QUANTIFICATION PROTOCOL FOR MECHANICAL PULP SLUDGE UTILIZATION PROJECTS RELATED TO FOREST APPLICATION

Table of Contents

List of Figures

List of Tables

1.0 Project and Methodology Scope and Description

The opportunities for generating carbon offsets with this protocol arise mainly from the direct and indirect reduction of atmospheric greenhouse gases (GHG) through the application of pulp sludge on juvenile forest stands.

1.1 Protocol Scope and Description

The carbon offsets from this protocol will be based on the quantification of increased carbon stocks and decreased GHGs resulting from the application of pulp sludge to juvenile forest stands as opposed to its incineration or placement in a landfill. Sludge application affects carbon reservoirs including tree biomass, herbaceous understory biomass, litter and duff and soil. The carbon reservoirs store and accumulate carbon rather than releasing greenhouse gases to the atmosphere. The sludge is traditionally a discarded by-product of the pulp mill and at baseline is incinerated or put in landfills which are practices that produce GHGs.

This protocol can be applied to all mechanical pulp mills spreading sludge in juvenile forest stands in Canada. This protocol can be used as a generic template for proponents to follow to meet the measurement, monitoring, and GHG quantification requirements. Due to the complexity and variability of forest management practices and locations, a measurement comparison based approach has been adopted for this protocol. Project developers will need to establish a baseline condition by maintaining control plots representing business as usual practices. An assurance factor has been included in the quantification equations to account for reversals. **FIGURE 1.1** and **FIGURE 1.2** describe typical project and baseline conditions as flow diagrams, respectively.

Some emissions are expected over the course of the project due to sludge transportation and application, however these emissions are negligible compared to the amount of GHGs reduced through the project.

Protocol Approach:

This protocol can be used as a general template for project proponents to follow. The amount of sludge applied by each mill will equal a set "reduction coefficient" equal to the amount of GHGs reduced through its use.

This protocol is focused on emissions avoidance from disposal practices, and increased above ground biomass and soil carbon storage resulting from sludge application in the forest. Business as usual practices for sludge handling includes drying, incineration, and beehive burner combustion. Baseline emissions related to disposal will be quantified based on energy use and resulting emissions from each business as usual practice. Emissions reductions related to application of sludge in juvenile forests will be based on increased merchantable volume of growing stock, and increased carbon in below ground carbon. Referenced equations and factors will be used to convert to emission reductions resulting from this project.

Deleted: Baseline emissions will be based on sludge disposal by incineration or landfilling, merchantable volume data collected in areas representative of the treatment areas. This protocol is focused on carbon biomass and soil carbon gained and on the decrease of GHGs emitted when sludge is no longer incinerated or placed in a landfill; other protocols will cover other aspects of carbon offsets for the mill, and could be used in conjunction with this protocol.¶

Deleted:

Figure 1.1. Process Flow Diagram for Project Condition.

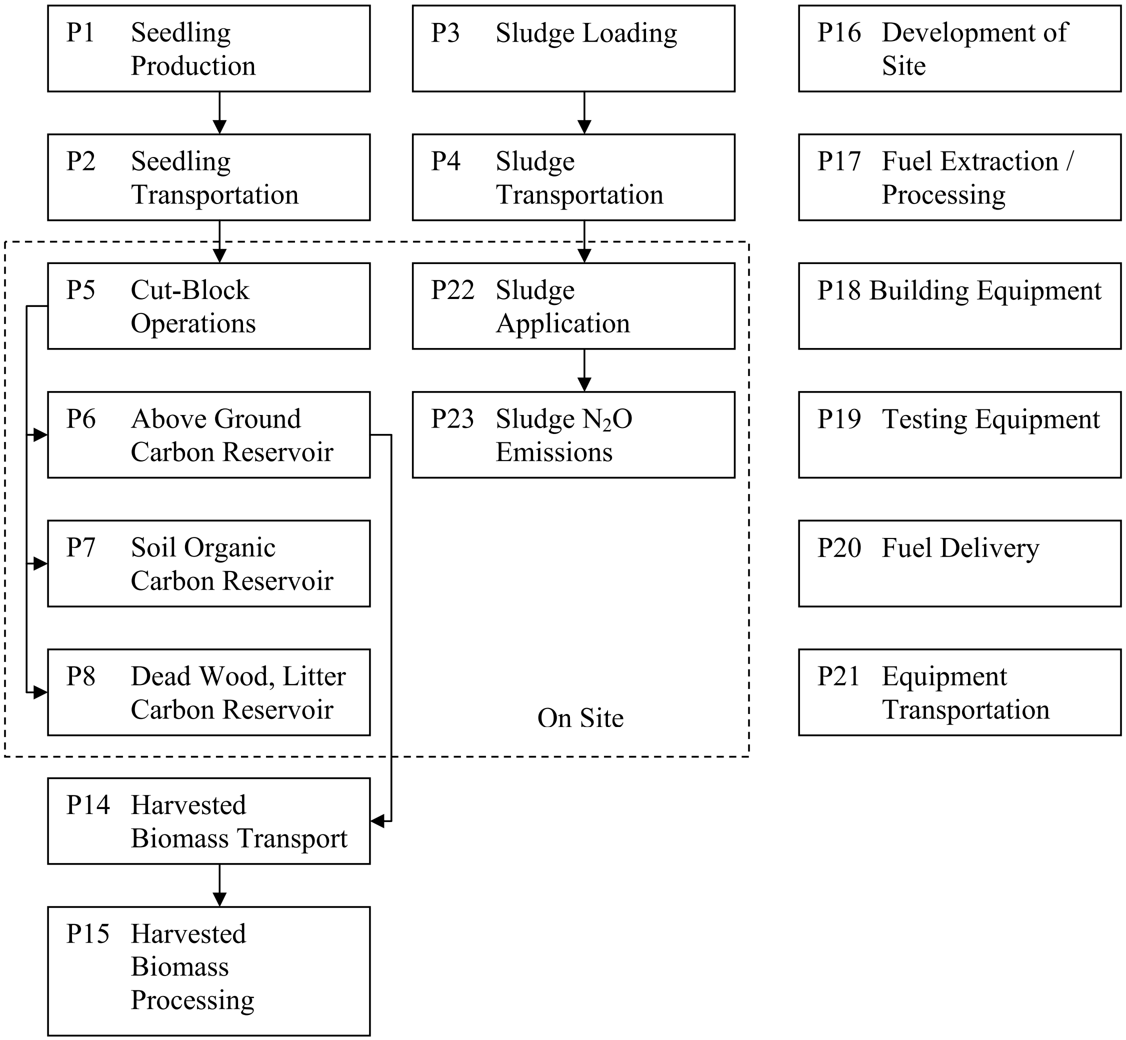
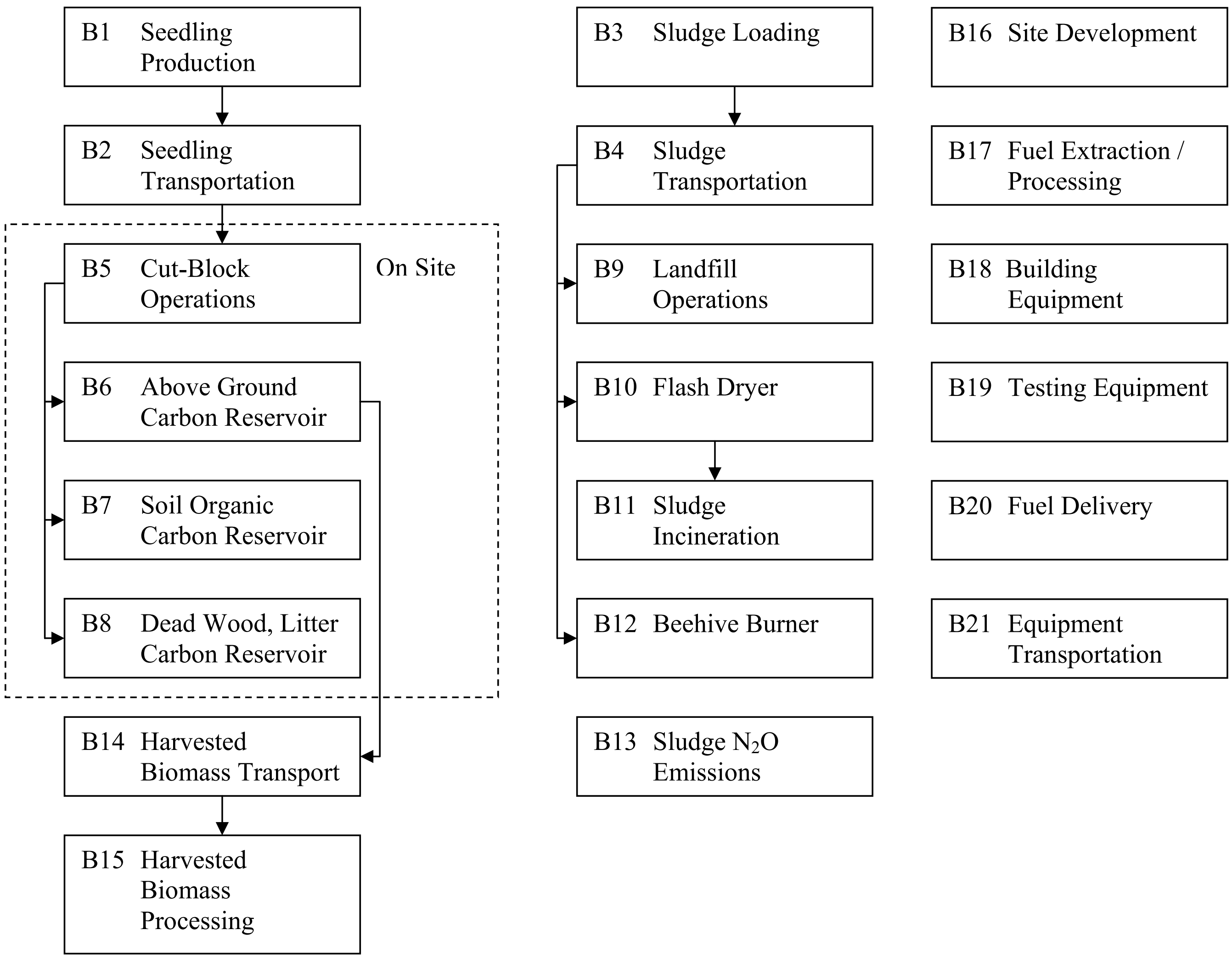


Figure 1.2. Process Flow Diagram for Baseline Condition.



Protocol Applicability:
This protocol is applicable to all mechanical pulp mills in Canada that are producing sludge and applying it in an environmentally acceptable manner to juvenile forest stands.

In order for a project to gain carbon offsets under this protocol, the project proponent must demonstrate that it meets the protocol requirements and produces sufficient evidence to indicate that:

1. The sludge was stored and spread in the approved method described in this protocol as confirmed by affirmation from the project developer and forestry company records.
   a. Mechanical pulp sludge should be stockpiled in a manner that prevents contamination of any surface watercourses and groundwater. The stockpile should not be located on land which has a slope greater than 9%. Not more than a quantity sufficient for one application of sludge should be stored at a designated application area at any time.
   b. Any method of spreading sludge that results in an even application to soil may be used. Following the contours of the land to minimize soil disturbance is also recommended.

2. The juvenile forest stands where the sludge is spread must have been properly planted or naturally regenerated within the past 5 to 10 years on an appropriate site as confirmed by affirmation from the project developer and forestry company records. Sludge should not be applied to:
   a. Organic soil
   b. Soil with a C:N ratio greater than 40:1
   c. An area where the slope exceeds 15%
   d. Soil in low lying areas that have saturated soil conditions for more than six consecutive weeks
   e. An area where the seasonally high watertable is within 1.5 meters of the soil surface

   The recommended distance from residences or watercourses on land with 0 to 3% slopes is 15 meters, 30 meters on land with 3 to 9% slopes and 50 meters on land with 9 to 15% slopes.

3. The quantification of reductions achieved by the project is based on actual measurement and monitoring (except where indicated in this protocol) as indicated by the proper application of this protocol.

4. The project must meet the requirements for offset eligibility as specified in the applicable regulation and guidance documents for the Alberta Offset System (Specified Gas Emitters Regulation – Offset Credit Project Guidance Document 2008).

Protocol Flexibility:
Flexibility in applying the quantification protocol is provided to project developers in two ways.

1. This protocol applies to the reduction of atmospheric GHGs through the use of mechanical pulp mill sludge. This protocol can be combined with other protocols where multiple projects are undertaken by the mechanical pulp mill to reduce overall GHG emissions.

2. Site specific emission factors may be substituted for the generic emission factors indicated in this protocol document. The methodology for generation of these emission factors must be sufficiently robust as to ensure reasonable accuracy.

This quantification protocol is written for the Pulp Mill Sludge Utilization project developer. Some familiarity with, or general understanding of, the operation of mechanical pulp mills and forestry practices is expected.

1.2 Glossary of New Terms:

Affected Greenhouse Gas source, sink or Reservoir	GHG source, sink or reservoir influenced by a project activity, through changes in market demand or supply for associated products or services, or through physical displacement. An affected GHG source, sink or reservoir is generally off the project site (ANSI/ISO/ASQ E14064-2:2006(E)).
Assurance Factor:	The assurance factor accounts for the risk and magnitude of carbon sequestration reversal due to fire, drought, pest and other disturbances. This factor accounts for the average number of reversal events anticipated over a 20 year period. The assurance factor accounts for the reversal event across all of the years that the project is eligible to receive credits for carbon sequestration. This prevents any liability accruing with credits for sludge utilization projects due to the risk of reversal.
Carbon Sequestration:	The process of increasing the carbon stored in a reservoir other than the atmosphere.
Carbon stock:	The quantity of carbon held within a reservoir at a specified time, expressed in units of mass.
Controlled greenhouse Gas source, sink or Reservoir	GHG source, sink or reservoir whose operation is under the direction and influence of the greenhouse gas project proponent through financial, policy, management or other instruments. A controlled GHG source, sink or reservoir is

generally on the project site (ANSI/ISO/ASQ E14064-2:2006(E)).

Functional Equivalence:	The Project and the Baseline should provide the same function and quality of products or services. This type of comparison requires a common metric or unit of measurement (i.e. sequestration of carbon on a given land area) for comparison between the Project and Baseline activity (refer to the Project Guidance Document for the Alberta Offset System for more information)
Related greenhouse gas Source, sink or reservoir	GHG source, sink or reservoir that has material or energy flows into, out of, or within the project. A related GHG source, sink or reservoir is generally upstream or downstream from the project, and can be either on or off the project site. It may also include activities related to design, construction and decommissioning of the site (ANSI/ISO/ASQ E14064-2:2006(E)).
Reservoir:	A physical unit or component of the biosphere, geosphere or hydrosphere with the capability to store or accumulate a greenhouse gas removed from the atmosphere by a greenhouse gas sink or a greenhouse gas captured from a greenhouse gas source. Examples of reservoirs include trees, soil, oil and gas reservoirs, and oceans.
Sludge	A traditionally discarded by-product created by the operations of mechanical pulp mills. Mechanical pulp sludge consists primarily of water, wood fiber, biomass, and residual process and wastewater treatment chemicals (mainly nutrients such as nitrogen and phosphorus). Sludge improves the nutrient status and physical properties of soil resulting in enhanced plant growth.

2.0 Quantification Development and Justification

The following sections outline the quantification development and justification.

2.1 Identification of Sources and Sinks (SS's) for the Project

Sources and sinks (SS's) were identified for the project by reviewing the seed protocol document and relevant process flow diagrams. This process confirmed that the SS's in the process flow diagrams covered the full scope of eligible project activities under the protocol.

Based on the process flow diagrams provided in **FIGURE 1.1**, the project SS's were organized into life cycle categories in **FIGURE 2.1**. Descriptions of each of the SS's and their classification as controlled, related or affected are provided in **TABLE 2.1**.

Figure 2.1. Project Element Life Cycle Chart – Sludge Utilization in the Forest.

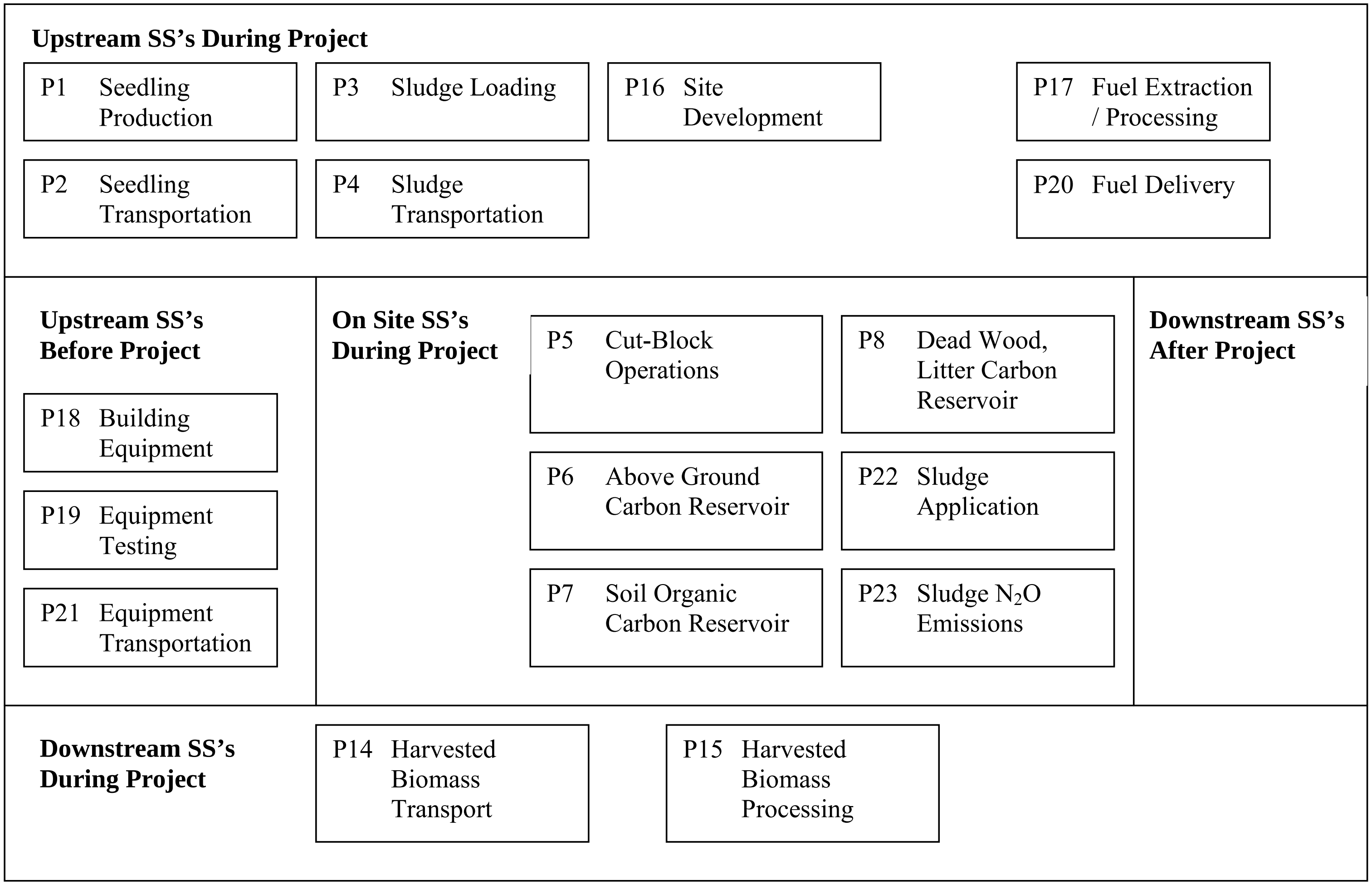


Table 2.1. Project SS's for Utilization of Sludge in the Forest.

SS	Description	Controlled, Related or Affected
Upstream SS's during Project Operation		
P1 Seedling Production	Greenhouse gas emissions may occur that are associated with the operation and maintenance of the production facility. This may include running any mechanical or electrical systems. Quantities and types for each of the energy inputs would be tracked.	Related
P2 Seedling Transportation	Seedlings may be transported to the site by truck. The related energy inputs for fuel will be used to calculate the resulting greenhouse gas emissions. Number of loads and distance travelled will be used evaluate the baseline equivalent emissions.	Related
P3 Sludge Loading	Sludge will be loaded from bunkers into trucks for delivery to the landfill site. The related energy inputs for fuelling this equipment are captured under this SS, for the purpose of calculating the resulting greenhouse gas emissions. Type of equipment and the number of loads would be used to evaluate functional equivalence with project condition.	Related
P4 Sludge Transportation	Sludge may be transported to a landfill. The related energy inputs for fuel will be used to calculate the resulting greenhouse gas emissions. Number of loads and distance travelled will be used to evaluate the baseline emissions.	Related
Onsite SS's during Project Operation		
P22 Sludge Application	Spreading equipment will be used to distribute the sludge in the cut-block. Type of equipment, number of loads and distance travelled would be used to evaluate emissions from this activity.	Controlled
P23 Sludge N_2O Emissions	Emissions associated with the breakdown of nitrogen in the sludge after land application.	Controlled
P5 Cut-Block Operations	Greenhouse gas emissions may occur that are associated with the operation and maintenance of the cut-block. This would include running vehicles at the site. Type of vehicle and fuel usage would be tracked.	Controlled
P6 Above Ground Carbon Reservoir	Carbon will accumulate in the above ground biomass, including trees, shrubs, and grasses. The extent of this accumulation would need to be tracked and compared to untreated areas to establish the baseline condition.	Controlled
P7 Soil Organic Carbon Reservoir	Carbon will be added to the soil through addition of carbon in the sludge matrix. Carbon will also accumulate in the below ground organic materials as a result of root biomass development and litter and grass decomposition. The soil carbon content prior to and after sludge addition will be tracked.	Controlled
P8 Dead Wood and Litter Carbon Reservoir	Carbon will accumulate within the dead wood and litter organic materials. The extent of this accumulation will be tracked.	Controlled

Table 2.1. (Concluded) Project SS's for Utilization of Sludge in the Forest.

SS	Description	Controlled, Related or Affected
Downstreatm SS's during Project Operation		
P16 Harvested Biomass Transport	Biomass harvested from this site would need to be transported to processing facilities or end-market users. Type of equipment, number of loads and distance travelled would be used to evaluate greenhouse gas emissions from this activity.	Related
P17 Harvested Biomass Processing	Biomass harvested from this site would need to be transported to processing facilities or end-market users. Quantities and types for each of the energy inputs would be tracked.	Related
Other		
P18 Site Development	The project site will need to be prepared. This would include building access roads, staging areas for sludge, grading and scarification. Greenhouse gas emissions would be primarily attributed to the use of equipment used to develop the site such scarifiers, graders etc. Quantities and types for each of the energy inputs would be tracked.	Related
P17 Fuel Extraction / Processing	Each of the fossil fuels used throughout baseline operations will need to be sourced and processed. This will allow for the calculation of the greenhouse gas emissions from various processes involved in the production, refinement and storage of the fuels. The total volumes of fuel for each of the on site SS's are considered under this SS. Volumes and types of fuels are the important characteristics to be tracked.	Related
P20 Fuel Delivery	Each of the fuels used throughout the baseline operations will need to be transported to the site. This may include shipments by tanker or by pipeline, resulting in the emissions of greenhouse gases. It is reasonable to exclude fuel sourced by taking equipment to an existing commercial fuelling stations as the fuel used to take the equipment to the site is captured under other SS's and there is no other delivery.	Related
P18 Building Equipment	Equipment may need to be built either on site or off site. This includes all the components of the storage, handling, processing, combustion, air quality control, system control and safety systems. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment for the extraction of the raw materials, processing, fabricating and assembly.	Related
P19 Equipment testing	Equipment may need to be tested to ensure that it is operational. This may result in running the equipment using fossil fuels in order to ensure that the equipment runs properly. These activities will result in greenhouse gas emissions associated with the combustion of fossil fuels and the use of electricity.	Related
P21 Equipment Transportation	Equipment built off site and the materials to build equipment on site, will all need to be delivered to the site. Transportation may be completed by train, truck, by some combination or even by courier. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels to power the equipment delivering the equipment to the site.	Related

2.2 Identification of Baseline

The baseline condition is defined by the disposal of pulp mill sludge by incineration and/or landfilling, the below ground biomass in the soil, and the growth of planted forest stands without pulp sludge application.

The emissions produced at baseline will differ for each project due to variations in annual sludge production, sludge disposal practices, forest management, climatic conditions, and soil chemical and physical properties. Emissions avoidance associated with baseline practices for disposal will track energy use and emissions related to incineration and landfilling. Baseline emissions related to land application will be quantified by carbon storage in above and below ground biomass in untreated areas . Merchantable volume based forest inventory and operational records will be converted to above ground biomass using biomass conversion and expansion factors. Below ground biomass at baseline will be determined from soil maps and databases. **TABLE 2.2** identifies all possible baseline approaches and provides justification for the selected comparison based baseline scenario. The baseline condition is defined, including the relevant SS's and processes, as shown in **FIGURE 1.2**. More detail on each of these SS's is provided in Section 2.3.

Deleted: Data collected through Alberta regeneration surveys will be used to establish the baseline condition

Table 2.2. Identification of Possible Baseline Quantification Approaches.

Baseline Options	Description	Static / Dynamic Baseline	Accept or Reject and Justify
Historic Benchmark	Typically site-specific and can be constructed to reflect reductions in a base period (such as the average emissions of the previous three years).	Dynamic	Reject: The amount of sludge being land applied is variable each year and this method would not give an accurate estimate of the amount of carbon being sequestered above or below ground due to variability.
Performance Standard	Assumes the typical emissions profile for the industry or sector is a reasonable representation of the baseline.	Dynamic	Reject: Each mechanical mill operator has different processes and operating procedures thus an industry baseline is not reasonable.
Comparison Based	Actual measurements of parameters from a control group to compare with the project.	Dynamic	Accept: Actual measurements produce the most accurate and reliable results and can not be discounted by variability.
Projection Based	Projections of reductions in the future can use a variety of techniques, from simple straight line growth assumptions to complex models.	Dynamic	Reject: There are too many variables that would need to be input into a model such as soil type, landscape variability, climate factors, tree and shrub species, and management practices, etc.
Adjusted Baseline	Takes into account current practice levels of a particular project and specified that the	Dynamic	Reject: There are no well documented current practice levels and too

	same baseline is used for all projects of a certain type, regardless of historical practices.		much variability associated with the baseline for an adjusted baseline.

2.3 Identification of SS's for the Baseline

Based on the process flow diagrams provided in **FIGURE 1.2**, the project SS's were organized into life cycle categories in **FIGURE 2.2**. Descriptions of each of the SS's and their classification as either controlled, related or affected is provided in **TABLE 2.3**

Figure 2.2. Baseline Element Life Cycle Chart – Sludge Utilization in the Forest.

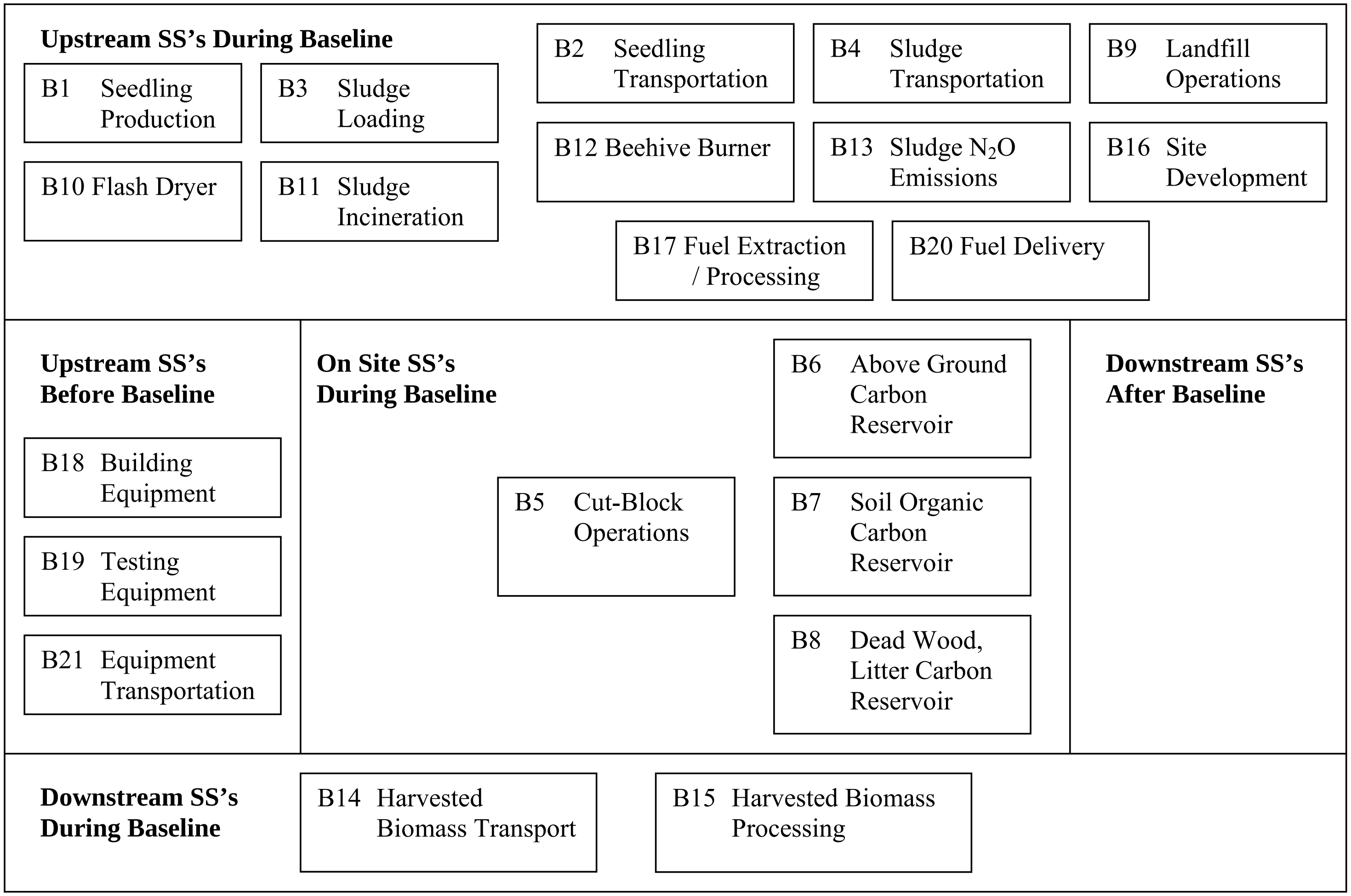


Table 2.3. Baseline SS's – Sludge Utilization in the Forest.

SS	Description	Controlled, Related or Affected
Upstream SS's during Baseline Operation		
B1 Seedling Production	Greenhouse gas emissions may occur that are associated with the operation and maintenance of the production facility. This may include running any mechanical or electrical systems. Quantities and types for each of the energy inputs would be tracked.	Related
B2 Seedling Transportation	Seedlings may be transported to the site by truck. The related energy inputs for fuel will be used to calculate the resulting greenhouse gas emissions. Number of loads and distance travelled will be used evaluate the baseline equivalent emissions.	Related
B3 Sludge Loading	Sludge will be loaded from bunkers into trucks for delivery to the landfill site. The related energy inputs for fuelling this equipment are captured under this SS, for the purpose of calculating the resulting greenhouse gas emissions. Type of equipment and the number of loads would be used to evaluate functional equivalence with project condition.	Related
B4 Sludge Transportation	Sludge may be transported to a landfill. The related energy inputs for fuel will be used to calculate the resulting greenhouse gas emissions. Number of loads and distance travelled will be used to evaluate the baseline emissions.	Related
B9 Landfill Operations	Sludge may be disposed of in a landfill. Quantities and types for each of the energy inputs would be tracked to calculate baseline emissions.	Related
B10 Flash Dryer	Sludge is sometimes dried prior to incineration in a flash dryer which requires natural gas for operation. The type and amount of fuel used and the number of hours of operation will be tracked to evaluate the baseline condition.	Related
B11 Sludge Incineration	Sludge may be disposed through incineration. The calculate the baseline emissions, the amount of CO_2 emitted after complete combustion of sludge in the incinerator would be calculated as well as the quantities and types of each of the energy inputs required for the operation and maintenance of the incinerator.	Related
B12 Beehive Burner	Sludge may be disposed through incineration in a beehive burner. Greenhouse gas emissions occur that are associated with the operation and maintenance of the beehive burner. Quantities of emissions would be estimated to evaluate total greenhouse gas emissions.	Related
B13 Sludge N_2O Emissions	N_2O emissions from baseline scenarios of landfilling, incineration or burning sludge.	Related
Onsite SS's during Baseline Operation		
B5 Cut-Block Operations	Greenhouse gas emissions may occur that are associated with the operation and maintenance of the cut-block. This would include running vehicles at the site. Type of vehicle and fuel usage would be tracked.	Controlled
B6 Above Ground Carbon Reservoir	Carbon will accumulate in the above ground biomass, including trees, shrubs, and grasses. The extent of this accumulation would need to be tracked and compared to treated areas to establish the baseline condition.	Controlled

B7 Soil Organic Carbon Reservoir	Carbon will be added to the soil through addition of carbon in the sludge matrix. Carbon will also accumulate in the below ground organic materials as a result of root biomass development and litter and grass decomposition. The soil carbon content prior to and after sludge addition will be tracked.	Controlled
B8 Dead Wood and Litter Carbon Reservoir	Carbon will accumulate within the dead wood and litter organic materials. The extent of this accumulation will be tracked.	Controlled
Downstream SS's during Baseline Operation		
B14 Harvested Biomass Transport	Biomass harvested from this site would need to be transported to processing facilities or end-market users. Type of equipment, number of loads and distance travelled would be used to evaluate greenhouse gas emissions from this activity.	Related
B15 Harvested Biomass Processing	Biomass harvested from this site would need to be transported to processing facilities or end-market users. Quantities and types for each of the energy inputs would be tracked.	Related
Other		
B16 Site Development	The site will need to be prepared. This would include building access roads, grading and scarification and tree planting. Greenhouse gas emissions would be primarily attributed to the use of equipment used to develop the site such scarifiers, graders, etc. Quantities and types for each of the energy inputs would be tracked.	Related
B17 Fuel Extraction / Processing	Each of the fossil fuels used throughout baseline operations will need to be sourced and processed. This will allow for the calculation of the greenhouse gas emissions from various processes involved in the production, refinement and storage of the fuels. The total volumes of fuel for each of the on site SS's are considered under this SS. Volumes and types of fuels are the important characteristics to be tracked.	Related
B20 Fuel Delivery	Each of the fuels used throughout the baseline operations will need to be transported to the site. This may include shipments by tanker or by pipeline, resulting in the emissions of greenhouse gases. It is reasonable to exclude fuel sourced by taking equipment to an existing commercial fuelling stations as the fuel used to take the equipment to the site is captured under other SS's and there is no other delivery.	Related
B18 Building Equipment	Equipment may need to be built either on site or off site. This includes all the components of the storage, handling, processing, combustion, air quality control, system control and safety systems. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels and electricity used to power equipment for the extraction of the raw materials, processing, fabricating and assembly.	Related
B19 Equipment testing	Equipment may need to be tested to ensure that it is operational. This may result in running the equipment using fossil fuels in order to ensure that the equipment runs properly. These activities will result in greenhouse gas emissions associated with the combustion of fossil fuels and the use of electricity.	Related
B21 Equipment Transportation	Equipment built off site and the materials to build equipment on site, will all need to be delivered to the site. Transportation may be completed by train, truck, by some combination or even by courier. Greenhouse gas emissions would be primarily attributed to the use of fossil fuels to power the equipment delivering the equipment to the site.	Related

2.4 Selection of Relevant Project and Baseline SS's

Each of the SS's from the project and baseline condition were compared and evaluated as to their relevancy using the guidance provided in the American National Standard – Greenhouse Gases Part 2 – Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements (ANSI/ISO/ASQ E14064-2, 2006). The justification for the exclusion or conditions upon which SS's may be excluded is provided. All other SS's listed previously are included. This information is summarized in **TABLE 2.4**.

Table 2.4. Comparisons of SS's for Utilization of Sludge in the Forest.

SS	Baseline (C,R,A)	Project (C,R,A)	Include or Exclude from Quantification	Justification for Exclusion
Upstream SS's				
B1 Seedling Production	Related	N/A	Exclude	Excluded as these SS's are not relevant to the project and the baseline and project conditions are functionally equivalent.
P1 Seedling Production	N/A	Related	Exclude	
B2 Seedling Transportation	Related	N/A	Exclude	The baseline and project conditions are functionally equivalent.
P2 Seedling Transportation	N/A	Related	Exclude	
B3 Sludge Loading	Related	N/A	Exclude	Excluded as the emissions from loading sludge are functionally equivalent in the project and baseline condition (i.e., sludge is loaded for landfilling or incineration and for land application).
P3 Sludge Loading	N/A	Related	Exclude	
B4 Sludge Transportation	Related	N/A	Include	N/A
P4 Sludge Transportation	N/A	Related	Include	N/A
B7 Landfill Operations	Related	N/A	Include	N/A
B10 Flash Dryer	Related	N/A	Include	N/A
B11 Sludge Incineration	Related	N/A	Include	N/A
B12 Beehive Burner	Related	N/A	Include	N/A
B13 Sludge N_2O Emissions	Related	N/A	Include	N/A

Onsite SS's				
B5 Cut-Block Operations	Controlled	N/A	Exclude	The baseline and project conditions are functionally equivalent.
P5 Cut-Block Operations	N/A	Controlled	Exclude	
B6 Above Ground Carbon Reservoir	Controlled	N/A	Include	N/A
P6 Above Ground Carbon Reservoir	N/A	Controlled	Include	
B7 Soil Organic Carbon Reservoir	Controlled	N/A	Include	N/A
P7 Soil Organic Carbon Reservoir	N/A	Controlled	Include	
B8 Dead Wood and Litter Carbon Reservoir	Controlled	N/A	Exclude	The baseline and project conditions would likely be functionally equivalent over the relatively short credit allocation period (8 years).
P8 Dead Wood and Litter Carbon Reservoir	N/A	Controlled	Exclude	
P22 Sludge Application	N/A	Controlled	Include	N/A
P23 Sludge N_2O Emissions	N/A	Controlled	Exclude	Excluded as N_2O Emissions from sludge application are likely negligible and no research has been conducted to verify quantifications.
Downstream SS's				
B14 Harvested Biomass Transport	Related	N/A	Exclude	Excluded as these SS's are not relevant to the project and the baseline and project conditions are functionally equivalent.
P14 Harvested Biomass Transport	N/A	Related	Exclude	

B15 Harvested Biomass Processing	Related	N/A	Exclude	Excluded as these SS's are not relevant to the project and the baseline and project conditions are functionally equivalent.
P15 Harvested Biomass Processing	N/A	Related	Exclude	
B16 Site Development	Related	N/A	Exclude	Excluded as these SS's are not relevant to the project and the baseline and project conditions are functionally equivalent
P16 Site Development	N/A	Related	Exclude	
Other				
B17 Fuel Extraction / Processing	Related	N/A	Exclude	Excluded as these SS's are not relevant to the project as the emissions from these practices are covered under proposed greenhouse gas regulations.. Further, emissions from fuel extraction and processing are likely functionally equivalent in the project condition as the baseline scenario.
P17 Fuel Extraction / Processing	N/A	Related	Exclude	
B20 Fuel Delivery	Related	N/A	Exclude	Excluded as these SS's are not relevant to the project as the emissions from these practices are covered under proposed greenhouse gas regulations.
P20 Fuel Delivery	N/A	Related	Exclude	
B18 Building Equipment	Related	N/A	Exclude	Emissions from building equipment are not material given the long project life, and the minimal building equipment typically required.
P18 Building Equipment	N/A	Related	Exclude	
B19 Equipment Testing	Related	N/A	Exclude	Emissions from testing of equipment are not material given the minimal testing of equipment typically required.
P19 Equipment Testing	N/A	Related	Exclude	
B21 Equipment Transportation	Related	N/A	Exclude	Emissions from transportation of equipment are not material given the minimal transportation of equipment that would be required.
P21 Equipment Transportation	N/A	Related	Exclude	

2.5 Quantification of Reductions, Removals and Reversals of Relevant SS's

2.5.1 Quantification Approaches

Quantification of the reductions, removals and reversals of relevant SS's for each of the greenhouse gases will be completed using the methodologies outlined in **TABLE 2.5**. A listing of relevant emission factors is provided in **Appendix A**. These calculation methodologies serve to complete the following equations for calculating the emission reductions from the comparison of the baseline and project conditions.

$$\text{Emission Reduction} = \text{Emissions}_{\text{Baseline}} - \text{Emissions}_{\text{Project}}$$

$$\text{Emissions}_{\text{Baseline}} = \text{Emissions}_{\text{Landfill Operations}} + \text{Emissions}_{\text{Sludge N20}} + \text{Emissions}_{\text{Flash Dryer}} + \text{Emissions}_{\text{Incineration}} + \text{Emissions}_{\text{Beehive Burner}} + \text{Emissions}_{\text{sludge transportation}} + [(-\text{Emissions}_{\text{carbon sequestration}}) \times \text{Assurance Factor}]$$

$$\text{Emissions}_{\text{Project}} = [(-\text{Emissions}_{\text{carbon sequestration}}) \times \text{Assurance Factor}] + \text{Emissions}_{\text{sludge transportation}}$$

Where:

Emission $_{\text{Baseline}}$ = sum of emissions under the baseline condition

Emissions $_{\text{Landfill Operations}}$ = Emissions under B9 Landfill Operations
Emissions $_{\text{Sludge N20}}$ = Emissions under B13 Sludge N_20 Emissions
Emissions $_{\text{Flash Dryer}}$ = Emissions under B10 Flash Dryer
Emissions $_{\text{Incineration}}$ = Emissions under B11 Incineration
Emissions $_{\text{Beehive Burner}}$ = Emissions under B12 Beehive Burner
Emissions $_{\text{Sludge Transportation}}$ = Emissions under SS B4 Sludge Transportation
Emissions $_{\text{carbon sequestration}}$ = Sequestration under SS B7 (Soil Organic Carbon Reservoir) + SS B6 (Above Ground Carbon Reservoir)

Assurance Factor = Factor to account for reversals (Appendix C)

Emissions $_{\text{Project}}$ = sum of emissions under the project condition

Emissions $_{\text{carbon sequestration}}$ = Sequestration under SS P7 (Soil Organic Carbon Reservoir) + SS P6 (Above Ground Carbon Reservoir)
Emissions $_{\text{Sludge Transportation}}$ = Emissions under SS P4 Sludge Transportation

Assurance Factors = Factor to account for reversals (Appendix C)

Table 2.5. Quantification Procedures – Sludge Utilization in the Forest.

Baseline SS's							
Project/ Baseline	**Parameter/ Variable**	**Unit**	**Measured or Estimated**	**Method**	**Sample Size**	**Frequency**	**Justify Measurement or Estimation or Frequency**
$Gi = Mi * k * Lo * exp^{(-k*ti)}$ Where: $Lo = MCF * DOC * DOC_F * F(16/12) * (1000\ kg\ CH_4/Mg\ CH_4)$							
B9 Landfill Operations	Gi = generation rate	kg CH_4/yr	estimated	Calculated using Scholl Canyon model as per IPCC/Environment Canada guidelines	N/A	Annual	Quantity being calculated
	Mi = mass of wet sludge	Mg	measured	Direct measurement of amount of sludge going to landfill	N/A	Continuous	May be measured when loaded or delivered to site
	k = CH_4 generation rate	CH_4/yr	estimated	NCASI, 2003 default = 0.03/yr	N/A	N/A	Default value for k based on NCASI (2003) report
	Ti = age of landfill	Years	measured	Age of sludge diverted from landfill	N/A	Continuous	CH_4 generated over credit period
	Lo = generation	kg CH_4/t sludge	estimated	IPCC/Environment Canada	N/A	Continuous	Represents amount of CH_4
	MCF = CH_4 correction	0.8	estimated	IPCC/Environment Canada	N/A		Correction factor accounts for difference between managed/unmanaged sites
	DOC=degradable organic fraction	wood waste=0.3	estimated	Environment Canada Greenhouse Gas Inventory, 2004	N/A	Continuous	Represents the amount of degradable organic carbon
	DOC_F	0.5	estimated	Environment Canada Greenhouse Gas Inventory, 2004	N/A	Continuous	Fraction of DOC dissimilated
	F=fraction of CH_4 in landfill gas	F=0.4 to 0.6	estimated	Environment Canada Greenhouse Gas Inventory, 2004	N/A	Continuous	Value of 5 was chosen for the fraction of CH_4 in landfill gas
Sludge combustion $CO_{2\ equiv}$ = BDT sludge * % carbon * MW CO_2/MW Carbon Flash Dryer Natural Gas Usage t $CO_{2\ equiv}$ = Mg wet sludge * 5.62 Gj/Mg wet * m^3/0.03723 Gj *1.902 kg CO_{2equiv} * Mg $CO_{2\ equiv}$ /1000 kg $CO_{2\ equiv}$							
B11 Incineration	BDT sludge	Mg dry sludge	Measured	Direct measurement of sludge produced	N/A	Continuous	Mill records of produced sludge
	% carbon	Mg C/Mg dry sludge	Measured	Analysis by total combustion and infrared detection	N/A	Continuous or with process	Determine carbon content of sludge incinerated
	CO2 equivalent	Conversion factor = 44/12	Measured	Stoichiometric factor to convert Mg carbon to CO2	N/A	Continuous	Factor to convert carbon to CO2 produced through complete combustion

Table 2.5. (Continuted) Quantification Procedures – Sludge Utilization in the Forest.

Project and Baseline SS's							
Project/ Baseline	**Parameter/ Variable**	**Unit**	**Measured or Estimated**	**Method**	**Sample Size**	**Frequency**	**Justify Measurement or Estimation or Frequency**
B10 Flash Dryer	Wet sludge	Mg wet	Measured	Direct measurement of amount of sludge to dryer	N/A	Continuous	May be determined from ratio of pulp to produced sludge
	Natural gas usage	Gj/Mg Wet	Measured	Metered gas usage to flash dryer	N/A	Annual	Natural gas usage for flash dryer
	Conversion of Gj to m^3 equivalent	m^3	Estimated	Natural resources Canada, issues table (1998-1999)	N/A	Continuous	Factor to convert Gj natural gas to m3
	GHG emission factor	1.902 kg e $/m^3$	Estimated	Environment Canada Greenhouse Gas Inventory, 2004	N/A	Continuous	Factor to convert m3 natural gas used in flash dryer to CO2 equivalent
CO_2 emissions t $CO_{2\ equiv}$ = t sludge * (% solid/100) * (21.1 GJ HHV/ t dry sludge) * (TJ HHV/1000 GJ) * (104 *10^3 kg CO_2/TJ HHV) * (t CO_2 /1000 kg) Methane emissions CH_4 = TJ HHV * (30 kg CH_4/TJ HHV) Nitrous oxide emissions $N_2 0$ = TJ HHV * (4 kg $N_2 0$ / TJ HHV)							
B12 Beehive Burner	BDT sludge	Mg dry sludge	Measured	Direct measurement of sludge produced		Continuous	Mill records of produced sludge
	Heat content	21.1 Gj (HHV/Mg) dry solids	estimated	Tier 1 emission factors, NCASI, 2005	N/A	continuous	based on heat content of 21.1 Gj (HHV/Mg)
	CO_2 emissions	104 *10^3 kg $C0_2$/TJ HHV	estimated	Tier 1 emission factors, NCASI, 2005	N/A	continuous	CO2 emission factor from biomass combustion
	CH_4 emissions	30 kg CH_4/TJ HHV	estimated	Tier 1 emission factors, NCASI, 2005	N/A	continuous	CH4 emission factor from biomass combustion
	N_2O emissions	4 kg N_2O/TJ HHV	estimated	Tier 1 emission factors, NCASI, 2005	N/A	continuous	N2O emission factor from biomass combustion
P4/B4 Sludge Transportation	combustion emission factor for fuel	T CO2e /L	estimated	Use data from Canada's GHG Inventory for Heavy Duty Diesel Vehicle	N/A	annually	Use truck haul records of haul distance, running hours, or actual fuel records

Table 2.5. (Continued) Quantification Procedures – Sludge Utilization in the Forest.

Project/ Baseline	Parameter/ Variable	Unit	Measured/ Estimated	Method	Sample Size	Frequency	Justify Measurement or Estimation or Frequency
t biomass/ha = m^3/ha * BCEF† t Carbon/ha = t biomass/ha * CF t CO_2/ha = t Carbon/ha * Conversion facto C_CO_2 (Source: Huang, S. 1994. Ecologically Based Individual Tree Volumes Estimation for Major Alberta Tree Species. Alberta Environmental Protection.)							
B6/P6 Above Ground Carbon Reservoir	Merchantable Volume	m^3/ha	Measured	Somogyi et al. 2006 *in 2006 IPCC guidelines*	As required by method	As required by method	Volume data from forest inventories, e.g. merchantable volume of growing stock
	BCEF	t/ m^3	Estimated	2006 IPCC Guidelines (Appendix B)	N/A	N/A	Transform volume data to above ground biomass to account for non-merchantable components
	CF = Mg C/Mg dm	TC/Tdm	Estimated	Andreae and Merlet 2001, *in 2006 IPCC guidelines*	N/A	N/A	Carbon fraction of above ground biomass
t Carbon/ha = bulk density * depth * (% Carbon/100) * Area							
B7 Soil Organic Carbon Reservoir	Soil Bulk Density	g/cm^3	Estimated	Estimation from published soil survey data (Appendix B)	N/A	Check for updates or site specific measurements	Soil bulk density information related to established soil series
	Soil carbon content	% carbon	Estimated	Estimation from published soil survey data (Appendix B)	N/A	Check for updates or site specific measurements	Carbon content information related to soil survey data
	Mix Depth	cm	Estimated	calculate using concentration * mass relations	N/A	continuous	Calculate based on 30 cm depth for comparison to project condition (30 cm depth)
X * $Sludge_{carbon}$ + Y * $Soil_{carbon}$ = final mix_{carbon} ‡							
P7 Soil Organic Carbon Reservoir	Sludge Application Rate	Mg/ha	Measured	Operational records	N/A	Continuous	Rate of application determines carbon loading
	Sludge wet bulk density	Wet Mg/m^3	Measured	Operational records	N/A	Continuous or to reflect process change	Wet bulk density and moisture content of applied sludge to determine application rate
	Sludge moisture content	% solids	Measured	Operational records	N/A		
	Sludge carbon content	% Carbon	Measured	Operational records	N/A		Carbon content of dry sludge to calculate applied carbon equivalent

P7 Soil Organic Carbon Reservoir (Continued)	Sludge depth	cm	Estimated	Based on application rate		Continuous	Depth of applied sludge to determine sludge:soil ratio in mix
	Soil Bulk Density	g/cm^3	Estimated	Estimation from published soil survey data (Appendix B)	N/A	Check for updates or site specific measurements	Soil bulk density information related to established soil series
	Soil carbon content	% carbon	Estimated	Estimation from published soil survey data (Appendix B)	N/A	Check for updates or site specific measurements	Carbon content information related to soil survey data
	Mix Depth	cm	Estimated	calculate using concentration * mass relations	N/A	continuous	Calculate based on 30 cm depth for comparison to baseline condition (30 cm depth)

† BCEF – combines conversion and expansion from merchantable volume of growing stock (Biomass and Conversion Factors – IPCC Guidelines, 2006) (Appendix B).

‡ Using simple mass relations an approximation of carbon in the final soil mix can be obtained as follows:

Let X = proportion of sludge in the final mix: X = (Sludge (Mg/ha)) / (Sludge (Mg/ha) + Soil (Mg/ha))

Let Y = proportion of soil in the final mix: Y = (Soil (Mg/ha) / (Sludge (Mg/ha) + Soil (Mg/ha))

Where: Sludge (Mg/ha) = application rate ($Mg_{dry\ sludge}$/ha)

Soil (Mg/ha) = soil depth (cm) * bulk density (g/cm^3) * Area (10 000 m^2/ha)

Soil depth = incorporation depth (cm) – sludge depth (cm)

Therefore: Carbon content of final mix = $X * Sludge_{carbon} + Y * Soil_{carbon} = final\ mix_{carbon}$

Then: Mg C/ha = (Mg Carbon/Mg mix) * Mg mix/ha

2.5.2 Contingent Data

An alternative quantification method for evaluating baseline emissions can be based on control plots representative of the treated areas and pre-application measurements. The established baseline will be considered as static for each project, where the coefficients remain constant, subject to periodic revision to reflect the evolving performance standard. The quantification approach would be the same as in the previous section.

Table 2.6. Contingent Quantification Procedures – Sludge Utilization in the Forest.

Project/ Baseline	Parameter/ Variable	Unit	Measured/ Estimated	Method	Sample Size	Frequency	Justify Measurement or Estimation or Frequency
Above Ground Carbon = ∑ Carbon $_{trees}$ + ∑ Carbon $_{shrubs}$ + ∑ Carbon $_{ground\ cover}$, where Carbon $_{species\ n}$ = Volume $_{species\ n}$ x Expansion Factor leaves, needles, branches $_{species\ n}$ x root-shoot factor $_{species\ n}$ x density factor $_{species\ n}$ x % carbon x carbon conversion factor $_{species\ n}$							
B6/P6 Above Ground Carbon Reservoir (Emission reductions resulting from biomass production Mg CO_2e/ha/yr)	Volume of above ground biomass accumulation in trees	m^3/ha	Tree height + diameter converted to volume and expansion factor for leaves, branches and bark	Tree counts, height, DBH from plots and operational spreading areas using Huang model for individual tree volume estimations	Statistically relevant number of samples	Annually or chosen credit interval	To calculate stem volumes of stand
	Expansion factors (leaves, needles, branches)	kg C/m^2	Estimated	From sources of species specific data tables and measurements in research plots (App. B)	Relates to volume calculation	Annually or chosen credit interval	Estimation of carbon content of leaves, needles and branches
	Root-shoot factor	kg C/m^2	Estimated	From sources of species specific data tables (Appendix B)	Relates to volume calculation	Annually or chosen credit interval	Ratio of shoot to roots using factors
	Density factor	kg/m^3	Estimated	From sources of species specific data tables (Appendix B)	Relates to volume calculation	Annually or chosen credit interval	For converting tree volumes to weight equivalent
	Organic carbon content of biomass	%	Measured carbon content of above ground carbon pools	LECO total combustion of Carbon to CO_2 and analysis by Infrared Detector	As required by standard lab procedure	Analysis of each sample collected	For calculation of carbon content of trees, shrubs and ground cover
	Volume of above ground biomass accumulation in shrubs and herbaceous understory	m^3/ha	Calculated using coefficients for shrub dimensions and leaf area	Shrub counts, length, width, height, leaf area and leaf density of individuals	Statistically relevant number of samples	Annually or chosen credit interval	For determination of shrub and herbaceous understory carbon poor reservoir
	Ground cover assessments	kg/ha	From measurement results of total weight and % ground cover assessments	Collection of all ground cover species with daubenmire frames	Statistically relevant number of samples	Annually or chosen credit interval	For determination of ground cover carbon pool reservoir

Table 2.6. (Continued) Contingent Quantification Procedures – Sludge Utilization in the Forest.

Project/ Baseline	Parameter/ Variable	Unit	Measured/ Estimated	Method	Sample Size	Frequency	Justify Measurement or Estimation or Frequency
Sequestration $_{\text{Below-ground Carbon Reservoir}}$ = SOC% x bulk density (g/cm^3) x sample depth (cm) x Conversion Factor $_{\text{C-CO2}}$							
B7/P7 Below Ground Carbon Reservoir **(Emission reductions from soil carbon addition and accumulation Mg CO_2e/ha/yr)**	Soil	Mg CO_2e/ha/yr	Convert % carbon content of soil to area basis using bulk density	Soil sampling to determine bulk density and total soil carbon analysis by combustion method	Statistically relevant number of samples	Annually or chosen credit interval	Quantity being calculated
	Soil bulk density	g/cm^3	Measured using core sample of known volume and dry weight	Collect sample to depth of 20 cm using bulk density sampler and dry to constant weight	Statistically relevant number of samples	Annually or chosen credit interval	Representative sample to account for variability in depth and receiving soil characteristics
	Soil organic carbon	%	Measured	LECO total combustion of carbon to CO_2 and analysis by infrared detector	As required by method	Analysis of each sample collected	For calculation of soil organic carbon content in sludge treated area
	Area treated	ha	Measured	Field survey or map	Statistically relevant number of samples	Initial survey of treated area	For determination of total credit of treated area

2.6 Management of Data Quality

Since this protocol is a measurement based comparison approach, data quality management must include field measurements, and data from the sampling and related analytical work. Procedures will be established for measurements completed and sampling and analytical techniques for the baseline and project scenarios.

2.6.1 Record Keeping

Generators that distribute mechanical pulp sludge for the purposes of land application are to document and retain the following information for a minimum of 10 years:

a) Legal land description of all areas of sludge application.
b) Quantity of sludge applied to each area.
c) Sample location, timing and name of qualified individuals conducting the sampling program.
d) Written logs of all field measurements and observations.
e) Electronic files of all raw and calculated data.
f) Blanks, duplicates, and internal standard tracking for all analytical data.
g) All records to be available for review and audit.

2.6.2 Quality Assurance/Quality Control Practices

a) Establish minimum experience standards for personnel conducting field measurements, sampling and analysis.

- Collection, analyses of samples and reporting should be conducted by qualified personnel in accordance with the following document:
    i. *Soil Sampling and Methods of Analysis*, Carter, M. (ed.), Lewis Publishers, 1993, Bocca Raton, Florida.

b) Check data integrity of field measurements by performing random checks.
c) Confirm estimated data with confirming measurements.
d) Maintain database of analytical standards and unknowns.
e) Recalculate data to ensure no mathematical errors have been made.

Appendix A. Conversion and Emission Factors Used

<u>Fuel Use – Sludge Transportation</u>

Emissions $_{\text{Energy Use Sludge Haul}}$ = # loads x distance/load x L fuel/100km x T CO_2e/L fuel

g CO2/ L fuel used = 2730
g CH4/L fuel used = 0.15
g N2O/L fuel used = 0.08

Fuel Economy factors

Diesel heavy truck = 33.6L/100 km
Greenhouse Gas Potential
$CO_{2e} = N_2O \times 310$
$CO_{2e} = CH_4 \times 21$

Source:
Canada's Greenhouse Gas Inventory, 2004, Environment Canada

<u>N2O emissions from fertilizer/sludge applications</u>

Emissions $_{\text{N2O emissions sludge}}$ = N_2O-N emissions from N inputs from sludge
Emissions $_{\text{fertilizer N2O emissions from synthetic fertilizer}}$ = kg N_2O-N/ha x EF_1

N_2Odirect = N_2O-N $_{\text{inputs}}$ x EF_1

Where:
$N_2O\text{-}N_{\text{inputs}} = F_{SN} + F_{ON}$
F_{SN} = annual amount of synthetic fertilizer applied to soils kg N yr^{-1}
F_{ON} = organic N additions applied to soil through sludge addition
EF1 = emission factor for N2O emissions from N inputs
Kg N20-N (kg N input)$^{-1}$ default value = 0.01

Source :
IPCC Guidelines for National Gas Inventories, 2006

Landfill Emissions

CH_4 emissions from landfilling pulp sludge (IPCC/OECD/IEA, 1997) calculated using the Scholl Canyon Model (IPCC/OECD/IEA, 1997) which is used to estimate methane generation from landfills using 1st order decay equation,

$$Gi = Mi * k * Lo * exp^{(-k*ti)}$$

Where: Gi = generation rate (kt CH_4/yr)
Mi = mass of sludge (Mt)
k = CH_4 generation constant (/yr)
Lo= CH_4 generation potential (kg CH_4/t sludge)
Ti = age of material in landfill (years)

$$Lo = MCF * DOC * DOC_F * F(16/12) * (1000 \text{ kg } CH_4/\text{t } CH_4)$$

Where: MCF = CH_4 correction factor (0.8)
DOC = degradable organic carbon (3)
DOC_F = fraction of DOC dissimilated (0.5)
F = fraction of CH_4 in landfill gas (0.5)
16/12 = stoicheometric factor to convert CH_4 to carbon

$$Lo = 0.8 * 3 * 0.5 * 0.5 (16/12)^{1.33} * 1000 = 80 \text{ kg } CH_4 / \text{t sludge}$$

MCF= CH_4 correction factor (fraction = 0.8 (IPCC/OECD/IEA, 1997))
DOC = degradable organic carbon (t C/t sludge = 0.3*100 (fraction of waste that is wood) = 3)
DOC_F =fraction of degradable organic carbon dissimilated = 0.5 (IPCC/OECD/IEA, 1997)
F = fraction of CH_4 in landfill gas = 0.5

The fraction of degradable organic carbon represents the amount of organic carbon that is accessible to biochemical decomposition, therefore assuming 100% wood composition the DOC value =3

Sludge Flash Dryer Emissions

CH_4= tonnes $_{sludge}$ * (21.1 GJ HHV/tonnes $_{sludge}$) * (1 TJ HHV/1000 GJ HHV) * (30 kg CH_4/TJ HHV)

IPCC tier 1 emission factors (Calculation Tools for Estimating Greenhouse Gas Emissions from Wood Product Facilities] (Prepared for ICFPA by NCASI 2005))

N_20 emissions estimated using the IPCC default method (IPCC/OECD/IEA, 1997)

N_20 = tonnes $_{sludge}$ * (21.1 GJ HHV/ tones $_{sludge}$) * (1 TJ HHV/1000 GJ HHV) * (4 kg N_20/TJ HHV)

Dryer – Natural Gas Usage

CO_2 equivalent = $t_{wet\ sludge}$ * (GJ nat.gas/ $t_{wet\ sludge}$) * (m^3/0.03723 GJ) * (kg CO_2e /m^3 nat.gas) * (t CO_2e/1000 kg CO_2e)

Calculation Tools for Estimating Greenhouse Gas Emissions from Wood Product Facilities] (Prepared for ICFPA by NCASI 2005)).

<u>Beehive Burner Emissions</u>

CH_4 Emission factor for wood, wood residuals and other biomass wastes = 30 kg/TJ HHV (NCASI 2005)

N_20 Emission factor for wood, wood residuals and other biomass wastes = 4 kg/TJ HHV (NCASI 2005)

Calculations based on heat content of 21.1 GJ (HHV)/tonne of dry solids

Energy content of Natural Gas = 0.03723 GJ/m^3 (National Inventory Report (1990-2004 - Greenhouse Gas Sources and Sinks in Canada))

Emission Factor = 1.902 kg CO_2e/m^3 of natural gas (National Inventory Report (1990-2004 - Greenhouse Gas Sources and Sinks in Canada))

$C0_2$ emissions
t $C0_2$e = t sludge * (% solid/100) * (21.1 GJ HHV/t dry sludge) * (TJ HHV/1000GJ) * (104 *10^3 kg $C0_2$/TJ HHV) * (t $C0_2$ /1000 kg)
(IPCC/OECD/IEA, 1997)

Methane emissions
CH_4 = TJ HHV * (30 kg CH_4/TJ HHV)
(IPCC/OECD/IEA, 1997)

Nitrous Oxide emissions
N_20= TJ HHV * (4 kg N_20/TJ HHV)
(IPCC/OECD/IEA, 1997)

Appendix B. Tables for Expansions and Conversions

Table B1. Stand level root to shoot ratios for different species and regions in Alberta

	Species				
Terrestrial Ecozone	Spruce	Pine	Hybrid Poplar	Other SW	Other HW
Boreal Plains	0.133	0.166	0.141	0.121	0.155
Boreal Shield West	0.121	0.121	0.143	0.121	0.143
Montane cordillera	0.134	0.133	0.13	0.131	0.155
Praires	0.121	0.121	0.143	0.121	0.155
Taiga Plains	0.104	0.095	0.133	0.109	0.133
Taiga Shield West	0.109	0.109	0.133	0.109	0.133

Source: Quantification Protocol for Afforestation Projects, Alberta Environment, 2007.

Table B2. Select Density Values for a Selection of Species

Species	Density (t/m^3)
Trembling Aspen	0.37
Willow	0.39
White Birch	0.51
Balsam Fir	0.34
Jack Pine	0.42
Lodgepole Pine	0.40
White Spruce	0.35
Western Larch	0.55
Other Softwood and hybrid poplars	0.37
Other deciduous hardwoods	0.60

Source: Quantification Protocol for Afforestation Projects, Alberta Environment, 2007.

Table B3. Stemwood Biomass to Total Above Ground Biomass

Species	Expansion Factor
Trembling Aspen	1.63
White Spruce	1.61
Larch	1.35
White Pine	1.05
Jack Pine	1.34
Misc. hardwoods	1.72

Source: Can Afforestation Contribute to a Reduction in Canada's Net CO2 Emissions? R.D. Guy et al. 1998.

Table B4. Soil Organic Carbon and Bulk Density Values

Soil Group	Horizon*	Organic Carbon (%)**	Bulk Density (Mg/m3)**
Dark Gray and Dark Gray Wooded	Ap B	3.5 to 12.0 0.5 to 2.0	0.60 to 1.0 0.90 to 1.4
Gray Wooded	Ap B	1.5 to 6.0 0.2 to 1.2	0.60 to 1.0 0.90 to 1.4

* Ap – defined as upper 15 cm of soil and representative of zone of incorporation
B – Defined as 15 to 30 cm of soil representing mineral zone below Ap (could include portions of Ae, AB and B horizons)

** Values based on data generated from field research trials resulting from sampling associated with operational sludge spreading programs in the vicinity of Whitecourt, Slave Lake and published soil survey data.

Dumanski, J., Macyk, T.M, Veaury, C.F, and J.D. Lindsay. 1972. Soil survey and land evaluation of the Hinton-Edson area, Alberta. Alberta Institute of Pedology Report No. S-72-31. 1972.

Wynnyk, A., Lindsay, J.D., and W. Odynsky. 1969. Soil survey of the Whitecourt and Barrhead area. Alberta Soil Survey Report No. 27, 1969.

Kyearsgaard, A. 1972. Soil survey of the Tawatinaw map sheet (83-I). Alberta Institute of Pedology Report No. S-72-29. 1972.

Pedocan Land Evaluation Ltd. 1993. Soil series information for reclamation planning in Alberta. Alberta Conservation and Reclamation Council Report No. RRTAC 93-7. ISBN 0-7732-6041-2.

Table B5. Default Biomass Conversion and Expansion Factors (BCEF), Tonnes Biomass (m^3 of wood volume). BCEF for expansion of merchantable growing stock volume to above ground biomass ($BCEF_S$), for conversion of net annual increment ($BCEF_I$) and for conversion of wood and fuelwood removal volume to above ground biomass removal ($BDEF_R$).

Climate Zone	**Forest Type**	**BCEF**	**Growing Stock Level (m^3)**			
			<20	21-50	51-100	>100
Boreal	Pine	$BCEF_S$	**1.2** (0.85-1.3)	**0.68** (0.5-0.72)	**0.57** (0.52-0.65)	**0.5** (0.45-0.58)
		$BCEF_I$	0.46	0.46	0.46	0.463
		$BDEF_R$	1.33	0.75	0.63	0.55
	Larch	$BCEF_S$	**1.22** (0.9-1.5)	**0.78** (0.7-0.8)	**0.77** (0.7-0.85)	**0.77** (0.7-0.85)
		$BCEF_I$	0.9	0.75	0.77	0.77
		$BDEF_R$	1.35	0.87	0.85	0.85
	Firs and Spruce	$BCEF_S$	**1.16** (0.8-1.5)	**0.66** (0.55-0.75)	**0.58** (0.5-0.65)	**0.53** (0.45-0.605)
		$BCEF_I$	0.55	0.47	0.47	0.464
		$BDEF_R$	1.29	0.73	0.64	0.59
	Hardwoods	$BCEF_S$	**0.9** (0.7-1.2)	**0.7** (0.6-0.75)	**0.62** (0.53-0.7)	**0.55** (0.5-0.65)
		$BCEF_I$	0.65	0.54	0.52	0.505
		$BDEF_R$	1.0	0.77	0.69	0.61

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Appendix C. Relevant Assurance Factors

Development of Assurance Factors

An Assurance Factor will account for the average risk of reversal for all sludge utilization projects within a region. Due to the variability of forest management systems , regions, and tree species response to sludge application, assurance factors will be need to developed for each site.

Based on the analysis of available data from research of sludge utilization projects in forests, a reasonable assurance factor would exceed 90%.   Since this protocol uses a measurement based approach for above and below ground carbon accumulation the assurance factor may exceed 90% over time. For the purposes of this protocol and until more operational data is available, a 90% assurance factor was deemed reasonable.

Appendix D. Example Calculation for Contingent Data Quantification Method

Baseline (t carbon/ha in upper 30 cm of soil)

Organic (10 cm)
Dbd = 0.9 g/cm3
%C = 3.29

Mineral (20 cm)
Dbd = 1.35 g/cm3
%C = 1.06

30 cm

<u>Organic</u>
10 000m^2 * 100cm/1m * 100cm/1m * 10cm * 0.9g/cm^3 * 3.29 gC/100g soil * 1kg/1000g * 1 tC/1000kgC = 26.1 T C/ha

<u>Mineral</u>
10 000m^2 * 100cm/1m * 100cm/1m * 20cm * 1.35g/cm^3 * 1.06 gC/100g soil * 1kg/1000g * 1 tC/1000kgC = 28.6 T C/ha

Total 30 cm = 26.1 + 28.6 = 54.7 t C/ha

Project (t carbon/ha in upper 30 cm of sludge and soil after addition of 50 t dry sludge/ha)

Sludge (3.5 cm)
% carbon = 45

Organic (10 cm)
Dbd = 0.9 g/cm3
%C = 3.29

Mineral (16.5 cm)
Dbd = 1.35 g/cm3
%C = 1.06

30 cm

<u>Depth of sludge at 50 t/ha</u>
50 tdry * 100 t wet/30 tdry * 1 m^3/0.48t wet * 1 ha/10 000m^2 * 100cm/1m = 3.5 cm

<u>Total Weight of 30 cm Mix (Sludge = 50 t)</u>
Organic - 10 000m^2 * 100cm/1m * 100cm/1m * 10cm * 0.09g/cm^3 * 1kg/1000g * 1 tC/1000kgC = 900 t organic
Mineral - 10 000m^2 * 100cm/1m * 100cm/1m * 16.5cm * 1.35g/cm^3 * 1kg/1000g * 1 tC/1000kgC = 2275 t mineral

Total 30 cm treated soil = 50 +900 + 2275 = 3225 t

<u>t C/ha/30 cm treated soil =</u>

$$\frac{(\text{t sludge} * \%\ C/100)}{\text{t mix}} + \frac{(\text{t organic} * \%\ C/100)}{\text{t mix}} + \frac{(\text{t mineral} * \%\ C/100)}{\text{t mix}} * \text{t Mix}$$

= (50*(45/100)/3225) + (900*(3.29/100)/3225) + (2275*(1.06/100)/3325 * 3225

= 76 t C/ha /30 cm treated soil

Emission Reduction = 54.7 t C/ha – 76 t C/ha = -21.3 t C/ha (or 78.1 t CO_2e/ha)