnipeg and then road to	Manitoba Hydro has not chosen a steel supplier. China is a conservative

		site)	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. [13]
AT11.	Transport Aluminum	Conductors produced in China	According to Manitoba Hydro recent manufacturers of tower components and conductors that have been successful in the bidding process have been from China and India.
AT12.	Mine Copper	Not included	Insignificant quantities of copper in transmission lines.
AT13.	Process Copper	Not included	Insignificant quantities of copper in transmission lines.
AT14.	Transport Copper	Not included	Insignificant quantities of copper in transmission lines
AT15.	Manufacture towers and conductors for transmission line	Producing conductors similar to extruding aluminum.	No life cycle data sets exist for producing conductors.
		Manufacture tower excluded	Portion of manufacture occurs on site (assembly), and majority of emissions 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 included in clearing activities.
AT18.	Clear transmission line right-of-ways	Estimate based on machinery, fuel and time.	Manitoba Hydro best estimate
AT19.	Mine aggregate	Aggregate requirements calculated from aggregate to concrete ratios for other Manitoba Hydro projects.	Estimates from this project were unavailable.
AT20.	Produce cement	Cement requirements calculated from concrete use, using concrete to cement ratios for other Manitoba Hydro projects.	Estimate based on Manitoba Hydro cement to aggregate ratios.
AT21.	Transport cement/aggregate to sites	Cement from Edmonton	Closest cement source and assumed for other Manitoba Hydro life cycle assessments.

[13] Americas P. *Life Cycle Impact Assessment of Aluminum Beverage Cans*.; 2010:127. And NREL LCI Database, Franklin Associates (Division of ERG)

		Transportation of cement from Edmonton to Winnipeg by rail car.	Rail line extends from Edmonton to Winnipeg.
		Transportation of cement from production site to Winnipeg is done by road transport.	Only form of transport along transmission line.
		Aggregate is available in Winnipeg and transported to site by road.	Likely source of aggregate given proximity.
AT22.	Mix concrete	Not included	Energy requirements unknown and likely small contributor to site GHG emissions.
AT23. to AT25.	Produce and transport crude oil to Transport diesel	No additional clearing or construction activities for access roads.	760 km of access roads will be required. However, access will be provided either by provincial roads or along the right-of-way itself.
		Diesel used at site and its associated production emissions are the same as those for the region as a whole.	Diesel is taken from general supply.
AT26.	Transport labourers to site	Each camp contains 70 people and are approximately 65 km apart. The average length of stay at each camp is 49 days and trips are by bus.	Best estimate provided by Manitoba Hydro based on previous experience.
AT27.	House labourers	Conservative assessment based on camp size >50 people and spending 7 weeks in each of 21 camps.	Conservative assessment based on camp size >50 people and spending 7 weeks in each of 21 camps.
		No natural gas used for heating.	Provided by Manitoba Hydro.
AT28.	Mine materials for 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.
AT29.	Produce ceramics		
AT30.	Transport 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.
AT31.	Rehabilitate laydown areas	Not Included	No laydown areas to rehabilitate.
AT32.	Construct 500kV HVDC transmission line	Diesel combustion is the only emission source associated with construction.	Only diesel is used to power construction equipment.
AT33.	Construct 230 kV line - Henday to converter station	Diesel combustion is the only emission source associated with the construction of the	Only diesel is required to power construction equipment.

		230 kV line.	
AT34.	Construct 230 kV line - Long Spruce to converter station	Diesel combustion is the only emission source associated with the construction of the 230 kV line.	Only diesel is required to power construction equipment.
AT35.	Construct converter - electrode facility AC connector lines (north and south)	Diesel combustion in construction equipment forms the majority of on-site diesel use	Only source of emissions on site.
AF36.	Clear sites	Diesel combustion in construction equipment forms the majority of on-site diesel use.	Only source of emissions on site.
AF37.	Clear laydown areas	Not Included	No laydown areas
AF38.	Clear access roads right-of-way	Not Included	Access roads accounted for in transmission line.
AF39.	Construct access roads	Not Included	Access roads accounted for in transmission line.
AF40.	Extract gravel materials	Not Included	Access roads accounted for in transmission line.
AF41.	Transport gravel materials	Not Included	Access roads accounted for in transmission line.
AF42.	Excavate/grade sites	Diesel combustion in construction equipment forms the majority of on-site diesel use.	Only source of emissions on site.
AF43.	Source backfill materials	No backfill materials required	None - camp sites will be chosen so that fill materials are not required. Trailers will be leveled with wood blocking as required. (KPD)
AF44.	Manufacture equipment for converter stations	Specific manufacturing processes are not estimated.	1. The material requirements are for many different pieces of equipment. 2. Metal working is estimated for steel and copper to account for metal manufacturing.
AF45.	Transport equipment for converter stations	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.
AF46.	Manufacture equipment for electrode facilities	Specific emission factors for systems are not included, generic emission factor for metal production and forming is used as proxy.	Finding emission factors for piece of equipment is not possible. In general metal equipment will require mining, refining, transportation and casting regardless of the end product.
AF47.	Transport equipment for electrode facilities	Electrodes are manufactured in North America.	MH expect to purchase from North American suppliers with manufacturing capacity in North America.

AF48.	Mine aggregate	Virgin aggregate is mined for concrete production.	Conservative assumption
AF49.	Produce cement	Generic North American emission estimates are representative of actual emissions.	Cement is being sourced from a North American facility so the data should be applicable.
AF50.	Transport cement/aggregate to sites	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
		Transportation of cement from production site to Winnipeg is done by road transport.	Only form of transport along transmission line.
		Aggregate is available in Winnipeg and transported to site by road.	Likely source of aggregate given proximity.
AF51.	Mix concrete	Not Included	Data unavailable and likely small contributor to emissions.
AF52. to AF54.	Produce and transport crude oil & Refine crude into diesel & Transport diesel	No additional clearing or construction activities for access roads.	760 km of access roads will be required. However, access will be provided either by provincial roads or along the right-of-way itself.
		Diesel used at site and its associated production emissions are the same as those for the region as a whole.	Diesel is taken from general supply.
AF55.	Transport labourers to site	Not Included	Included as part of transmission line.
AF56.	House labourers	Not Included	Included as part of transmission line calculations.
AF57.	Rehabilitate laydown areas	Not Included	No active rehabilitation
AF58.	Construct northern converter station	Diesel combustion in construction equipment forms the majority of on-site diesel use.	Only source of emissions on site.
AF59.	Construct southern converter station	Diesel combustion in construction equipment forms the majority of on-site diesel use.	Only source of emissions on site.
AF60.	Construct northern ground electrode facility	Diesel combustion in construction equipment forms the majority of on-site	Only source of emissions on site.

		diesel use.	
AF61.	Construct southern ground electrode facility	Diesel combustion in construction equipment forms the majority of on-site diesel use.	Only source of emissions on site.
BT1.	Transport operators to and from site	Not Included	Included as part of maintain transmission line right-of-way.
BT2. to BT5.	Onsite maintenance activities - Transmission lines	Not Included	Included in other activities
BT6.	Generate electricity	Not Included	No electricity generated as part of maintenance activities.
BT7.	Maintain transmission line right-of-way	Emissions of maintaining transmission line equivalent to average for Great Britain's transmission network.	Manitoba Hydro has no estimate; however flyovers and physical inspection would generally be the same.
BT8.	Transmit electricity	Losses excluded	Losses are included in life cycle assessments for hydro facilities. Including here would double count.
BT9.	Produce materials for replacement parts	10% of all equipment replaced over life.	Based on Harrison GP, Maclean E (Ned) J, Karamanlis S, Ochoa LF. Life cycle assessment of the transmission network in Great Britain. Energy Policy. 2010;38(7):3622-3631. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421510001205.
BT10.	Manufacture replacement equipment	Not Calculated	Included in BT9
BT11.	Transport replacement equipment	10% of all material replaced over life of project.	Based on Harrison GP, Maclean E (Ned) J, Karamanlis S, Ochoa LF. Life cycle assessment of the transmission network in Great Britain. Energy Policy. 2010;38(7):3622-3631. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421510001205.
BT12.	Install replacement equipment	Not Included	Preliminary calculations show that installation would be <.1% of emissions
BT13.	Transport removed material for recycling	Material would be recycled within 3,000 km of Winnipeg.	Recycling capacity exists within 3,000 km.
BT14.	Recycle metals	All metals are recycled	Manitoba Hydro
BF15.	Transport operators to and from site	Not Included	No information available and likely small based on other transportation estimates.
BF16. to BF19.	Maintenance activities	Primary emission sources is SF6 emissions.	Manitoba Hydro provided SF6 emissions based on similar facilities.

BF20.	Produce materials for replacement parts	Not Calculated	Included in Transmission line.
BF21.	Manufacture replacement equipment	Not Calculated	Included in transmission line.
BF22.	Transport replacement equipment	Not Included	Included in transmission line.
BF23.	Install replacement equipment	Not included	Likely small
BF24.	Transport removed material for recycling	Not included	Included in transmission line.
BF25.	Recycle the steel equipment	Not included	Included in transmission line.
CT1.	Remove transmission lines	Fuel requirements are approximately 50% of construction fuel requirements.	Best estimate by MH
CT2.	Transport Materials for Recycling	Steel recycling occurs in Manitoba.	Manitoba has steel recycling capacity
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	Right-of-way will likely re-vegetate naturally.
CT5.	Rehabilitate transmission lines and access roads	Not included	Right-of-way will likely re-vegetate naturally.
CT6.	Produce crude	Diesel used at site and its associated production emissions are the same as those for the region as a whole.	Diesel is taken from general supply.
CT7.	Transport crude	Not calculated	Included in emission factor.
CT8.	Refine crude into diesel	Not Calculated	Included in emission factor.
CT9.	Transport diesel	Not Calculated	Included in emission factor.
CT10.	Combust diesel on-site in equipment to decommission site	Not calculated	All calculations included in CT1.
CF11.	Remove supporting	Diesel required approximately 50% of	Manitoba Hydro rough assumption.

	infrastructure	construction.	
CF12.	Transport steel for recycling	Steel recycled in Manitoba, copper in North America.	Steel recycling capacity exists in Winnipeg and copper in North America.
CF13.	Recycle metals	Steel and copper recycled.	Steel and copper primary metals in the converter stations.
CF14.	Transport other materials for recycling or landfilling	Not included	Most materials are recyclable.
CF15.	Remove access roads	Not Included	Any access roads will be allowed to reclaim naturally.
CF16.	Rehabilitate facility sites and access roads	Not Included	Will rehabilitate naturally.
CF17.	Produce crude	Diesel used at site and its associated production emissions are the same as those for the region as a whole.	Diesel is taken from general supply.
CF18.	Transport crude	Not calculated	Included in emission factor.
CF19.	Refine crude into diesel	Not Calculated	Included in emission factor.
CF20.	Transport diesel	Not Calculated	Included in emission factor.
CF21.	Combust diesel on-site in equipment to decommission site	Not Included	Included in other activities.

Land-Use-Change Assumptions

Land use change from land clearing for access roads, transmission lines and dykes are based on IPCC guidance documents[14] and carbon contents are from the Canadian Forest Service.[15] Pembina used the following overarching assumptions to guide calculations. These assumptions are followed by details on the carbon contents used for each forest type cleared.

- Forest land is converted to grassland/shrub land. Total forested area disturbed is 3,253 ha.
- Other land types (grassland, agricultural land, shrub land etc…) remain unchanged except for the area directly beneath the tower. The total land area directly beneath the transmission towers is 16.62 ha.
- Wetlands remain undisturbed along the length of the right-of-way.

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

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

- CO_2 is released at the time of clearing because all biomass is combusted.
- There is no significant decay.
- There is no change in the intensity of land use. That is the carbon content of soils is unchanged after clearing.
- There are no new road right-of-ways. Access will be along existing road structure or the transmission line right-of-way.
- The carbon content of all forest types being cleared are based on Manitoba specific carbon contents.

Table 3: Additional detail on Land use change calculations

Forest Type	Carbon Content (tonnes C/ha)
Coniferous	31.4
Broadleaf	55.1
Mixed	69
Grassland/Shrub	15.3

Appendix 3 – Inventory Assessment

Inputs

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

Activity #	Title	Quantity	Sources
AT6. & AT7.	Mine iron ore & Produce steel	33,007 Tonnes Steel	Manitoba Hydro. For central line and connector lines. 30,000 tonnes of steel primarily for steel towers and 3,007 for Keewatinoow to Henday and Longspruce to Keewatinoow and Keewatinow construction power.
AT9. & AT10.	Mine Bauxite & Produce Aluminum	Tonnes of Aluminum for mainline conductors 20,020 Tonnes	Manitoba Hydro
		Tonnes of Aluminum for connecting lines to converter stations 1,156 Tonnes	
		Tonnes of Aluminum for additional equipment 546 Tonnes	
AT19.	Mine aggregate	69,916 tonnes aggregate	Manitoba Hydro
AT20.	Produce cement	11,547 tonnes	Manitoba Hydro
AT28.	Mine materials for ceramics	2,570 tonnes	Manitoba Hydro
AF44.	Manufacture equipment for converter stations	Mass of steel 26,419 tonnes	Manitoba Hydro
		Mass of Coper 3,912 tonnes	Manitoba Hydro
		Mass of cement 28,087 tonnes	Manitoba Hydro
AF46.	Manufacture equipment for electrode facilities	Mass of steel 72 tonne	Manitoba Hydro
		Copper 23 tonne	Manitoba Hydro
AF48.	Mine aggregate	170,064 tonnes	Manitoba Hydro
AF49.	Produce cement	28,087 tonnes	Manitoba Hydro
		Energy	
AT18.	Clear transmission line right-of-ways	2,500 m3 diesel	Manitoba Hydro
AT27.	House labourers	30,870,000 kWh	Based on Manitoba Hydro estimates of camp electricity requirements.

AT32.	Construct 500kV HVdc transmission line	1,500 m3 diesel	Manitoba Hydro
AT34.	Construct 230 kV line - Henday to converter station	120 m3 diesel	Manitoba Hydro
AT35.	Construct converter - electrode facility AC connector lines (north and south)	20.5 m3 diesel	Manitoba Hydro
AF36.	Clear sites	1 m3 diesel	Manitoba Hydro
AF42.	Excavate/grade sites	1 m3 diesel	Manitoba Hydro
AF58.	Construct northern converter station	150 m3 diesel	Manitoba Hydro
AF59.	Construct southern converter station	150 m3 diesel	Manitoba Hydro
AF60.	Construct northern ground electrode facility	10.25 m3 diesel	Manitoba Hydro
AF61.	Construct southern ground electrode facility	10.25 m3 diesel	Manitoba Hydro
Transportation Distances			
AT8.	Transport steel	Distance by ship 9,797km	Assumed based on likely steel equipment manufacture.
		Distance by rail 2,340km	
		Distance by road 682km	
AT11.	Transport Aluminum	Distance by ship 9,797km	Assumed based on likely aluminum equipment manufacture.
		Distance by rail 2,340km	
		Distance by road 682km	
AT21.	Transport cement/aggregate to sites	Distance cement transported by Rail 2,350 km	Assumed based on likely cement production in Edmonton.
		Distance cement transported by Road 682 km	
		Distance aggregate transported by Road 682 km	Based on aggregate source for the project.

AT30.	Transport to site	Distance ceramics transported by Rail 3,000 km	Ceramic source unknown, distance based on assumption that cermaics could be sourced within 3,000 km of the project site.
		Distance ceramics transported by Road 682 km	
AF45.	Transport equipment for converter stations	**Steel**	
		Overseas Distance of ship 9,797 km	Equipment source unknown. Estimates are for overseas and North American steel production.
		Overseas Distance by rail 2,340 km	
		Overseas Distance by road 682 km	
		North America Distance of ship 0 km	
		North America Distance by rail 2,000 km	
		North America Distance by road 682 km	
		Copper	Equipment source unknown. Estimates are for overseas and North American copper production.
		Overseas Distance by ship 11,060 km	
		Overseas Distance by rail 2,340 km	
		Overseas Distance by road 682 km	
		North America Distance by ship 0 km	
		North America Distance by rail 3,205 km	
		North America Distance by road 682 km	
		Cement	Based on likely cement and aggregate sources.
		Distance by ship 0 km	
		Distance by rail 2,350 km	
		Distance by road 682 km	
AF47.	Transport equipment for electrode facilities	Distance by rail 3,000 km	Distance uncertain. Estimate based on 3,000 km radius for supplier.
		Distance by road 682 km	
AF50.	Transport cement/aggregate to sites	Distance cement transported by Rail 2,350 km	Based on likely cement and aggregate sources.
		Distance cement transported by Road 682 km	
		Distance aggregate transported by Road 682 km	

Data Sets – Example information provided for each data set

Unit Process Name	Produce Portland Concrete
Data Set Name	Life Cycle Inventory of Portland Cement Concrete
Description	Includes Quarry, Raw Material Preparation, Pyroprocessing, Finish Grinding and Storage as well as raw material, solid fuel and gypsum and other cementitius material transportation.(i.e.portland cement manufacture, aggregate production, transport and concrete plant production)
Source of Data	Jan R. Prusinski, Medgar L. Marceau, Martha G. VanGeem (2003) *Life Cycle Inventory of Slag Cement Concrete,* Presented at the Eighth CANMET/ACI
Assumptions/Considerations	Based on Ready Mixed Concrete (20MPa) with 100% Portland Cement.
Limitations of Use	Portland cement is a hydraulic cement composed primarily of hydraulic calcium silicates. Hydraulic cements harden by reacting chemically with water. During this reaction, cement combines with water to form a stonelike mass, called paste. When the paste (cement and water) is added to aggregates (sand and gravel, crushed stone, or other granular materials) it binds the aggregates together to form concrete, the most widely used construction material. Although the words "cement" and "concrete" are used interchangeably in everyday usage, cement is one of the constituents of concrete. Cement is a very fine powder and concrete is a stonelike material. Cement constitutes 8 to 15 percent of concrete's total mass by weight. Using cement LCI data incorrectly as concrete LCI data is a serious error.
Uncertainty	

OUTPUTS	Amount	Units	+\- %	Allocation	Primary Output
Concrete	1	m^3	0	1	Yes
ENVIRONMENTAL OUTPUTS				Medium	
CO_2	228	kg		Air	
NO_x	0.713	kg		Air	
SO_2	0.545	kg		Air	

Appendix 4 – Detailed Results

Table 5 includes the results per activity for the life cycle analysis. The activities highlighted in red were either not calculated or are included in other activities. The intensity calculations are based on electricity transmission of 542,000 GWhr over the project life including 7,300 GWhr/yr for the first 3 years, followed by 8,550 GWhr/yr for the next 4 years and 11,300 GWhr/yr for the remaining years (50 year life).

Table 5: Detailed life cycle results

Summary Table of Life Cycle Emissions				
Activity #	Activity	t CO2e	t CO2e / GWH	% CO2 total
	Land use change	303,395.00	0.56	32.86%
AT1.	Clear access roads right-of-way	0	-	0.00%
AT2.	Construct access roads	0	-	0.00%
AT3.	Extract gravel materials	0	-	0.00%
AT4.	Transport gravel materials	0	-	0.00%
AT5.	Clear laydown areas	0	-	0.00%
AT6. & AT7.	Mine iron ore & Produce steel	89,383	0.16	9.68%
AT8.	Transport steel	8,387	0.02	0.91%
AT9. & AT10.	Mine Bauxite & Produce Aluminum	210,703	0.39	22.82%
AT11.	Transport Aluminum	964	0.00	0.10%
AT12.	Mine Copper	0	-	0.00%
AT13.	Process Copper	0	-	0.00%
AT14.	Transport Copper	0	-	0.00%
AT15.	Manufacture towers and conductors for transmission line	18,681	0.03	2.02%
AT16.	Transport towers and conductors to site	0	-	0.00%
AT17.	Harvest trees	0	-	0.00%
AT18.	Clear transmission line right-of-ways	6,777	0.01	0.73%
AT19.	Mine aggregate	155	0.00	0.02%

AT20.	Produce cement	6,402	0.01	0.69%
AT21.	Transport cement/aggregate to sites	4,954	0.01	0.54%
AT22.	Mix concrete	0	-	0.00%
AT23. to AT25.	Produce and transport crude oil to Transport diesel	5,367	0.01	0.58%
AT26.	Transport labourers to site	267	0.00	0.03%
AT27.	House labourers	30,223	0.06	3.27%
AT28.	Mine materials for ceramics	2,699	0.00	0.29%
AT29.	Produce ceramics	0	-	0.00%
AT30.	Transport to site	275	0.00	0.03%
AT31.	Rehabilitate laydown areas	0	-	0.00%
AT32.	Construct 500kV HVdc transmission line	4,066	0.01	0.44%
AT33.	Construct 230 kV line - Henday to converter station	325	0.00	0.04%
AT34.	Construct 230 kV line - Long Spruce to converter station	230	0.00	0.02%
AT35.	Construct converter - electrode facility AC connector lines (north and south)	56	0.00	0.01%
AF36.	Clear sites	3	0.00	0.0003%
AF37.	Clear laydown areas	0	-	0.00%
AF38.	Clear access roads right-of-way	0	-	0.00%
AF39.	Construct access roads	0	-	0.00%
AF40.	Extract gravel materials	0	-	0.00%
AF41.	Transport gravel materials	0	-	0.00%
AF42.	Excavate/grade sites	3	0.00	0.00%
AF43.	Source backfill materials	0	-	0.00%
AF44.	Manufacture equipment for converter stations	91,672	0.17	9.93%
AF45.	Transport equipment for converter stations	5,424	0.01	0.59%
AF46.	Manufacture equipment for electrode facilities	249	0.00	0.03%

AF47.	Transport equipment for electrode facilities	11	0.00	0.00%
AF48.	Mine aggregate	378	0.00	0.04%
AF49.	Produce cement	15,572	0.03	1.69%
AF50.	Transport cement/aggregate to sites	12,051	0.02	1.31%
AF51.	Mix concrete	0	-	0.00%
AF52. to AF54.	Produce and transport crude oil & Refine crude into diesel & Transport diesel	410	0.00	0.04%
AF55.	Transport labourers to site	0	-	0.00%
AF56.	House labourers	0	0.00	0.00%
AF57.	Rehabilitate laydown areas	0	-	0.00%
AF58.	Construct northern converter station	407	0.00	0.04%
AF59.	Construct southern converter station	407	0.00	0.04%
AF60.	Construct northern ground electrode facility	28	0.00	0.00%
AF61.	Construct southern ground electrode facility	28	0.00	0.00%
BT1.	Transport operators to and from site	0	-	0.00%
BT2. to BT5.	Onsite maintenance activities - Transmission lines	0	-	0.00%
BT6.	Generate electricity	0	-	0.00%
BT7.	Maintain transmission line right-of-way	5,923	0.01	0.64%
BT8.	Transmit electricity	0	-	0.00%
BT9.	Produce materials for replacement parts	41,954	0.08	4.54%
BT10.	Manufacture replacement equipment	0	-	0.00%
BT11.	Transport replacement equipment	1,458	0.00	0.16%
BT12.	Install replacement equipment	0	-	0.00%
BT13.	Transport removed material for recycling	422	0.00	0.05%
BT14.	Recycle metals	147	0.00	0.02%
BF15.	Transport operators to and from site	0	-	0.00%

BF16. to BF19.	Maintenance activities	28,568	0.05	3.09%
BF20.	Produce materials for replacement parts	0	-	0.00%
BF21.	Manufacture replacement equipment	0	-	0.00%
BF22.	Transport replacement equipment	0	-	0.00%
BF23.	Install replacement equipment	0	-	0.00%
BF24.	Transport removed material for recycling	0	-	0.00%
BF25.	Recycle the steel equipment	0	-	0.00%
CT1.	Remove transmission lines	2,033	0.00	0.22%
CT2.	Transport Materials for Recycling	3,035	0.01	0.33%
CT3.	Recycle metals	11,753	0.02	1.27%
CT4.	Remove access roads	0	-	0.00%
CT5.	Rehabilitate transmission lines and access roads	0	-	0.00%
CT6.	Produce crude	953	0.00	0.10%
CT7.	Transport crude	0	-	0.00%
CT8.	Refine crude into diesel	0	-	0.00%
CT9.	Transport diesel	0	-	0.00%
CT10.	Combust diesel on-site in equipment to decommission site	0	-	0.00%
CF11.	Remove supporting infrastructure	437	0.00	0.05%
CF12.	Transport steel for recycling	1,440	0.00	0.16%
CF13.	Recycle metals	4,993	0.01	0.54%
CF14.	Transport other materials for recycling or landfilling	0	-	0.00%
CF15.	Remove access roads	0	-	0.00%
CF16.	Rehabilitate facility sites and access roads	0	-	0.00%
CF17.	Produce crude	205	0.00	0.02%
CF18.	Transport crude	0	-	0.00%
CF19.	Refine crude into diesel	0		0.00%

			-	
CF20.	Transport diesel	0	-	0.00%
CF21.	Combust diesel on-site in equipment to decomission site	0	-	0.00%
Construction Emissions		**389,916**	0.72	42%
Support Infrastructure Construction		**126,641**	0.23	14%
Operating Emissions		**78,473**	0.14	8%
Decommissioning Emissions		**24,848**	0.05	3%
Land Use Change		**303,395**	0.56	33%
Total Emissions		**923,273**	1.70	

Appendix 5 – Sensitivity Analysis

Pembina performed 3 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 Project life cycle GHG emissions. The sensitivity results are compared directly with these results.

Table 6: Base case emissions

Base Emissions

Air Emission	Units	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	
Greenhouse Gas	tCO2eq	**441,672**	**32,333**	**42,553**	**303,395**	**78,473**	**24,848**	**923,273**

7.1.1 Aluminum Production Intensity

Aluminum production accounts for 23% 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 CO2eq/kg aluminum ingot from Americas P. Life Cycle Impact Assessment of Aluminum Beverage Cans.; 2010:127. To test the sensitivity of the life cycle results to this emission factor, we modified increased the intensity by 30% to 12.61 kg CO2eq/kg.

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

Aluminum accounts for 23% of emissions. The emission factor is for generic aluminum production and may be higher or lower. This sensitivity tests the impact on results from changing this value.

Increase

Air Emission	Units	Construction			Land Use Change*	Operation	Decommissioning	Total
	tCO2eq	Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line right-of-way	Offsite	Decommissioning Activities	
Greenhouse Gas	Total	**504,883**	**32,333**	**42,553**	**303,395**	**84,794**	**24,848**	**992,805**

Percent Difference

Air Emission	Units	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	
Greenhouse Gas		*14%*	*0%*	*0%*	*0%*	*8%*	*0%*	*8%*

7.1.2 Forest Carbon Contents

The transmission line right-of-way will permanently disturb over 3,000 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*".[16] The sensitivity is based on high end generic carbon content emissions from the IPCC.

Table 8: Summary of changes to carbon content

Type of Forest	Carbon content in base case (tonnes C/ha)[17]	Sensitivity carbon content (tonnes C/ha)[18]
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

The sensitivity is based on high end generic carbon content values from the IPCC.

Air Emission	Units	Construction	Land Use Change*	Operatio n	Decommission ing	Total

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

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

[18] High generic values from Intergovernmental Panel on Climate Change. "Good Practice Guidance for Land Use, Land-Use Change and Forestry." International Panel on Climate Change, 2003. Anx 3A.1, Table 3A.1.2

		Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line right-of-way	Offsite	Decommissioning Activities	
Greenhouse Gas	tCO2eq	**441,671.75**	**32,333.29**	**42,552.57**	**660,768.00**	**78,472.55**	**24,847.89**	**1,280,646.06**

Percent Difference

Air Emission	Units	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	
Greenhouse Gas		*0%*	*0%*	*0%*	*118%*	*0%*	*0%*	*39%*

7.1.3 Ground Line Electrode

The Project requires the construction of a ground line electrode. However, Manitoba Hydro does not have material estimates for the ground line electrode. The line will likely be 15km and Manitoba Hydro estimates it will require 10% of the materials required for the construction of 230 kV connector lines. This sensitivity tests the impact of this assumption. Table 10 summarizes the changes to the Project's life cycle results and the percent difference relative to the base case.

Table 10: Summary of changes to results and percent difference

The project requires a ground line electrode. However, material estimates do not yet exist. This sensitivity tests the potential contribution of this component to life cycle GHG emissions. Manitoba Hydro estimates the ground line electrode will require 10% of the materials for the 230 kV connector lines.

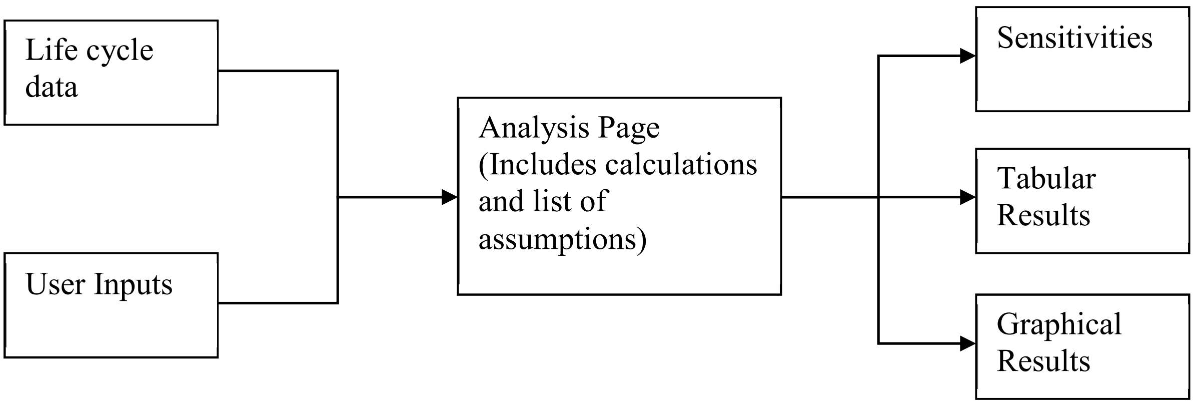
Air Emission	Units	Construction			Land Use Change*	Operation	Decommissioning	Total
		Building Material - Manufacture	Transportation	On-Site Construction Activities	Clearing for transmission line right-of-way	Offsite	Decommissioning Activities	
Greenhouse Gas	tCO2eq	*443,903.44*	*32,333.29*	*42,552.57*	*303,395.00*	*78,472.55*	*24,847.89*	*925,504.7*

Percent Difference

Air Emission	Units	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	
Greenhouse Gas		*0.51%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0.24%*

Appendix 6 – 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. In addition key factors, 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 the 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.

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

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

Equation 2: Sample Calculation for Steel Production

where the emissions factor for steel production was obtained 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.